FISHING IMPACTS ON MARINE ECOSYSTEMS OFF BRAZIL, WITH EMPHASIS ON THE NORTHEASTERN REGION

by

KÁTIA DE MEIRELLES FELIZOLA FREIRE

B. Sc., University of Rio Grande, 1990

M. Sc., University of Rio Grande, 1995

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Abstract

This study is the first contribution towards the development of ecosystem-based fisheries management in northeastern Brazil, through the exploration of fishing policies based on a trophic model. The following objectives were addressed: 1) analysis of the richness of common names of Brazilian fishes; 2) reconstruction of time series of marine catches; 3) modelling of trophic interactions off northeastern Brazil; and 4) assessment of fishing policies. The analysis of common names indicated a high richness of names per species (average = 6) and the use of the same common name for different species, with a negative impact on the accuracy of catch statistics. The reconstruction of catch time series was based on landings from national yearbooks, and from ICCAT and FAO's databases (1978-2000), allowing for the detection of 'fishing down the food web' in northeastern Brazil. The trophic model estimated a total biomass for this ecosystem of 222 tonnes·km^{-2} (excluding detritus), and indicated a low degree of omnivory and the high importance of detritus. Simulations for 2001-2028 indicated that current fishing effort is unsustainable for lobsters and swordfish; however, the model inadequately described the dynamics of swordfish, tunas, and other large pelagics, which have large distribution areas. The simulation of optimum fishing policies led to a diverse fleet when ecosystem health was emphasized. If the main objective was economic or social (or a combination of both and ecosystem health), manual collection of coastal resources, and demersal industrial fisheries could be boosted, while the lobster and longline fisheries should be phased out. A 50% reduction in effort for lobster fisheries would not produce significant changes in lobster biomass; a reduction in effort to the 1978 level (f_{MSY}) would lead to biomass recovery. The instability of institutions responsible for fisheries management in Brazil

has had a deleterious impact on the resources. This negative impact is expected to increase due to the current split of responsibility between two institutions with diverse agendas. An improvement in the collection system of catch statistics is recommended, which would consider a standardized set of common names, as well as gathering information on biological, economic, and social components of this ecosystem and its fisheries.

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CHAPTER 1. General introduction

Globally, the fishing sector is in crisis as most stocks are fully exploited, overfished or recuperating, with indications that present catches are not sustainable (Watson and Pauly, 2001). The crisis is particularly significant for large predators (Baum *et al.*, 2003; Myers and Worm, 2003). Since 1884, when T. Huxley suggested the inexhaustibility of fish marine stocks (Hall, 1999), scientific inquiries have changed from debating the existence of an exploitation limit to defining what the limits are.

Recently, research has centered on the following major issues: uncertainty when defining exploitation limits (Francis and Shotton, 1997); reducing fishing costs and increasing the market value of fishing products (Hilborn *et al.*, 2003); quantifying the relative importance of environmental and/or fishing effects on the collapse of stocks (Steele, 1996); understanding recruitment overfishing (Myers *et al.*, 1999); explicit inclusion of socio-economic vectors (Hall, 1999; Jennings *et al.*, 2001); recognizing the increasing importance of recreational fisheries, whose harvest, in some cases, may exceed that from commercial fisheries (Gentner and Lowther, 2002); considering the need for ecosystem-based approaches (NRC, 1999; Gislason *et al.*, 2000; Murawski, 2000; Pauly and Christensen, 2002); and food security (Choo and Williams, 2003).

1.1. Historical perspective of the world fisheries

The Food and Agriculture Organization of the United Nations (FAO) has been compiling global catch data since 1950. World total catch increased 6% per year from 1950 to 1970, and 2% per year from 1970 to 1990 (FAO, 2000). No increase was observed after 1990 and an annual catch figure of slightly over 85 million tonnes was registered in 2002 for marine waters (www.fao.org; FISHSTAT). This figure would be much higher if discards were considered, estimated at 27 million tonnes per year in 1980-1992 (Alverson *et al.*, 1994) and 7.3 million in 1992-2003 (Kelleher, 2004), together with illegal, unreported, and unregulated (IUU) catches. Fish landings have likely been declining since 1988, a trend disguised by over-reporting of Chinese catches (Watson and Pauly, 2001). Thus, there is enough evidence to proceed with a "regime shift in fisheries management" (borrowing the terminology from Steele, 1996).

One of the primary reasons for this condition is the race for fish caused by open access to fishing resources. As early as 1968, G. Hardin pointed out the consequences of open access systems, and made suggestions about how to avert the resulting impact by the race for the resource (Hardin, 1968). Factors contributing to the crisis of fisheries include human population growth, increasing consumption rates, stronger disparities in access to resources, prevalence of individualism, materialism and competition, higher speed in the development and adoption of new technologies, and broader and more unpredictable impacts of those technologies (Burger *et al.*, 2001).

The need for 'responsible fisheries' is evident. Sissenwine and Mace (2003) attempt to clarify this concept. For them, responsible fisheries have to be sustainable, provide fairly distributed benefits, and not produce unacceptable or irreversible changes to the ecosystem. For a movement towards responsibility, two key changes must occur. First, the burden of proof should shift such that one must prove that a new fishing activity is not going to cause unacceptable impacts to the ecosystem, rather than the converse, wherein one fishery is, by default, assumed to have no impact (Sissenwine and Mace, 2003). Second, fisheries should be recognized as being embedded in ecosystems and thus their impacts on ecosystems must always be evaluated (Link, 2002). Although there is some conceptual acceptance that ecosystem approaches should be implemented, practical examples are rare.

In 1995, FAO presented the Code of Conduct for Responsible Fisheries for effective conservation and management of living aquatic resources, a global and voluntary code to be applied in accordance to the United Nations Convention on the Law of the Sea - UNCLOS (FAO, 1995). This code deals with issues related to the "capture, processing and trade of fish and fishery products, fishing operations, aquaculture, fisheries research, and the integration of fisheries into coastal area management" (FAO, 1995).

An important contribution of UNCLOS, in force since 1994, is the concept of Economic Exclusive Zone (EEZ), which establishes that coastal States have the right to exploit, manage, and preserve resources within a limit of two hundred nautical miles from their coastline. This was one step towards the zoning of the oceans and the control of the race for fish, but it has not been sufficient to prevent fishery collapses. The extension of the jurisdiction over marine waters in 1977 was seen as a solution to the fishery crisis of Northern cod off eastern Canada, for example, but this was not sufficient to avoid the fishery collapse of 1992 (Walters and Maguire, 1996). Instead, extension of jurisdiction must be used together with input controls, output controls, and/or technical measures embedded in a sound fishery management policy, with clear objectives, in order to be effective. Several international agreements have been established and international commissions have been created to deal with the issue of managing migratory stocks.

Besides zoning of the oceans and the use of input/output controls, there remains a need to recognize fisheries as embedded in ecosystems. Since the beginning of the 1990s, the research community has directed efforts towards this end, although this issue had been identified much earlier. As early as the mid 1950s, M.B. Schaefer presented an ideal fishery research program with three priority levels of research (Smith, 1994):

- Level I (high priority) – intensity of fishing, selectivity of the fishing method, yield, size composition by age and sex for both catch and biomass, biomass distribution and its availability to fishery, and rate of population growth;
- Level II (medium priority) – reproduction, growth, and natural mortality;
- Level III (low priority) – environmental forces, competition, and predation (Schaefer, 1956).

Although M.B. Schaefer recognized the importance of all three levels to fishery management, he also called attention to the high priority of only the first level, as it was sufficient to evaluate if higher yields would result after reductions in fishing effort. The other levels should be addressed through long-term research. After fifty years of research, level II is already incorporated into fisheries management, but not level III. This is probably the right time to do so, with an additional socio-economic vector. Level III is currently known as Ecosystem-Based Fishery Management (EBFM). NRC (1999) describes ecosystem based-management (EBM) as "an approach that seriously takes all major ecosystem components and services –

both structural and functional – into account in managing fisheries and one that is committed to understanding larger ecosystem processes for the goal of achieving sustainability in fishery management". Pikitch *et al.* (2004) describe some of the essentials of this 'new' management system.

In addition to EBFM, there is a need to decrease fishing capacity worldwide and to recognize the deleterious effects of subsidies (Munro and Sumaila, 2002). Capacity reductions should be undertaken by both developed and developing countries, although it seems easier in developed countries due to governmental support and because alternatives are available (Jennings *et al.*, 2001). In developing countries, which are responsible for approximately 60% of the total world catch (Jennings *et al.*, 2001), these mechanisms are usually absent. The conflict between small-scale (artisanal and subsistence) and industrial fisheries is particularly serious in these countries due to the high number of fishers involved in the former. Brazilian fisheries are also in crisis (Dias Neto and Dornelles, 1996), although some argue that there is still potential to increase production (DPA, 1999). This will be discussed in more detail later in this thesis.

1.2. A framework for fisheries management

The procedures currently used to manage fisheries are widely questioned due to the succession of fishery collapses, and new approaches are being proposed. Whatever new approach for fisheries management is set up, it is likely to be embedded in the classical framework presented in Figure 1.1 and summarized below. A management authority is established within a society, which can be structured between two extremes: as a government authority, where the government decides without consulting with fishers, and as a fishers' authority, where fishers act independently (McCay, 1996). Typically, extremes are not the best choice, and some form of co-management seems to be a better option. Under co-management, government and fishers work together and this is recognized as a key point for a management system to be successful. This arrangement is expected to be consonant with global and regional initiatives, and is subject to the 'institutional uncertainty' associated with political changes (Francis and Shotton, 1997).

Once a management authority is established, its objectives must be clearly defined. Although this seems to be a trivial issue, unclear and conflicting objectives have been recognized as one important factor behind management failures. The first trade-off a fisheries manager has to face is between short-term and long-term goals and within each of those, which factors should be considered and how. An objective function may be used to facilitate the decision process, but the use of a weight system for each factor is an additional source of controversy (Healey, 1984). Once agreed upon, objectives are then translated into management strategies and finally into management actions, which include input controls, designed to control effort (licences, individual effort quotas, individual effort transferable quotas, vessel restrictions), output controls for controlling removals (total allowable catches, individual quotas, individual transferable quotas), and technical measures (size and sex restrictions, gear restrictions, time and area closures) (Jennings *et al.*, 2001). Each of these control approaches has strengths and weaknesses, and as such is not expected to perform well on its own. Walters and Martell (2004) and others argue that managing fisheries using methods that depend on estimates of total abundance are too costly and riddled with uncertainty. Instead, direct control of exploitation rates (u-control) using time-area closures and tagging experiments could be more efficient and less costly. However, much research is still required for using tagging for specific fisheries.

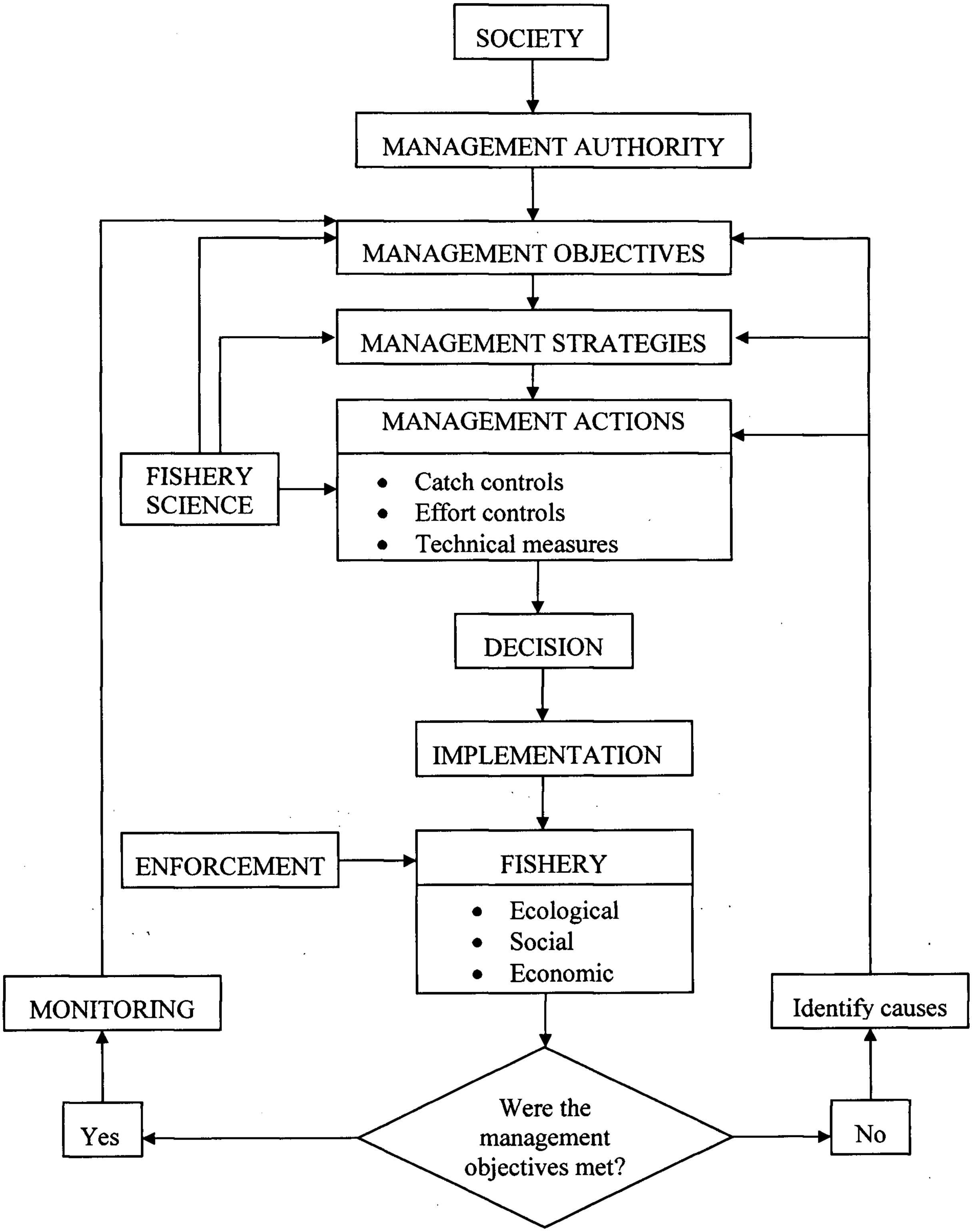

Figure 1.1: Framework for fisheries management (based on Jennings *et al.*, 2001).

Fishery scientists provide advice towards the establishment of management objectives, strategies, and actions, while decision makers are responsible for choosing which actions should be implemented. However, there is an ongoing debate about the need for a more active participation of scientists in the decision process. Others consider that this movement would undermine the credibility and objectivity of science. Others still consider that being a scientist does not entitle one to express preferences, mainly if the scientist is not going to be directly affected by the outcomes (Walters and Martell, 2004).

Fisheries include ecological, economic, and social components, and all should be considered in decision-making. Since its onset, fisheries management was mainly centred in the ecological component. It was not until the 1950s that the importance of economics in fisheries was formally recognized (Gordon, 1954). The social component was not incorporated until the 1970s (Acheson, 1981). However, the process of properly incorporating these two last components in the traditional ecological framework has been rather slow, partially due to the high degree of complexity involved, mainly after including other interest groups such as those tourism-related and non-governmental organizations - NGOs (Caddy and Cochrane, 2001). The ecological component has been continuously re-assessed, leading to the need for an ecosystem-based approach and the search for ecosystem indicators to detect signs of non-sustainability (Christensen, 2000; Pauly *et al.*, 2000). The other two components have also been continuously assessed leading to, for example, the realization that the most well-designed fisheries management plans would be undermined in the presence of pervasive subsidies (Munro and Sumaila, 2002).

One issue frequently over-looked during the planning of the fisheries management process is the evaluation of short- and long-term results from the proposed actions, a fundamental step within an adaptive management strategy (Walters, 1986). If the objectives are met, the key elements of the strategy should be monitored on a long-term scale; if not, the objectives and actions should be re-evaluated and changed when necessary.

Enforcement is also an essential part of this process, which can be facilitated using co-management. Costs of enforcement, monitoring and even research should be shared by all parties involved (Sissenwine and Mace, 2003). Each of the steps presented in this general framework is subjected to different degrees of uncertainty (Francis and Shotton, 1997), which should be numerically stated when possible, or otherwise considered qualitatively.

One new component in this framework is the importance of consumers in delineating the future of fishing practices. Consumers and NGOs have played an important role in fisheries that involve unsustainable practices such as dolphin by-catches in tuna fisheries, and turtle and other by-catches in shrimp trawling. This has led to initiatives such as eco-labelling (Deere, 1999; Gardiner and Kuperan Viswanathan, 2004). Users also have an important role when they choose eco-tourism, which is seen as an important mechanism for preserving ecosystem functions (Gossling, 1999).

Fisheries in developing countries present additional challenges, as they are usually multi-species and involve multiple gears. In this case, the use of output controls such as total allowable catches (TAC) based on stock assessment for all individual species would be constrained by the large number of species and the high cost involved. Considering the importance of artisanal and subsistence fisheries in those areas, it would be also hard to effectively control total catches. Marine protected areas (MPAs) have been increasingly proposed as a tool for fisheries management in developing (as well as in developed) nations. However, Polunin (2002) points out that there is no strong evidence of greater catches in areas near MPAs, except when closed areas are large enough in relation to the total fishing ground areas. In order to assess the performance of MPAs, clear objectives and success indicators have to be defined. Considering the restricted degree of planning and management of MPAs in most tropical areas (Alder, 1996), it is hard to assess their performance.

Another characteristic of developing countries is both high population density and growth, leading to high pressure on fish resources. Marginalization and the resultant Malthusian overfishing are critical issues over and above those previously described (Pauly, 1997). This kind of overfishing is characterized by stagnating overall catches and increasing numbers of fishers, decreasing catch per fisher, evidence of biological, ecological, and economic overfishing, recruitment of young men with no fishing background into the fisheries and the consequent use of destructive practices, and women (wives, sisters, daughters) subsidizing fishermen (Pauly, 1997). Some of the Malthusian overfishing indicators, such as the declining trend in the overall catches, have been observed in Brazil (Dias Neto and Dornelles, 1996), the increasing number of women as fishers in land-based fisheries, targeting mainly molluscs, and the use of explosives and poisonous substances in some States of the northeastern region (Quinamo and Melo, 1997; Alcântara, 2001). In addition, developing regions such as northeastern Brazil have high marine biodiversity, with complex trophic webs, resulting in higher uncertainty in the evaluation of indirect effects of fishing. Finally, the migration of fishing fleets from developed regions (under strict effort control aiming at decreasing overcapacity) to developing regions is an additional source of concern (Mathew, 2003).

1.3. History of fisheries management in Brazil

Barbosa (1983) and Paiva (2004) present the history of the organization of the fishing sector in Brazil. Portuguese 'discovered' Brazil in 1500. During the 16th century, Portugal regulated all fishing rights in Brazilian waters. In 1571, incentives were given to build fishing boats. Small fisheries targeting groupers and anchovies (amongst others) were unable to properly develop due to a State monopoly of salines, which lasted for more than one century.

In 1602, fishers from the Bay of Biscay were permitted to catch whales in Brazilian waters and to build factories to process their oil. This fishery was the only large-scale fishery in Brazil during the colonial period. Because of whaling, the first fishers' associations were established in Bahia State and spread along the Brazilian coast: Rio de Janeiro, São Paulo, and Santa Catarina. By the end of the 1880s, whaling began to decline due to the decrease of whale population size, foreign competition in the market, and the use of products other than whale oil for lighting.

Fishery management was handed to local governments ('câmaras das vilas') at the end of the 18th century. In 1802, fisheries were recognized as having national importance and more incentives were given to their development. Fishing licenses were not required, but the type of fishing boats, gears used, and number of fishers had to be reported. The first gear restrictions were put in place: no trawling was allowed; trawling nets were burnt and fines were applied.

Following the independence of Brazil from Portugal in 1822, the fishing sector was put under the control of the Brazilian Navy. Nets with small mesh size were not allowed and new instructions were given to register all the types of large fishing boats and report on the size of their crew (1824). In 1825 and 1826, these instructions were extended to small fishing boats. However, they were enforced only after 1846, when a Port Authority was created and the legislation was given a national scope. With the national decree No. 876 (1856), the first steps were taken towards the industrialization of the fishing sector. However, this decree was only put in practice after decree no. 8338 (1881), which is considered the first 'Fishing Code'. Several fishers' associations were established and fishers could finally secure some basic rights.

In 1897, after the declaration of the Brazilian Republic, the fishing sector was nationalized, still under jurisdiction of the Brazilian Navy, and all professional fishers were required to register with the Port Authority. In 1912, a decree created a Fishing Authority ('Inspectoria de Pesca'), associated with the Ministry of Agriculture, Industry and Trade. This institution remained active only for three years. In 1915, the Station of Marine Biology was created within the scope of the same Ministry in order to promote research in Brazilian marine waters. This station closed one year later due to the lack of financial support and technical capacity. In 1919/1920, fisheries issues returned to the responsibility of the Brazilian Navy and in 1923, the regulation for the Directorate of Fishing ('Diretoria da Pesca e Saneamento do Litoral') was launched. This regulation allowed for better organization of fishers, destruction of illegal fishing gears, and fisheries research. In 1930, the first Fishing School was created in São Paulo State, specifically to improve both theoretical and practical knowledge of fishers' children in terms of the fishing industry. This school was later turned into a research institution, still active today.

From 1933 to 1961, the Division of Fish and Game became responsible for Brazilian fisheries and the Code of Fish and Game of 1934 (reviewed in 1938) was the legal basis for its activities (Anon., 1973). That division was linked to the National Department of Animal Production, a unit of the Ministry of Agriculture. In 1942, an Executive Fishery Commission was created within the same ministry to organize the fishing industry (closed three years later). As part of this attempt, a regulation was implemented in 1950 to oversee the activities of the General Confederation of Brazilian Fishers and other fishers' associations. In 1961, the Council for Fisheries Development (CODEPE) was created and the Division of Fish and Game was transferred to that council. One year later, that division closed and the National Institute for Fishery Development (SUDEPE) was created, which was made part of the Ministry of Agriculture (Anon., 1973). The main goal of SUDEPE was to promote the development of a highly organized fishing sector. The specific objectives of that superintendence were to elaborate the National Plan for Fishery Development, to give technical and financial assistance to fisheries projects, to conduct research, and to promote the application of a Fishing Code. In 1967, decree no. 221 was approved to stimulate the development of fishing industries. Unfortunately, this legal measure also removed rights that fishers had enjoyed in early years. In that same year, SUDEPE and the United Nations established the Brazilian Fisheries Research and Development Program (PDP) and fisheries research finally began to develop in a structured context.

In 1970, the Brazilian 'territorial sea' was extended unilaterally from 12 to 200 nautical miles. As a consequence, a decree related to the rational use and conservation of the renewable resources was approved in 1971 (Anon., 1973). The Institute of Research and Development of the Fishing Sector was created in 1980, which was linked to SUDEPE and responsible for the continuation of the activities developed by the PDP. In 1989, SUDEPE was abolished and replaced by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA). This institute deals with issues formerly within the province of the Secretary of Environment (SEMA), the Superintendence of Rubber (SUDHEVEA), the Brazilian Institute for the Development of Forests (IBDF), and SUDEPE. This had a negative impact on the fishing sector since IBAMA, which lacks financial and human resources, is faced with too broad a range of issues. IBAMA has three centres associated with fisheries research and management of marine fisheries resources off northern (CEPENOR), northeastern (CEPENE), and southern (CEPSUL) regions.

In 1982, Brazilian authorities signed the United Nations Convention on the Law of the Sea and ratified it in 1988, committing the country to specific conservation and management standards for living aquatic resources; the Law of the Sea has been enforced since 1994. Since that year, Brazil has been working on a program called Living Resources of the Exclusive Economic Zone (REVIZEE), established to assess the most important exploited stocks and to search for remaining unexploited stocks.

In 1995, an Executive Group for the Fishing Sector was created. This group proposed a National Plan for Fishery and Aquaculture (GESPE, 1998), which never became operational. In the same year, a decree split fisheries responsibility between the Ministry of Environment

(MMA) and the Ministry of Agriculture and Supply (MAA) (Cardoso *et al.*, 1998), with the establishment of the Fishery and Aquaculture Department (DPA) to stimulate fishing production. In 2003, the DPA was closed and a Special Secretary for Aquaculture and Fisheries (SEAP) was created with the same objectives as the DPA, but directly linked to the President of the Republic. IBAMA still retains some influence on the fishing industry and a clear conflict of interests is evident. These changes in the institutions managing the fishing sector do not allow for the establishment of a sound national fishery policy.

New fisheries management schemes have been applied, such as those in the southern (Kalikoski and Satterfield, 2004) and northeastern (Scharer and Scharer, 2004) regions. However, these are localized initiatives attempting to empower small-scale fishers, which are often overlooked at the national scale. Four maritime extractive reserves[1] were created since 1992 and 13 others have been proposed in order to guarantee the access of local communities to their resources through the exclusion of members from other communities and to promote resource conservation (www.ibama.gov.br/resex/cnpt/). Lima and Dias-Neto (2002), however, mention that the conservation component may not be properly addressed due to lack of clarity in the definition of such objective in the management plans for these reserves. A concern that seems to be shared by Silva (2004), when emphasizing the importance of the partnership between government and local community for the success of these reserves.

[1] Extractive reserve is a new conservation category created under the auspices of IBAMA/Brazil in 1989, with the objective of decentralizing the management of natural resources through the delegation of rights to communities historically associated with the sustainable use of local resources (Silva, 2004).

Brazil is also involved in at least twelve international or regional agreements directly or indirectly related to the management of fishery resources (Table 1.1). Some of these agreements do not have legal power to deal with international conflicts. Others became obsolete due to the lack of political disposition such as CARPAS in 1974 (J.P. Castello, University of Rio Grande/Brazil, pers. comm.). However, much progress was made, for example, after the establishment of the International Whaling Commission (IWC), which led to the ban of whaling practices in Brazil by 1985. Brazil has also implemented some national regulations to be able to follow recommendations set by the International Commission for the Conservation of Atlantic Tunas (ICCAT) for the management of tuna and tuna-like fishes in the Atlantic Ocean (Lima, 2001). The Special Secretary for Aquaculture and Fisheries (SEAP) is currently responsible for negotiating quotas for these migratory species in Brazil and for their implementation.

1.4. Issues on fisheries management in Brazil

The institutional instability described in the previous section has some negative effects in the collection of basic data required for managing Brazilian fisheries. First, there is a lack of continuity in the collection of catch data (Lima and Dias Neto, 2002). Second, effort data are not properly gathered and/or lack continuity (CEPENE, 2000a; Fonteles Filho, undated). Third, there is the chronic problem of attributing catch records to the proper species, a problem longed recognized (Welcomme *et al.*, 1979). Finally, there is no attempt to estimate unreported or illegal catches from Brazilian waters at a national level. This probably reflects a disconnection between the system responsible for data collection and data users.

Table 1.1: Some international or regional fisheries-related agreements in which Brazil is involved (FishBase; www.fishbase.org).

Acronym	Name	Coverage	Year		
			Establishment	In force	Ratified
CARPAS	Regional Fisheries Advisory Commission for the Southwest Atlantic	Fisheries	1961	-	-
CBD	Convention on Biological Diversity	Biodiversity	1992	1993	1995
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources	Environment	1980	1982	-
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora	Biodiversity	1973	1975	-
COPESCAL	Commission for Inland Fisheries of Latin America	Fisheries	1976	-	-
ICCAT	International Commission for the Conservation of Atlantic Tunas	Fisheries	1966	1969	-
INFOPESCA	Center for Marketing Information and Advisory Services for Fishery Products in Latin America and the Caribbean	Fisheries	-	-	-
IWC	International Whaling Commission	Fisheries	1946	-	-
RAMSAR CONVENTION	Convention on Wetlands of International Importance, especially as Waterfowl Habitat	Environment	1971	1975	-
SHMFSA	Conservation and Management of Straddling and Highly Migratory Fish Stocks Agreement	Fisheries	1995	2001	2000
UNCLOS	United Nations Convention on the Law of the Sea	General	1982	1994	1988
WECAFC	Western Central Atlantic Fishery Commission	Fisheries	1973	-	-

Brazilian fisheries are managed by the federal government and thus, the problems identified above are also observed in northeastern Brazil. This thesis aims to analyze these issues in a context of data requirements towards ecosystem-based fisheries management in northeastern Brazil, and to identify new issues to be addressed. Attempts to quantify the magnitude of the problem would require that data are analyzed at the national level for comparison with alternative existing databases.

1.5. Objectives

The overall goal of this study is to evaluate the fishing impacts on marine ecosystems off Brazil, with emphasis on the northeastern region (East Brazil Large Marine Ecosystem; Fig. 1.2). In order to reach this goal, the following specific objectives were pursued:

I) to identify the richness of common names of Brazilian fishes and to analyze its effect on fishery statistics;

II) to analyze catches originating from Brazilian marine fisheries and to assess their use as an indicator of ecosystem health;

III) to describe the mass and energy fluxes throughout functional groups living in the East Brazil Large Marine Ecosystem that encompasses northeastern Brazil;

IV) to assess the impact of current fishing policies and some alternatives.

These objectives were addressed according to the methodological framework presented in Figure 1.3 and discussed in the next chapters.

Figure 1.2: Location of the East Brazil Large Marine Ecosystem (gray) along the Brazilian coast.

1.6. Description of the study area

Brazil (and its fisheries) cannot be analyzed as a single unit because of its size and history. The country is politically divided into five regions, North, Northeast, Center-West, Southeast, and South, reflecting socio-economic differences (Figure 1.4). Goldsmith and Wilson (1991) present a historical perspective for the difference between the South (called Centre-South), where manufacturing was dominant, and the Northeast, which was traditionally responsible for supplying raw materials and cheap labour to the South and for providing a market for its manufactured products. This disparity is also reflected in fishing activities, with a decreasing degree of importance of artisanal fishery from the North (93%) to the South (20%) (Paiva, 1997). Matsuura (1995) proposed the division of the Brazilian coast into North, Northeast, East, Southeast, and South based on bathymetry, oceanographic structure, fauna, flora, and fisheries. This division has been used in the assessment of the resources off the

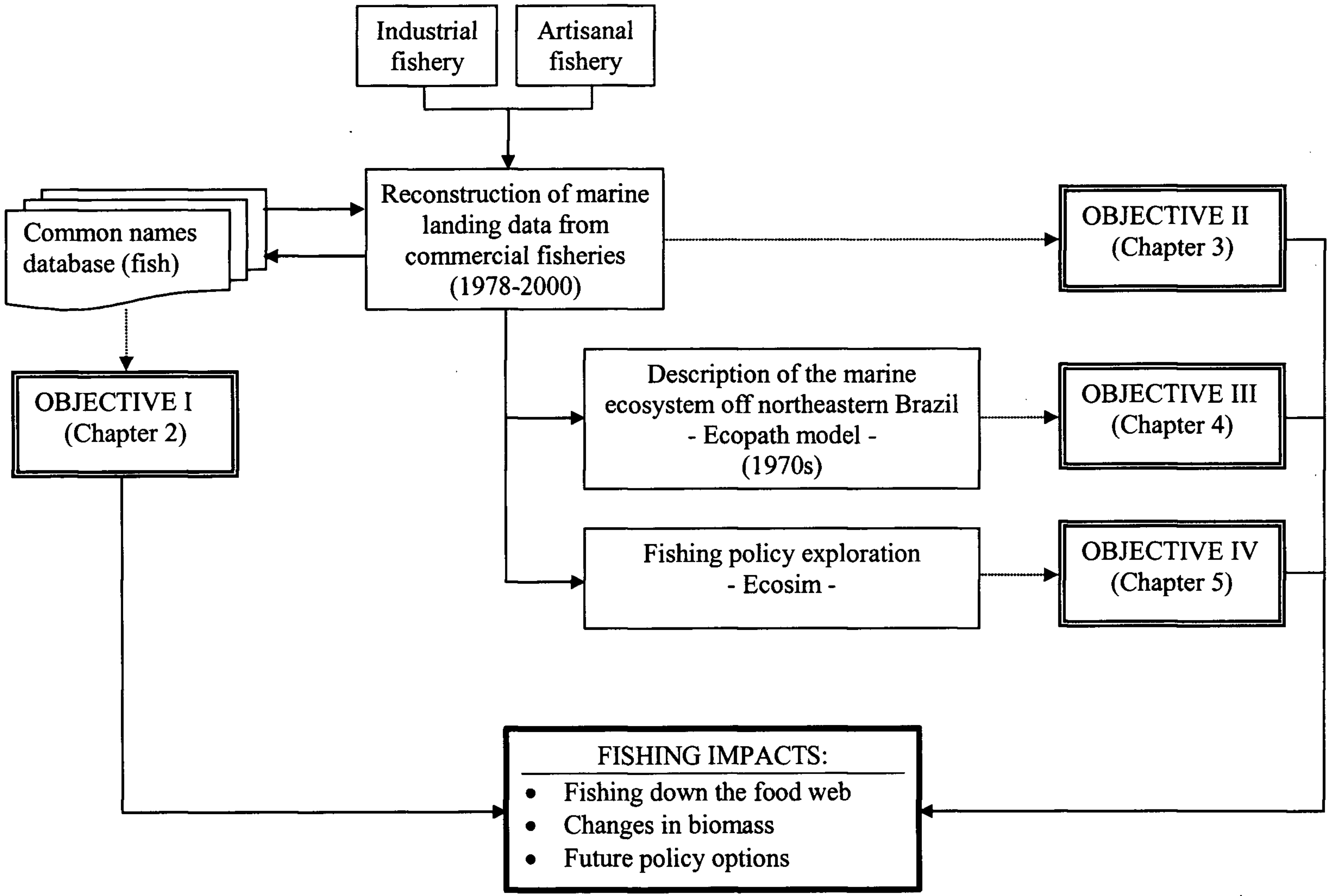

Figure 1.3: Framework to the development of the analysis of the impact of fisheries on the marine ecosystem off northeastern Brazil.

Brazilian coast. The Brazilian northeastern region is differentiated from the others by its narrow and irregular continental shelf, deep thermocline, presence of corals, and low primary production.

The study area corresponds to a tropical region located between 1°S and 16°S (Figs. 1.2 and 1.4). The continental shelf off the northeastern Brazil bordering the States of Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia is influenced, according to Gulland (1971), by a branch of the South Equatorial Current (SEC) and by the Brazil Current. The latter current is shallow (axis above the 200 m isobath) and represents the western branch of the anticyclonic gyre of the South Atlantic, which moves southwards. The continental shelf off the States of Maranhão, Piauí, Ceará, and Rio Grande do Norte is influenced by the North Brazil Current.

1.7. Overview of the main marine resources exploited off northeastern Brazil

Brazilian marine catches amount to roughly 500,000 tonnes, which correspond to approximately 0.5% of the world capture (FAO, 2001). Although this figure is small (and probably underestimated), it has high social importance, as it involves about seven hundred thousand fishers (CNIO, 1998). Overall, the artisanal fishery, defined as operated inshore by small boats of less than 20 tonnes, is responsible for 60% of total national catches. This value is probably an underestimate due to the absence of a well-structured system of data collection. Northeastern Brazil is responsible for 11.7% of the total Brazilian catches, the smallest contribution amongst all regions (Paiva, 1997).

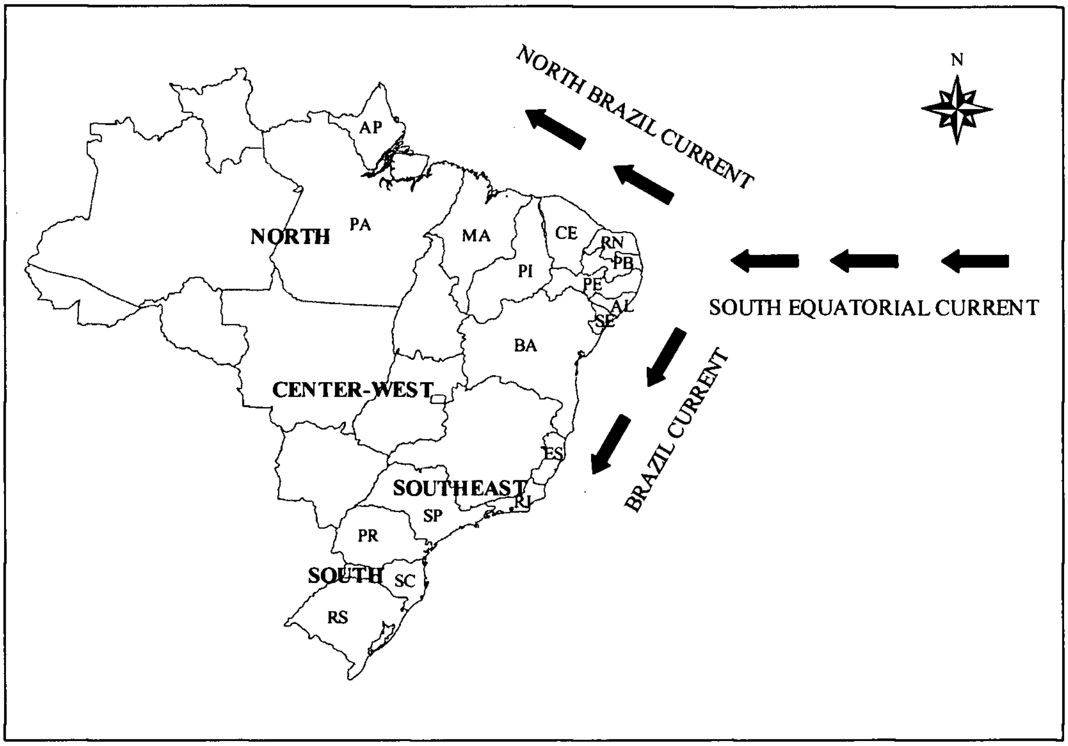

Figure 1.4: The five political regions of Brazil (North, Northeast, Center-west, Southeast, and South) and the nine States of the northeastern region: MA = Maranhão, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, SE = Sergipe, and BA = Bahia. Other states mentioned throughout the thesis are: AP = Amapá and PA = Pará (North); ES = Espírito Santo, RJ = Rio de Janeiro, and SP = São Paulo (Southeast); and PR = Paraná, SC = Santa Catarina, and RS = Rio Grande do Sul (South). Near-surface currents are also presented, based on Johns and Lee (1990).

The annual potential catches off the northeastern shelf estimated by Gulland (1971) were the lowest amongst all the Brazilian regions: 50,000 tonnes for demersal species and 50,000 tonnes for pelagic species (excluding oceanic tuna fishing), i.e., 6% of the potential marine catches for the whole country. Based on other estimates, Paiva (1997) points out that there is still potential to increase catches in this region, although some resources such as lobsters and snappers have already shown signs of decline (Dias Neto and Dornelles, 1996). An overview of the main marine resources exploited in the region is presented below, although several other artisanal multi-species fisheries take place in the region.

a) Lobsters

The artisanal exploitation of Brazilian lobsters began in 1955. Motorboats were introduced by the early 1960s, as the traditional fishery could not supply the demand (Paiva, 1997). Two species represent the majority of the catch, *Panulirus argus* and *Panulirus laevicauda*, which are distributed from a depth of 20 m to the shelf break (Farias, 1980). Some catches have been recently reported for a third species, *Panulirus echinatus*, which is found on rocky bottom off oceanic islands (Paiva, 1997). Most of the lobster catches are exported and those specimens that are smaller than the size required for export are sold in the domestic market (Dias Neto and Dornelles, 1996).

The collection of catch and effort data for lobsters began in 1958 and 1965, respectively (Dias Neto and Dornelles, 1996). Currently, the main sources of catch data are the export figures. Two main sources of bias must be considered relative to these estimates: a) lack of data related to the domestic market, considered low (5%) in relation to the exports by IBAMA/CEPENE (as cited in Lins-Oliveira *et al.*, 1993); and b) the absence of data on catches taken by illegal methods such as diving with compressors (hookah). The Permanent Study Group (GPE) for lobsters analyzes these basic data using single-species approaches. The maximum catch ever registered for Brazilian lobsters was 11,000 tonnes in 1979, although the maximum sustainable yield was estimated at 9,000 tonnes (Dias Neto and Dornelles, 1996). According to these authors, lobster catches have been declining since 1991 and reached 8,000 tonnes in 1994, with an effort 240% higher than f_{opt} (i.e., the level of effort that generates maximum sustainable yield); in 1999, the catch was even lower (6,000 tonnes). Rocha *et al.* (2001) consider that these stocks are overexploited (Table 1.2).

The first regulatory measures were established in 1961/1962: a) annual closures for 3-4 months; b) minimum tail sizes; c) minimum mesh sizes; d) prohibition of fishing in nursery areas; e) prohibition of the use of trawlers, gillnets, and purse seiners; f) establishment of production quotas; and g) prohibition of capture of mature females (Paiva, 1997). Nowadays, lobsters are caught by traps, gillnets, and diving (with and without compressors, although the use of compressors is prohibited) (Rocha *et al.* 2001). These regulatory measures continuously change and enforcement is poor, which constitute two major problems in managing Brazilian fisheries (GESPE, 1998).

b) Shrimps

Shrimps were initially caught by artisanal fisheries mainly near Maranhão State, and between Alagoas and Bahia (Farias, 1980). Currently, shrimp fisheries are spread all over the region, mainly operating down to a depth of 20 m (Dias Neto and Dornelles, 1996). The main target species are *Xiphopenaeus kroyeri* and *Litopenaeus schmitti*, although *Farfantepenaeus subtilis* and *Farfantepenaeus brasiliensis* are also caught in lower proportion (CEPENE, 2000b). By the late 1970s and the early 1980s, the first motorboats were introduced. Single and double otter trawls are the main fishing gears used, although gillnets, traps, and beach seines are also found (Farias, 1980). More than 17,000 tonnes were caught in 1999, associated with a high proportion of by-catch, mainly juveniles of other exploited species (Dias Neto and Dornelles, 1996). Catches are lower than the shrimp production provided by aquaculture: 37,000 tonnes in 2001 (Roubach *et al.*, 2002). This is an industry that has been growing since 1996 with the introduction of *Litopenaeus vannamei*, but there is some concern about its sustainability due to the destruction of mangroves.

Table 1.2: Status of the main fisheries off northeastern Brazil.

RESOURCE	SCIENTIFIC NAME	REGION	MSY[6] (t·year^{-1})	STATUS	SOURCE
Caribbean spiny lobster	*Panulirus argus*	N-NE[2]	6,706	Overexploited	(Rocha *et al.*, 2001)
Smoothtail spiny lobster	*Panulirus laevicauda*	N-NE	2,744	Overexploited	(Rocha *et al.*, 2001)
Shrimps	Various	NE	—	Not overexploited	(CEPENE, 2000b)
Crabs	Various	N-NE	—	Unknown	(CNIO, 1998)
Southern red snapper	*Lutjanus purpureus*	N-NE	6,401	Overexploited and risk of recruitment overfishing	(Charuau *et al.*, 2001)
Yellowfin tuna	*Thunnus albacares*	ATL[3]	148,000	Fully exploited	(ICCAT, 2004b)
Albacore	*Thunnus alalunga*	SATL[4]	26,333-30,915	Fully exploited	(ICCAT, 2004b)
Bigeye tuna	*Thunnus obesus*	ATL	93,000-114,000	Fully exploited	(ICCAT, 2004b)
Northern bluefin tuna	*Thunnus thynnus*	WATL[5]	—	Overexploited	(ICCAT, 2004b)
Swordfish	*Xiphias gladius*	SATL	—	Unknown	(ICCAT, 2004b)
Atlantic blue marlin	*Makaira nigricans*	ATL	1,000-2,400	Overexploited	(ICCAT, 2004b)
Atlantic white marlin	*Tetrapturus albidus*	ATL	323-1,320	Overexploited	(ICCAT, 2004b)
Atlantic sailfish	*Istiophorus albicans*	WATL	—	Unknown	(ICCAT, 2004b)
Oceanic sharks	*Prionace glauca* *Isurus oxyrhynchus*	SATL	—	Unknown	(ICCAT, 2004b)
Line fish[1]	Various	NE (Abrolhos)	1,445	At equilibrium	(CNIO, 1998)

1. Line fish are those caught using bottom hand line (groupers and snappers); 2. N = North region and NE = Northeast region; 3. ATL = Atlantic Ocean; 4. SATL = South Atlantic; 5. WATL = Western Atlantic; 6. MSY = Maximum sustainable yield estimated by different methods for each species.

The main control measures in place for shrimp fisheries are: a) time closure; b) mesh size control; c) control of issued licences; and d) prohibition of trawling closer to 3 or 10 nautical miles from the shore (CEPENE, 2000b). These measures vary amongst neighbour States causing local conflicts. The GPE for shrimps points out that there is no need for stronger enforcement as the shrimp stocks do not present any signs of overexploitation (CEPENE, 2000b). However, the by-catch is very high, as pointed out by Dias Neto and Dornelles (1996) and must be considered if an ecosystem-based approach is to be implemented.

c) Tuna and tuna-like fishes

The industrial fishery for tuna and tuna-like fishes began in 1956, through joint ventures with Japanese vessels based in Pernambuco, and ceased in 1964, owing to political and economical reasons (Farias, 1980). Korean vessels started to operate in the region in 1976 (Lessa *et al.*, 2004). By 1983 a national fleet was formed in Pernambuco, but this fleet moved to Rio Grande do Norte after 1994 (Paiva, 1997). In 1993, a fleet was established in Paraíba State. By 2002, 98 longliners were operating from ports located in northeastern Brazil: 61 in Rio Grande do Norte (29 Brazilian vessels and 32 through joint ventures) and 37 in Paraíba (only joint ventures) (Lessa *et al.*, 2004). This represents more than 75% of the total fleet of 129 longliners operating in Brazil (ICCAT, 2004a). Some baitboats (39) and purse seiners (2) also operate off Brazilian ports, but usually fish in southern waters. Since 2000, joint ventures have been established with Spain, Taiwan, United States, Equatorial Guinea, Saint Vincent, Uruguay, and Vanuatu (www.iccat.es), of which some provide flags of convenience.

The main species traditionally caught off northeastern Brazil by the national fleet were yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), and sharks. In addition to these species, the catch composition from the leased fleets also included albacore (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*), a difference attributed to the concentration of effort offshore. Both fleets use surface longline, although the yield obtained by the leased fleet is superior to the national. One serious problem associated with longliners is shark finning, the practice of removing the high valued shark fins and returning the dead shark to the sea. This practice is common within the leased fleet. Although shark finning was officially prohibited in 1998 (Kotas *et al.*, 2001), this activity was not discontinued and was denounced by local fishers in the First Fishing Forum in Paraíba State (August 2001).

Until late 1980s, swordfish catches were low and exported unprocessed (Weidner and Arocha, 1999). After 1996, a fishery targeting swordfish developed, which exported fresh swordfish to the US (Evangelista *et al.*, 1998). Because of the decreasing price in the international market, fishers began to sell this product in national markets (Weidner and Arocha, 1999). Since 1996, swordfish quotas for the South Atlantic have been negotiated with ICCAT after the stock presented the first signs of overexploitation, probably caused by the migration of the fleet from the North Atlantic (Lima, 2001). Brazil is entitled to 16% of the total allowable catch (TAC) of 14,620 tonnes for the South Atlantic, but has been consistently fishing over this limit. Brazil has also increasingly caught southern albacore after 1997. Albacore in the Southern Atlantic is also subject to a TAC system, although no consensus about the quota sharing system has been reached yet (www.iccat.es).

ICCAT (2004) presents revised estimates for the status of all tuna and tuna-like fishes for the Atlantic Ocean. In general, the stocks are fully or over exploited, but for some species such as swordfish and pelagic sharks there is no clear information (Table 1.2). Assessments presented in this ICCAT document are subjected to high level of uncertainty due to the presence of fleets from several countries using different gears that end up issuing, in some cases, contradictory signals about the status of the stocks. Furthermore, increasing efficiency of some gears and unknown IUU (illegal, unregulated, and unreported) catches make assessments even more difficult.

d) Southern red snapper

The Southern red snapper (*Lutjanus purpureus*) is targeted by both artisanal and industrial fleets, which have a national and international market, respectively (Dias Neto and Dornelles, 1996). The industrial fishery began in early 1960s off Ceará and Rio Grande do Norte coasts (Farias, 1980), but gradually expanded northwards because of the high demand from the international market (Dias Neto and Mesquita, 1988).

This snapper is caught by vertical longline ('pargueira') in oceanic banks, 150 nautical miles off the coast of Ceará and Rio Grande do Norte (depth = 30-140 m) and in the outer continental shelf, 50 nautical miles from the coast (depth = 40-140 m) (Dias Neto and Dornelles, 1996). These authors point out that other species are also caught in this fishery: *Lutjanus vivanus*, *Lutjanus buccanella*, *Ocyurus chrysurus*, *Epinephelus* spp., and *Balistes vetula*.

Southern red snapper catches decreased from 1977 to 1990 (Dias Neto and Dornelles, 1996), but partially recovered afterwards because of the effort reduction resulting from decreasing US imports (Paiva, 1997). The first restrictive measures were adopted in the early 1980s: a) no increase in the number of issued licences, and b) minimum capture size. These measures probably helped the stock to recover as well. Assessment estimates indicate a maximum sustainable yield of 4,000-6,000 tonnes (Dias Neto and Dornelles, 1996) or 6,401 tonnes (CNIO, 1998), depending on the source considered. After being overexploited and showing signs of recovery, the status of this stock is still a matter of concern (Table 1.2). In 1999, the catch was approximately 3,360 tonnes, which indicates a declining trend.

e) Crabs

Ucides cordatus is caught by artisanal fisheries in mangroves of northeastern Brazil. Dias Neto and Dornelles (1996) present an overview of this fishery and some of its aspects are summarized below. This fishery usually employs no gears other than fishers' hands ('braceamento'). Small nets ('redinha') were introduced in the early 1990s, and have been considered deleterious to this fishery due to lack of selectivity and impact on mangroves as their roots are used to attach the nets (Botelho *et al.*, 2000). Crab fishers normally exploit oysters and estuarine fish as well, and are marginalized by other segments of the local society (Alves and Nishida, 2003).

Maranhão, Piauí, and Paraíba States are the main producers and Ceará is the main consumer. The internal market absorbs the total production (about 3,000 tonnes). There is no consensus about the present exploitation status of this species (Table 1.2), but there is some concern related to the susceptibility of the mangroves to direct human impacts. Since 1950, these areas have been seriously degraded because of the construction of harbours and petrochemical/chemical industries, saline deposits, the growth of settlements, sewage, increasing land value, tourism, and expansion of agriculture, specially sugar cane and rice (Diegues, 1996). Additionally, the rapid growth of aquaculture since 1996 has raised reasons for concern, although some authors suggest that mangrove areas have not been used (Roubach *et al.*, 2002).

Some conservation measures have been adopted by IBAMA: a) minimum catch size; and b) prohibition of catching females of any size at any time (Dias Neto and Dornelles, 1996). In Paraíba State, regulation no. 01/2003 prohibited the capture of undersized males (5 cm carapace length) and any females during the 'andança' (reproductive period). Although important, these measures are particularly difficult to enforce in relation to other fisheries because fishers are highly dispersed along mangrove areas.

Other crab species are also caught by local artisanal fisheries: *Cardisoma guanhumi*, *Goniopsis cruentata*, and *Callinectes* spp. No information on the status of these stocks is available.

f) Turtles

Five species of turtles were exploited in Brazil: leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), loggerhead (*Caretta caretta*), and green turtle (*Chelonia mydas*). In 1967, a program to protect turtles was initiated and a complete ban of the turtle fishery was declared in 1986 (Marcovaldi and Marcovaldi, 1999). A national conservation project was established in 1980 (TAMAR Project), which currently operates in twenty-one bases spread along the coast (Marcovaldi and Marcovaldi, 1999). However, turtles are still caught as by-catch in swordfish and other pelagic longline fisheries (Weidner and Arocha, 1999; Pinedo and Polacheck, 2004) and in gillnet lobster fisheries (Sales and Lima, 2002).

g) Whales

As previously reported, whaling is a very old activity in Brazil, dating back to the 1600s. In the northeastern region, this activity started in Bahia and in 1911, a company was established further north (in Paraíba State), with one, two or three vessels in operation each year. The main whale species caught were minke (*Balaenoptera acutorostrata*), sperm (*Physeter catodon*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), Bryde's (*Balaenoptera edeni*), and fin (*Balaenoptera physalus*) (Paiva and Grangeiro, 1970; Singarajah, 1985).

Brazil signed and ratified the International Convention on the Regulation of Whale Fishery in 1950, and since then, its exploitation rates followed the quotas established by the International Whaling Commission (Farias, 1980). From 1981 to 1985, only minke whales could be caught. In 1987, the Brazilian government declared a complete ban of cetacean fisheries (Federal law no. 7643, December 18th, 1987).

Summary of the exploitation status of the main resources

Most marine resources off northeastern Brazil are fully or overexploited. The status of some resource remains unknown. The national system of fishery statistics is considered poor and more insight would be gained if statistics were corrected for discards, and illegal and unreported catches were incorporated, including those originating from recreational fisheries. Commercial fisheries are managed using single-species models and there is no initiative to adopt an ecosystem-based management approach.

1.8. Thesis outline

Following this introductory chapter, each specific objective will be presented in a separate chapter containing introduction, methods, results, discussion, conclusion, and bibliography related to each subject. Chapter 2 will address the richness of common names of Brazilian marine fishes and how this richness might affect the national fishery statistics. The analysis of catch data from marine fisheries off Brazil will be addressed in Chapter 3. Chapter 4 will analyze the trophic structure of the East Brazil Large Marine Ecosystem and Chapter 5 will present some of the possible effects of future fishing practices. The last chapter (Chapter 6) will summarize and integrate the thesis and present concluding remarks.

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CHAPTER 2. Richness of common names of Brazilian marine fishes and its effect on catch statistics

2.1. Introduction

Fishing impacts are seen not only on target species, but also on non-target species caught as by-catch that is largely discarded. Decreasing trends in the biomass of some species may go unnoticed, as correct species identification may never have been assigned. In addition, the connection between common and scientific names may not be correctly established and different species may be combined in catch statistics, thus undermining stock assessments. This problem, which can remain concealed for a long time, is common in the multi-species fisheries of tropical developing countries.

Overcoming this problem requires an understanding of the connection between common and scientific names. One must be able to comprehend the way names are assigned to living beings. Berlin (1992) presents some principles that govern the naming process of animals and plants: commonness, ease of observation, large size relative to humans, and striking appearance. According to this author, these principles are language universals applying to all cultures. Palomares *et al.* (1999) corroborated these principles for Philippine fishes. Freire and Pauly (2003), investigating names of Brazilian marine fishes, could confirm only the first three of these principles: commonness, expressed in terms of commercial interest, with 78% of commercial species associated with at least one common name versus 26% of non-commercial species; ease of observation, indicating that 73-75% of easily seen reef-associated and pelagic species were named; and size, with 79% of the large species receiving names against 50% of the small species. Striking appearance could not be confirmed, at least not using monotypy as a proxy, as suggested by Palomares *et al.* (1999).

Some scientists consider common names completely unnecessary and suggest they should not be included in scientific publications, reports or legislation. However, common names convey much information about what is known about each organism/species and it is the preferred way for people to refer to them in daily life. Paradoxically, common names can sometimes be more stable than scientific names (Robins *et al.*, 1991). On the other hand, common names are associated with high local and spatial heterogeneity. This creates problems when dealing with catch statistics, especially in tropical and developing regions such as Brazil, where artisanal, multi-species fisheries are very important (Paiva, 1997; Freire, 2003).

The objective of this chapter is to investigate the richness of common names of Brazilian marine fishes, to assess the importance of commercial interest and ease of observation in the richness of common names, and to quantify the effect of the richness of common names on Brazilian catch statistics. The results presented here may contribute, as well, to an understanding of how fisheries induce losses of local biodiversity.

2.2. Material and methods

A database (hereafter referred to as NAMEDAT) of 4,156 common names of 725 Brazilian marine fish species was compiled from 30 sources published between 1962 and 2000. It included names that ranged geographically from Pará State, in northern Brazil, to Rio Grande do Sul State, in southern Brazil (Barcellos, 1962; Brandão, 1964; Ihering, 1968; Lima, 1969;

Anon., 1976; SUDENE, 1976; Carvalho and Branco, 1977; Figueiredo, 1977; CEPA-MA, 1978; Figueiredo and Menezes, 1978; Lima and Oliveira, 1978; Figueiredo and Menezes, 1980; Menezes and Figueiredo, 1980; Rosa, 1980; Chao *et al.*, 1982; Santos, 1982; Nomura, 1984; Menezes and Figueiredo, 1985; Suzuki, 1986; Godoy, 1987; Martins-Juras *et al.*, 1987; Soares, 1988; Ferreira *et al.*, 1996; Ferreira *et al.*, 1998; Santos *et al.*, 1998; Carvalho-Filho, 1999; Ferreira, 1999; CEPENE, 2000; Figueiredo and Menezes, 2000; Szpilman, 2000). This extended database was constructed based on previous work by Freire and Pauly (2003), which resulted in a large expansion of the list of Portuguese common names of Brazilian marine fishes available in FishBase (www.fishbase.org). The State where the name is used was recorded in the database, when this information was available. The richness of common names was assessed as (1) number of common names per species, and (2) number of species per common name.

The number of common names per species was grouped into classes: 0, 1, 2-5, 6-10, 11-20, 21-30, and >30. Information on local commercial importance was obtained from CEPENE (1997; 1998), Carvalho-Filho (1999), and Szpilman (2000). Habitat type (pelagic, demersal, reef-associated, bathypelagic, bathydemersal, and benthopelagic) was used as a proxy for ease of observation and reflects the definition presented in FishBase (Froese and Pauly, 2000, and www.fishbase.org). See Appendix 1 for the description of each habitat type.

The association amongst number of common names, commercial importance, and habitat type was measured using multiple correspondence analysis – MCA (Greenacre and Blasius, 1994) and was performed using SAS Version 8.2.

Mean catches for the period 1995-2000, obtained in Chapter 3, were used to analyze the effect of the richness of common names in the Brazilian catch database (hereafter referred as CATCHDAT). This period was chosen because of the existence of an electronic catch database and because the catches were relatively stable throughout the period (Freire, 2003). This analysis followed three steps:

1) Identification of common names associated with the ten highest mean annual catches from Brazilian artisanal fisheries (1995-2000);
2) Identification of common names associated with the ten highest mean annual catches from Brazilian industrial fisheries (1995-2000);
3) Selection of ten common names with the highest associated number of species.

The catch recorded for one group by common name (e.g., 'linguado' or 'sardinha') was split equally amongst the species associated with that common name in each State, following the steps defined in Figure 2.1. The definition of industrial and artisanal fisheries is as presented in the Appendix 1.

2.3. Results

a) Richness of common names

The richness of common names of Brazilian marine fishes is very high, with an average of six common names per species. Although 208 species have only one common name, there is one extreme case where one species, *Macrodon ancylodon*, has 37 common names (Fig. 2.2a). In contrast, there are 1,908 common names that refer to only one species. The worst case here is one common name 'linguado' (flatfish), which is used for 31 different species (Fig. 2.2b). Some of the common names such as 'linguado' and 'cação' refer to species associated with five different families (Table 2.1). Many others are associated with at least two different families.

Table 2.1: Common names related to the highest number of species for the Brazilian marine realm (representing 25% of all species in the NAMEDAT database), and the respective families associated with each name.

COMMON NAME	# SPECIES	FAMILIES
'Linguado'	31	Achiridae, Bothidae, Cynoglossidae, Paralichthyidae, Pleuronectidae
'Manjuba'	24	Atherinidae, Clupeidae, Engraulidae
'Cação'	20	Carcharhinidae, Lamnidae, Sphyrnidae, Squalidae, Triakidae
'Solha'	19	Achiridae, Bothidae, Cynoglossidae, Paralichthyidae
'Budião'	18	Labridae, Scaridae
'Sardinha'	17	Clupeidae, Engraulidae
'Moréia'	15	Chlopsidae, Gobiidae, Muraenidae, Ophichthidae
'Baiacu'	13	Diodontidae, Ostraciidae, Tetraodontidae
'Pescada'	13	Sciaenidae, Sphyraenidae
'Voador'	12	Dactylopteridae, Exocoetidae
Total	182	

The richness of common names was related to the commercial importance of the species and habitat types, with commercial or easily visible species (reef-associated, pelagic, and demersal) receiving between 2 and 30 common names or even more (Figure 2.3). Species of no commercial interest were linked to only one common name, while no common name was associated with benthopelagic, bathypelagic, and bathydemersal species.

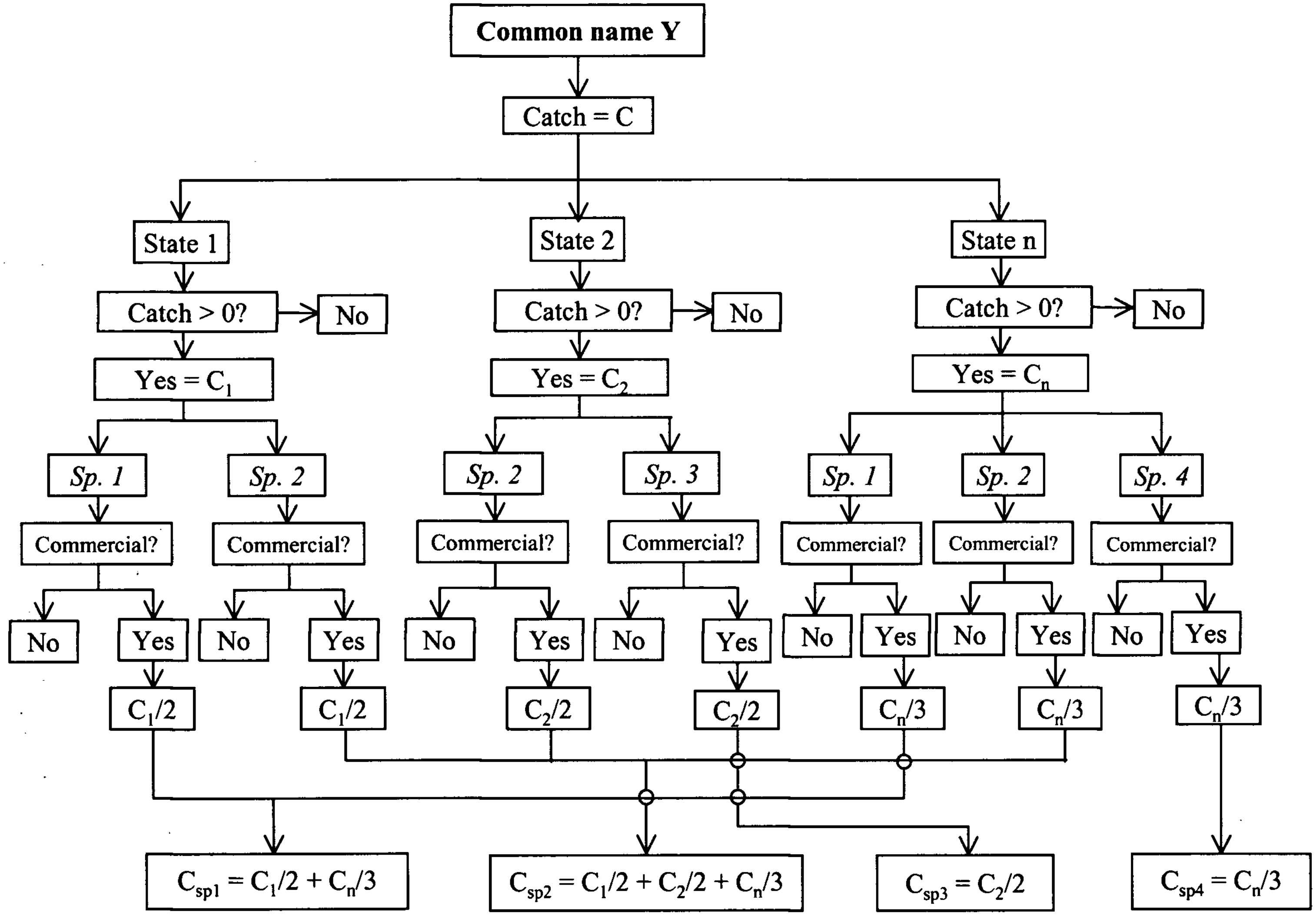

Figure 2.1: Flowchart used to split catch (by common name) amongst all possible commercial species. 'C' represents catch and 'n' represents the number of coastal States in Brazil (Total = 17).

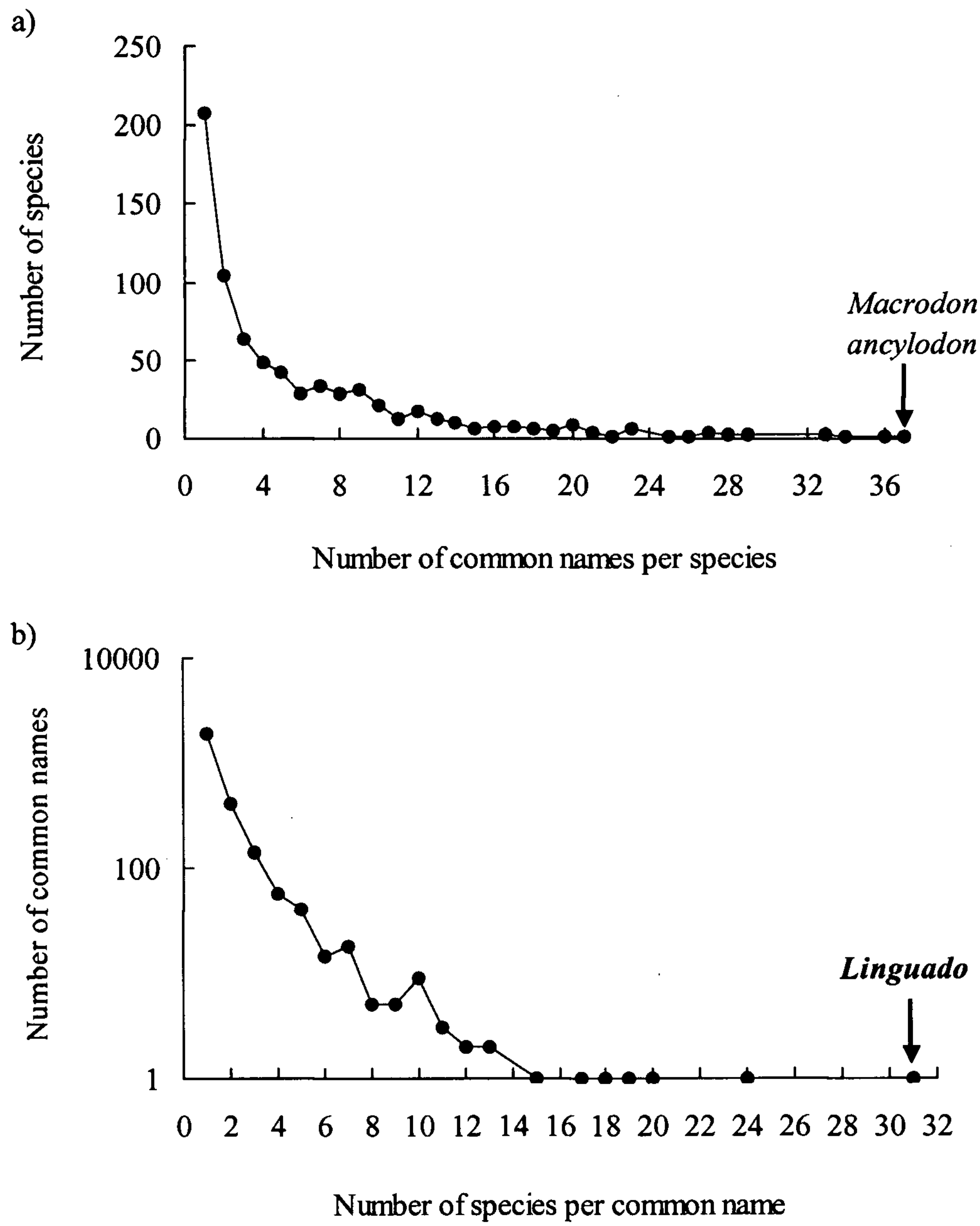

Figure 2.2: Richness of names of Brazilian marine fishes: a) Frequency of scientific species that have one to thirty-seven common names; b) Frequency of common names that correspond to a range of one to thirty-one species.

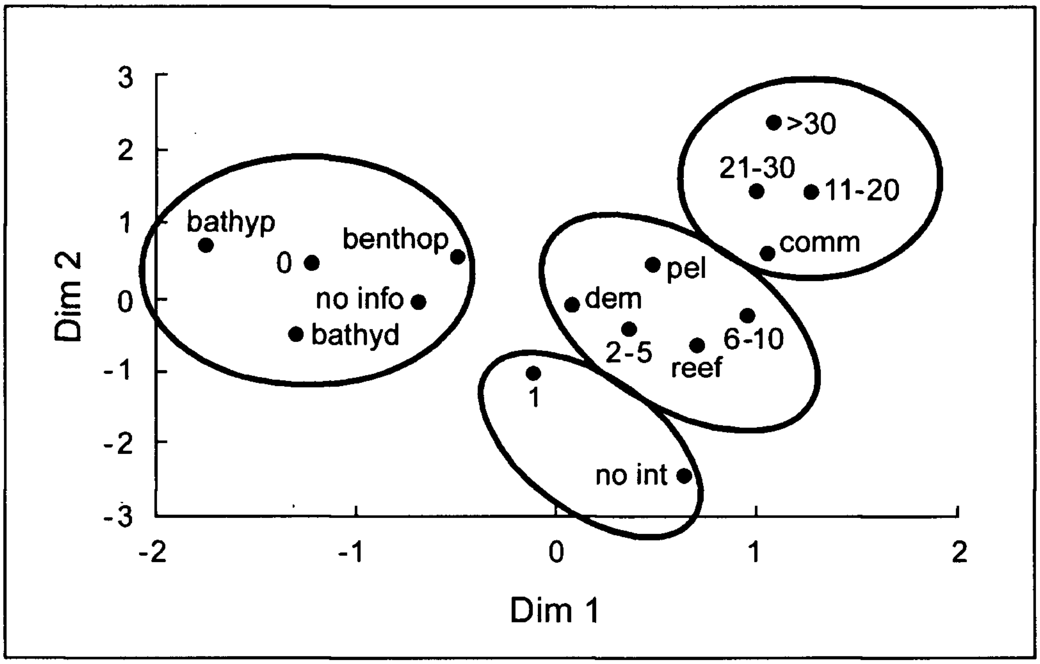

Figure 2.3: Relationship between number of common names (0, 1, 2-5, 6-10, 11-20, 21-30, >30), commercial importance (no information available, no commercial interest, commercially important), and habitat (demersal, pelagic, reef-associated, bathypelagic, benthopelagic, bathydemersal). Dim 1 and Dim 2 are the two axes obtained with the multiple correspondence analysis, which explain 100% of variation in the data. Dim 1 may be seen as the 'habitat dimension' and Dim 2 as the 'commercial dimension'.

b) Effect of common names' richness on catch statistics

Step I – Artisanal fisheries

The highest catches from Brazilian artisanal fisheries (1995-2000) are associated with the category 'shrimps' and 'other fishes', accounting for mean annual catches of about 39,500 tonnes (Table 2.2). These two broad terms are the first symptom of the low quality of the system responsible for gathering catch statistics in Brazil. In third place is the Atlantic seabob, *Xiphopenaeus kroyeri*, with a mean annual catch of 11,553 tonnes.

Catfish are in fourth place with a mean annual catch of 10,879 tonnes. These catfishes are recorded under the common name 'bagre', which may refer to ten different species, of which only six are recognized as commercially important: *Aspistor quadriscutis, Bagre bagre, Cathorops spixii, Genidens genidens, Hexanematichthys herzbergii*, and *Hexanematichthys proops* (Fig. 2.4). These six species are associated with 59 other common names: 'ariaçu', 'ariassu', 'bagre branco', 'bagre cinzento', 'bagre do Natal', 'bagre guribu', 'bagre mandi', 'bagre pararê', 'bagre-amarelo', 'bagre-bandeira', 'bagre-bandeirado', 'bagre-crucifixo', 'bagre-curiaçu', 'bagre-da-areia', 'bagre-de-areia', 'bagre-de-manta', 'bagre-de-penacho', 'bagre-fidalgo', 'bagre-fita', 'bagre-gonguito', 'bagre-guri', 'bagre-guriaçu', 'bagre-guru', 'bagre-leilão', 'bagre-mandim', 'bagre-sari', 'bagre-sarí', 'bagre-urutu', 'bagrinho', 'bandeira', 'bandeirado', 'bandim', 'beiçudo', 'cangatã', 'conguito', 'guriaçu', 'guri-branco', 'gurijuba', 'ieicéca', 'iriceca', 'iricéca', 'irideca', 'iridéca', 'iritinga', 'jahu amazonense', 'jandiá-uva', 'jau', 'jundiá-uva', 'pareré', 'peixe fita', 'pirá-bandeira', 'sarasará', 'sarassará', 'sargento', 'sarí', 'sarí-açú', 'sarí-assu', 'uriacica amarelo', and 'uritinga'. Note that several names are very similar and these small differences reflect the use of these common names in oral tradition. The total catch for this group was split amongst all possible commercial species (Fig. 2.4). It is worth pointing out that three of those species would not be otherwise associated with any catches: *Aspistor quadriscutis, Cathorops spixii,* and *Genidens genidens*. Furthermore, species such as *Hexanematichthys proops* could be associated with annual catches as high as 3,777 tonnes.

Step II – Industrial fisheries

The highest industrial catches are Brazilian sardine, skipjack, croaker, other fishes, and sardine, which together account for about 134,300 tonnes or 42% of total industrial catches

(Table 2.2). With the exception of skipjack, which is clearly linked to *Katsuwonus pelamis*, all the other four categories reveal the ambiguity in catch statistics from Brazil. 'Sardinha verdadeira' is normally associated with *Sardinella brasiliensis*, especially in southeastern Brazil, where the bulk of catches originates. However, 'Sardinha verdadeira' is also associated with four other species (*Sardinella aurita, Opisthonema oglinum*, *Cetengraulis edentulus,* and *Anchovia clupeoides*) in different States (Fig. 2.5). On the other hand, *S. brasiliensis* is also known by 13 other common names: 'biribiri', 'boca-torta', 'charuto', 'escamuda', 'manjuvão', 'maromba', 'sardinha', 'sardinha charuto', 'sardinha-azul', 'sardinha-de-galha', 'sardinha-do-

Table 2.2: Common names associated with the ten highest mean annual catches from Brazilian artisanal and industrial fisheries (1995-2000), based on CATCHDAT.

FISHERY	PORTUGUESE	ENGLISH	CATCH (t)
Artisanal	'Camarão'	Shrimp	19,959
	'Outros peixes'	Other fishes	19,488
	'Camarão sete barbas'	Atlantic seabob	11,553
	'Bagre'	Catfish	10,879
	'Caranguejo'	Crab	10,382
	'Corvina'	Croaker	9,811
	'Garajuba'	–	8,878
	'Tainha'	Mullet	8,075
	'Serra'	–	6,817
	'Peixe porco'	–	6,366
		Total	112,208
Industrial	'Sardinha verdadeira'	Brazilian sardine	65,424
	'Bonito listrado'	Skipjack	24,276
	'Corvina'	Croaker	15,512
	'Outros peixes'	Other fishes	19,388
	'Sardinha'	Sardine	9,699
	'Cação'	Shark	8,109
	'Albacora'	Tuna	7,647
	'Camarão'	Shrimp	7,563
	'Pescada olhuda'	Weakfish	7,262
	'Sardinha laje'	Herring	6,973
		Total	171,852

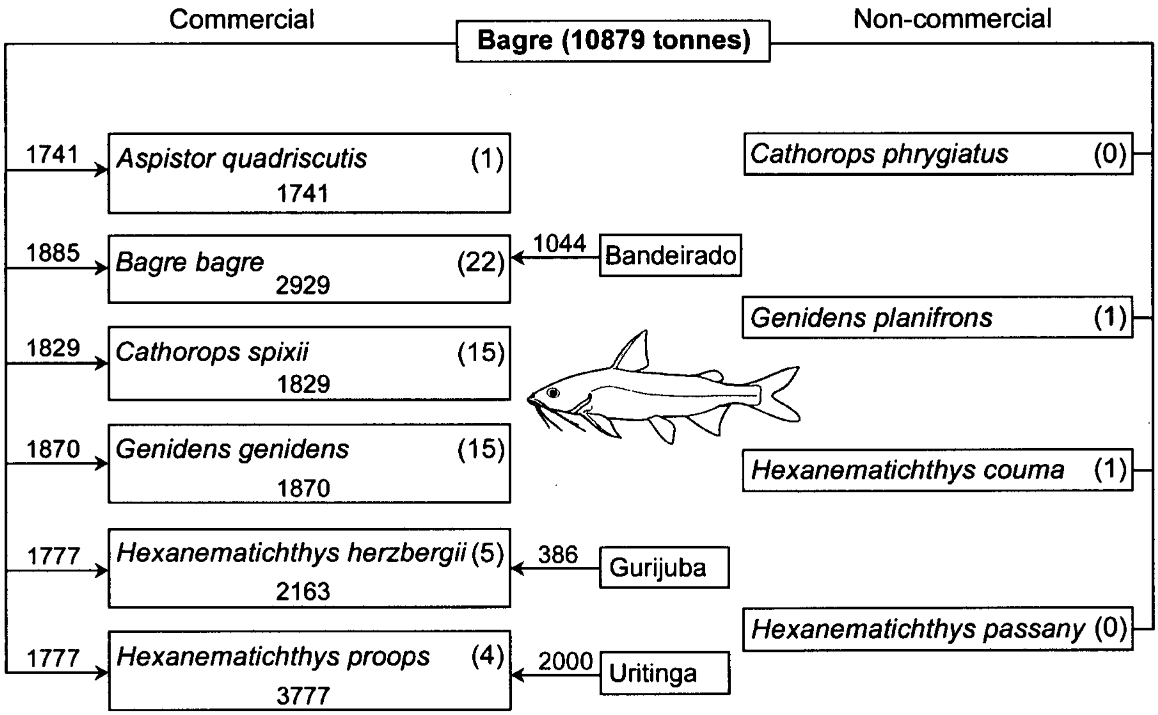

Figure 2.4: Mean annual catch of 'bagre' (in tonnes) by artisanal fisheries in Brazil (1995-2000), split amongst all possible commercial species. Numbers in parentheses represent other names besides 'bagre' that each species is linked to. The other number in the box represents the total catch for each species, considering all common names they receive.

reino', 'sardinha-legítima', and 'sardinha-maromba'. Amongst all these names, only 'sardinha' is recorded in catch statistics and is associated with 16 other species besides *S. brasiliensis*.

Here, the catch data for 'sardinha' was split amongst the ten commercial species linked to that name (Fig. 2.5). One of these species (*Anchoviella lepidentostole*, also known as 'manjuba') presents one of the highest name richness (24). Its catch was split amongst 12 commercial species related to the name 'manjuba' and some of them may be associated with catches as high as 5,200 tonnes.

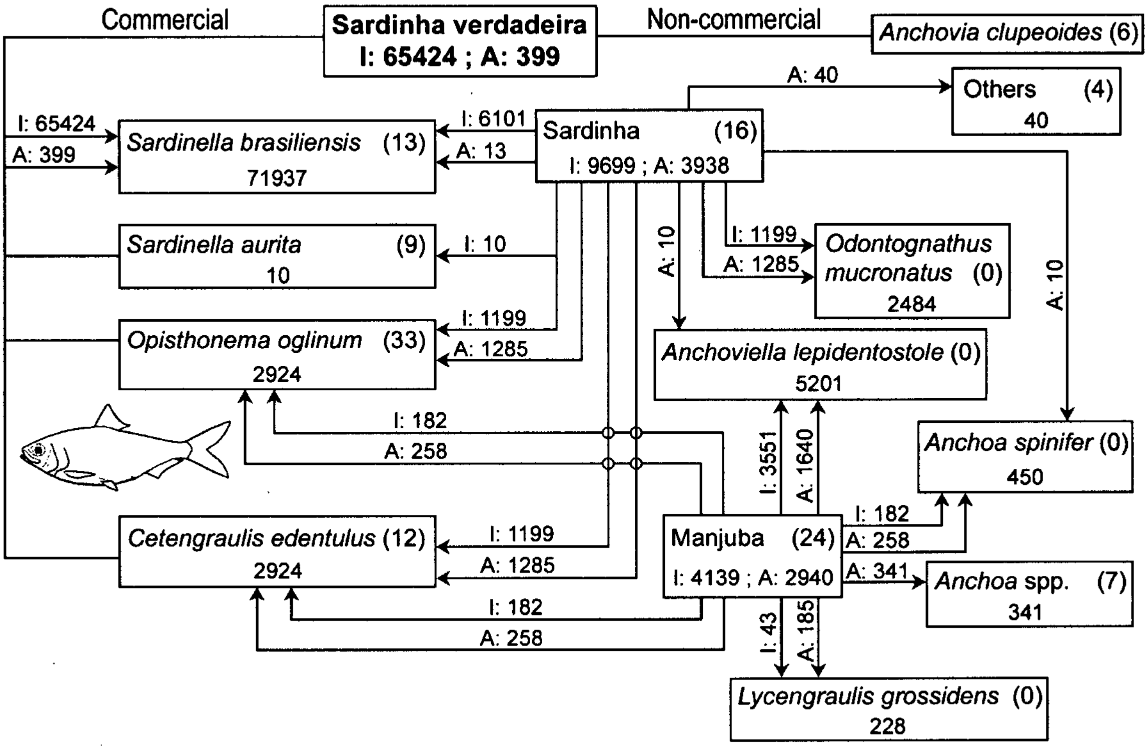

Figure 2.5: Industrial (I) and artisanal (A) mean annual catch (in tonnes) of 'sardinha verdadeira' in Brazil (1995-2000) split amongst all possible species. Numbers in parentheses represent other names each species can receive in addition to the ones presented or the number of species associated with a common name. The group 'Others' includes *Anchoviella guianensis, Brevoortia pectinata, Harengula clupeola,* and *Pellona harroweri*. The group '*Anchoa* spp.' includes *A. januaria, A. filifera, A. tricolorm, A. lamprotaenia, A. marinii, A. lyolepis*, and *A. parva*.

Step III – 'Linguado', the most diverse common name

Even though 'linguado' does not figure as one of the most important species in terms of catch volume at a national scale, it is associated with the highest number of species, both commercial and non-commercial (Fig. 2.6). Only 13 species out of the total have no other common name associated with it besides 'linguado'. The remaining 18 species are interchangeably associated with 31 other common names.

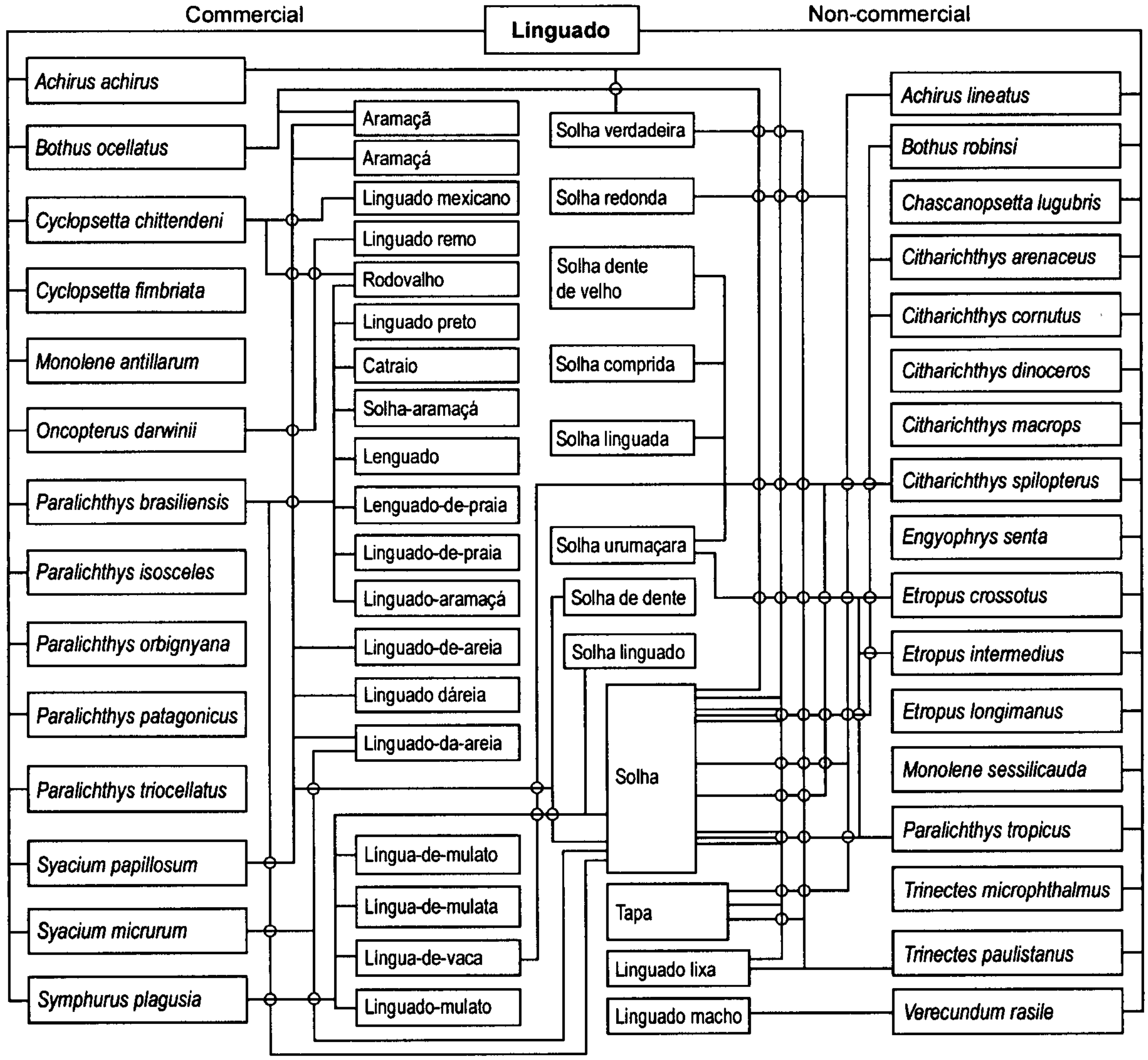

Figure 2.6: Link between common and scientific names for all commercial and non-commercial species that receive the common name 'linguado' (flatfish).

The split of the total catch of 'linguado' amongst all species of commercial interest indicates that catches of some species associated only with that common name could be as high as 308 tonnes, as it is the case for *Paralichthys orbignyana* (Fig. 2.7 – right side). The same catch value would be associated with *Paralichthys brasiliensis* (Fig. 2.7 – left side), a species associated with nine other common names.

c) The case for standardization of common names

Only 37 species of Brazilian marine fishes have a unique common name that refers to no other species (Table 2.3). The rest of the species have more than one common name or share the same name with other species. To overcome this confusion, a list needs to be created containing all names linked to each species and indicating the States where they are used. A unique name would then be chosen from that list and declared as the 'official' name. The reasons for each specific choice must be given. The names presented in Table 2.3 could function as a starting point of such a list. Thus, the proposed list should deal first with species having increasingly higher richness of common names, i.e., one should deal first with species with 2 common names, 3, 4, and so on. Emphasis should be given in the first stage to species of commercial importance, which would contribute to an improvement in the statistical recording system of catch statistics. In cases where names are not available, they could be borrowed from the list of Portuguese names assembled by Sanches (1989) or translated from other languages to Portuguese.

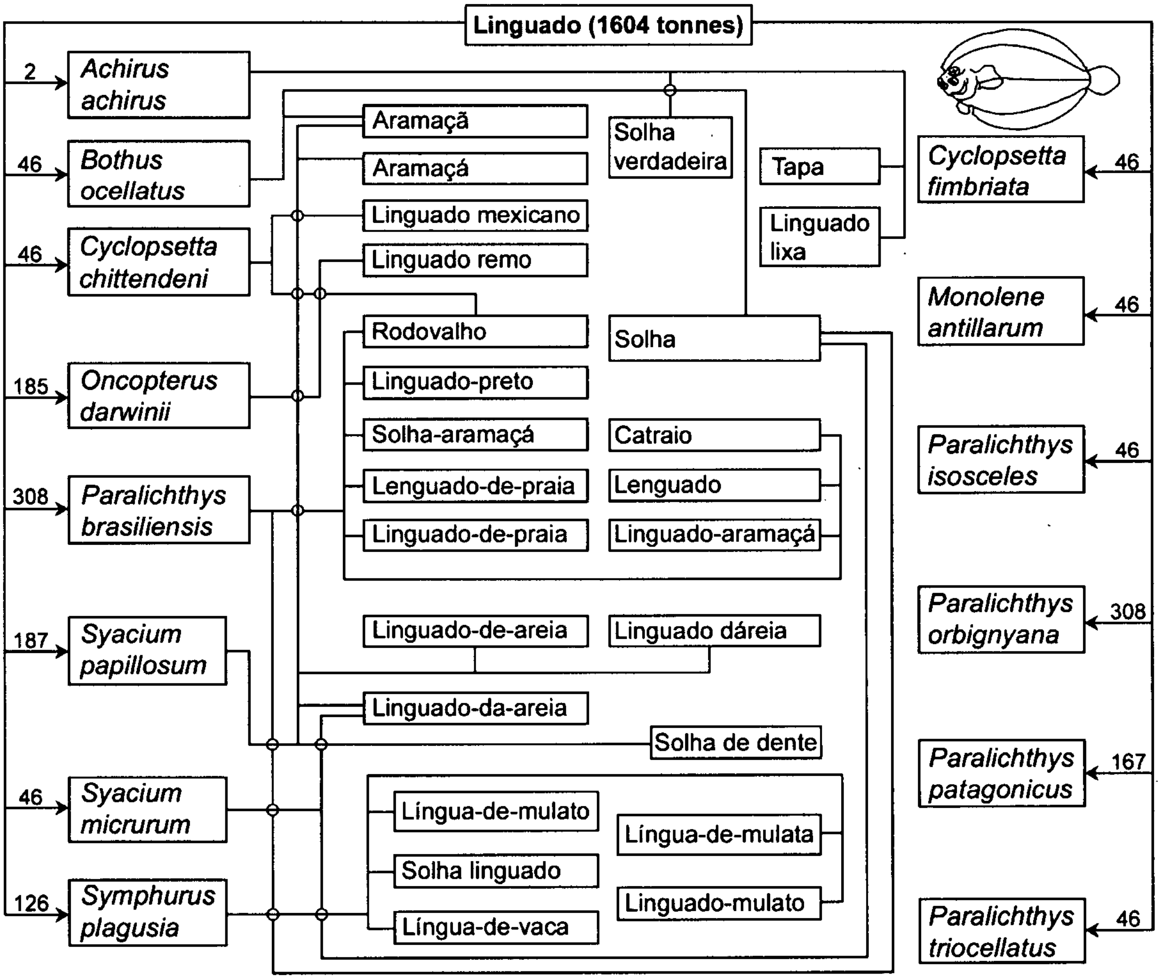

Figure 2.7: Catch data (in tonnes) split amongst species that share the same common name ('linguado'), based on an average for the period 1995-2000 (Brazilian marine industrial and artisanal fisheries).

Table 2.3: List of species presenting one unique common name in Brazil, based on NAMEDAT.

SPECIES	PORTUGUESE NAME	ENGLISH NAME
Apogon pseudomaculatus	‘Totó’	Twospot cardinalfish
Canthidermis maculatus	‘Cangulo machado’*	Spotted oceanic triggerfish
Carcharhinus isodon	‘Cação dente liso’*	Finetooth shark
Carcharhinus longimanus	‘Galha branca’*	Oceanic whitetip shark
Carcharhinus perezi	‘Cação coralino’*	Caribbean reef shark
Carcharhinus signatus	‘Cação noturno’*	Night shark
Chilomycterus atringa	‘Baiacu de espinho pintado’*	Spotted burrfish
Cichla ocellaris	‘Tucunaré’	Peacock cichlid
Conger triporiceps	‘Congro dentão’*	Manytooth conger
Congiopodus peruvianus	‘Peixe dragão’*	Peruvian pigfish***
Cyclichthys schoepfi	‘Baiacu de espinho listrado’*	Striped burrfish
Dactyloscopus tridigitatus	‘Mira céu da areia’*	Sand stargazer
Enchelycore nigricans	‘Moréia negra’*	Mulatto conger
Etelis oculatus	‘Pargo mariquita’	Snappers
Evoxymetopon taeniatus	‘Tirante’	Channel scabbardfish
Gramma brasiliensis	‘Loreto’	Brazilian basslet
Haemulon chrysargyreum	‘Cocoroca boquinha’*	Smallmouth grunt
Haemulon macrostoma	‘Cocoroca espanhola’*	Spanish grunt
Halichoeres garnoti	‘Gudião amarelo’**	Yellowhead wrasse
Heros severum	‘Acará preto’*	Banded cichlid
Isistius brasiliensis	‘Cação luminoso’	Cookiecutter shark
Isurus paucus	‘Anequim preto’*	Longfin mako
Negaprion brevirostris	‘Cação limão’*	Lemon shark
Notopogon fernandezianus	‘Beija flor’*	Orange bellowsfish
Ophichthus ophis	‘Muçum pintado’	Spotted snake eel
Ophioblennius atlanticus	‘Punaru’	None
Paradiplogrammus bairdi	‘Peixe pau’	Lancer dragonet
Pellona flavipinnis	‘Sardinha dourada’	Yellowfin river pellona
Phaeoptyx pigmentaria	‘Cardeal pintado’*	Dusky cardinalfish
Plectrypops retrospinis	‘Fusquinha’	Cardinal soldierfish
Polymixia nobilis	‘Barbudo olhão’	Stout beardfish
Rhincodon typus	‘Tubarão baleia’*	Whale shark
Sparisoma aurofrenatum	‘Budião manchado’*	Redband parrotfish
Stegastes leucostictus	‘Gregory’	Beaugregory
Stegastes variabilis	‘Donzela cacau’*	Cocoa damselfish
Synchiropus agassizii	‘Mandarim’	Spotfin dragonet
Torpedo nobiliana	‘Torpedo’	Atlantic torpedo

*All these names had the hyphen removed; **The original name was gudião-amarelo; *** Obvious common name, if new coinage, given the family name.

Robins *et al.* (1991) list the criteria used in the standardization process of common names of North American fishes (updated in Nelson *et al.*, 2004). These criteria may be followed, as they have been used for more than 50 years. Preference could be given for simple and descriptive names. Names tied to scientific names, the ones that include the word 'common', and names that honour people or are offensive should be avoided. The spelling available in the most widely used Portuguese dictionary in Brazil – Aurélio (Ferreira, 1999) – would be the best choice amongst the names available. Two additional criteria could be used: no inclusion of hyphens (to avoid different spellings) and the first letter of the common name should be capitalized. According to Joseph S. Nelson (pers. comm., Dept. Biological Sciences, University of Alberta, Canada), the use of names with the first letter in lower case has generated some problems when, for example, adjectives are part of the name.

One example of the process of selection of a unique name, based on criteria similar to those of Robins *et al.* (1991), is presented for *Balistes carolinensis* (Grey triggerfish), which is presently connected to 21 common names: 'cangulo' (from an African language and used in 6 States), 'peixe porco' (Latin, 14 States), 'cangulo papo-amarelo' (African, 9), 'capado' (Latin, 9), 'peroá' (Tupi, 9), 'cangulo-da-parede' (African, 1), 'cangulo-de-Fernando' (African, 1), 'peroatinga' (Tupi-guarani, 1), 'acará-fuso' (Tupi), 'acará-mocó' (Tupi), 'acaramuçu' (Tupi), 'acarapicu' (Tupi), 'acarapucu' (Tupi), 'cangulo-branco' (African), 'cangurro' (African), 'fantasma' (Greek), 'maracuguara' (Tupi-guarani), 'perua' (Tupi), 'piraaca' (Tupi-guarani), 'pirá-acá' (Tupi-guarani), and 'piruá' (Tupi). The number of States where the name is used and its contribution to the diversity of languages could be used as initial criterion to choose the official name. In this case, 'cangulo' and 'peixe porco' would be the best candidates as they are used in almost all States. However, these two names are too general, with no descriptive power at the species level. Moreover, they are associated with six and 11 different species, respectively. 'Capado', 'cangulo papo amarelo', and 'peroá' are the next most frequent names, but they are also associated with *Balistes vetula*. 'Peroatinga' is recorded in only one State, but it is not used for any other species. 'Peroatinga' originated from Tupi-guarani and would thus contribute to maintaining the diversity of languages amongst the common names, representing a good choice for an official name.

The national official list of common names proposed here would be appropriate whenever species are dealt with in a national context (in scientific publications or reports), in catch statistics, and in legislation.

2.4. Discussion

Two interconnected concepts and their implications have been extensively discussed worldwide: biodiversity and risk of extinction. More recently, the risk of extinction of marine species has been estimated. It appears that both artisanal and industrial fisheries are capable of pushing species towards extinction (Dulvy *et al.*, 2003). As a signatory country to the Convention on Biological Diversity, Brazil is committed to reduce the rate of biodiversity loss by the year 2010 (see www.biodiv.org). Although there is an intense effort towards quantifying biodiversity in Brazilian territory and adjacent waters (MMA, 1998; Baer, 2001; Sabino and Prado, 2003), Brazil is still far from being able to assess how fisheries may be contributing to biodiversity loss.

The lack of accuracy in catch statistics can also have serious implications, as some species may have been caught for years without information being recorded. A series of local depletions can remain unnoticed, with the process ending with global extinction (Pitcher, 2001). *Scarus guacamaia*, a parrotfish once distributed throughout the tropical portion of the Brazilian coast, is considered extinct in Brazil (Ferreira *et al.*, 2005). The authors consider that spearfishing probably had an important role in the process of extinction of this species. The national database cannot be used to infer about the influence of fishing on the extinction due to the underestimation of catches that will be addressed in Chapter 3. Additionally, the catch database compiled here (CATCHDAT) indicates that in 1978/1979, two tonnes of 'papagaio' (parrotfish) were caught only in Pernambuco State (no register for other States). 'Papagaio' refers to seven species occurring in Brazil: *Bodianus pulchellus, B. rufus, Halichoeres cyanocephalus, Sparisoma chrysopterum, Sparisoma viride, Aetobatus narinari* (ray), and the extinct species *Scarus guacamaia*. As it stands, it is not possible to indicate how much of this total catch was associated with *S. guacamaia*, if at all. *Balistes vetula* (queen triggerfish) is considered threatened by the World Conservation Union – IUCN. Aquarium fisheries have caught this species in waters off Ceará State (Monteiro-Neto *et al.*, 2003), but its participation in the total commercial catches in Brazil is not known. This species is locally known as 'peixe gatilho', 'piruá', 'peixe porco', and 'peroá'. The latter two were associated with an annual catch of 8,212 tonnes, but again there is no indication of the share of *B. vetula* in this total.

Other species may be associated with catches higher than thought. *Sardinella brasiliensis* catches, for example, were increased by 9% when catches attributed to the category 'sardinha' were split evenly amongst different commercial species (Figure 2.5). This stock is one of the most important in the country and declined severely, with catches dropping from about 228,000 tonnes in 1973 to 32,080 tonnes in 1990 (Dias Neto and Dornelles, 1996). For a stock with low biomass, and which fisheries managers would like to see recovering, a catch increase of 9% is no small matter.

Catches recorded as 'catfish' could be split in up to six species from five different genera. Some of these species may have annual catches of almost 3,800 tonnes, if catches assigned to other common names are combined. Given that we are dealing with an artisanal fishery, this difference is too high to be neglected. A similar situation occurs for flatfish, although with lower catches (1,604 tonnes). This total may be associated with 14 different species, with catches as high as 308 tonnes for some of these species.

The standardization of common names suggested here could help to avoid this problem and should be achieved through a consultation process including all parties directly or indirectly involved with fish and fisheries: universities, government institutions (such as the Brazilian Institute for Environment and Renewable Natural Resources/IBAMA and the Special Secretary for Aquaculture and Fisheries/SEAP), non-governmental organizations, associations of recreational and commercial fishers, the Brazilian Society of Ichthyology (SBI), the Brazilian Society for the Study of Elasmobranchs (SBEEL), etc. There is no reason to think that an attempt to standardize common names of Brazilian fishes, within a diverse cultural context, would be easy. Besides, the standardization should be seen as a necessary, but not sufficient condition, for a better catch data system.

The understanding of how people name fishes (and life forms in general) would help in the selection process of official names. In this regard, Berlin (1992) and, more generally, Lakoff (1987) present a significant contribution on the principles involved in the naming process and categorization. More specifically, Begossi and Garavello (1990), Begossi and Figueiredo (1995), Costa-Neto and Marques (2000), Mourão (2000), and Seixas and Begossi (2001) have dealt with categorization of fish in local communities along northern, northeastern, and southeastern Brazil. At a national level, Freire and Pauly (2003) analyzed the naming process for Brazilian marine fishes. However, no attempt was made here to consider the influence of this process in the selection of official names, except for showing the effect of the commercial importance in the richness of common names (also previously recorded by Begossi and Garavello, 1990; Mourão, 2000 in some localities), and the effect of habitat types as representing accessibility. It must be kept in mind that the standardization proposed here is not intended to extinguish local linguistic diversity, but to avoid misinterpretations of national data and their undesirable consequences.

Some of the sources of uncertainty related to this work are: overestimation or (more probably) underestimation of catches, misidentification of species, non-exhaustive list of commercial species, list of common names not properly attributed to one State because of the lack of local fish name lists, and the equal weights used to split catches amongst common names available per State. There will be many ways of dealing with this uncertainty in the future: improving landing data through the incorporation of discards or raising up the available data based on any indication of bias; checking the commercial status of species with local experts; accessing lists of common names used by local authorities; and estimating better weights (with the help of local experts) to split the catch amongst species. As soon as more local data are incorporated in the common names database, an analysis of the impact of the richness of common names can be performed in more detail for each State.

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CHAPTER 3. Analysis of catch data from marine fisheries off Brazil

3.1. Introduction

Fishery management aims to maintain fished stocks at sustainable levels, despite the lack of consensus on what 'sustainability' means. The stock size and species composition found in fished areas at the present have certainly been altered by decades or even centuries of fishing pressure (Jackson *et al.*, 2001). To better understand these changes, it is necessary to have at least some indirect indicators, such as time series of catch and effort data, for those cases where no direct information on stock abundance is available. However, one should be aware that an abundance trend based on catch and effort data may issue conflicting signs about the stock state when there is, for example, a range collapse in its distribution area (Walters and Martell, 2004).

The time series of these indicators should be long enough to help us understand issues such as the "shifting baseline syndrome", directly associated with the way in which successive cohorts of scientists perceive the health of a stock based on increasingly depleted stocks (Pauly, 1995). If we do not accept and understand the effects and implications of this phenomenon, we will continue attempting to preserve current stock levels, which may not be a sustainable solution. Instead, we may want to rebuild stocks and ecosystems (Pitcher, 2001). Jackson *et al.* (2001) point out that short time series also fail to detect some long-term environmental shifts and their impact on stocks, which consequently influence our misperception of the depletion process of most fishing stocks worldwide.

Detailed, long series of catch and effort data are lacking or not easily available in many countries, including Brazil, with the exception of landing data at the national level available from the Food and Agriculture Organization (FAO) and from the International Commission for the Conservation of Atlantic Tunas (ICCAT) for tuna and tuna-like fishes. Aragão (1997) presents an overview of the evolution of data collection systems related to the Brazilian fishing sector and this overview will help to understand why such a detailed database does not exist. Before 1967, the Production Statistical Service (SEP) of the Ministry of Agriculture was responsible for assembling landing data collected by the IBGE (Brazilian Institute of Statistics and Geography), State institutions, and the Ministry of Finance. In 1967, SUDEPE created the Statistical Advisory Board, which proposed a new plan for data collection. However, it was never implemented. In 1968, the PDP Program (SUDEPE/FAO) began collecting landing data in the southernmost region and later extended its activities to other regions. In the early 1970s, PDP and SUDENE (Superintendence for the Development of the Northeastern Region) collaborated to collect data from the northeastern region. When PDP became the sole responsibility of SUDEPE, in 1980, the system of data collection began to deteriorate. During this period IBGE continued to collect data, but their quality was considered low.

One year after the demise of SUDEPE and the establishment of IBAMA, the latter developed a system of data collection that began in Ceará (ESTATPESCA), northeastern Brazil. This system was gradually extended to other States of the northeastern region, but was not able to encompass all its States. Some States did not collect any data during this transitional period due to the lack of human and financial resources. At present, data collection is highly heterogeneous, being performed by IBAMA, State institutions, and/or universities. IBAMA remains responsible for gathering data from all these institutions and presents them in the form of national bulletins ('Estatística da Pesca'). One of IBAMA's branches, CEPENE is responsible for gathering data for northeastern Brazil and publishes them as regional bulletins. Only the 2001 CEPENE Bulletin is available online. With the recent political changes, the future of data collection from the fishing sector is unclear.

Some argue that the importance of the artisanal fishery in Brazil is one of the factors leading to poor data collection (Paiva, 1997). Others attribute this difficulty to problems in communication and organizational structure (see e.g. Marcílio and Lisanti, 1973). For the fishing sector, this is magnified by the lack of institutional interest in an activity with low contribution (0.25%) to the gross domestic product (FAO, 2002b), by the shortage of financial and specialized human resources, and probably by unstable institutional arrangements.

A complete assessment of the state of marine resources requires that all extractions are properly documented. Recreational fisheries, for example, are associated with expenditures of US$ 5-38 billion worldwide (Cowx, 2002), but there is no precise estimate of global catches as many countries do not have the mandate to record their catches. Recreational catches may be higher than those from commercial fisheries in some areas (Gentner and Lowther, 2002) and differentially affect stocks at risk (Coleman *et al.*, 2004). Ornamental fisheries are also a growing industry with a worldwide export value of about US$ 350 million (Hardy, 2003). Most of the marine ornamental fishes are caught in the wild as opposed to the freshwater species, which are bred in captivity (Andrews, 1990), putting an additional pressure on marine resources. H. Bleher (cited in Andrews, 1990) estimates that 150 million fishes are traded in the ornamental market each year. Catches from subsistence fisheries are often high in developing countries and at the same time harder to obtain due to the highly dispersed fishing grounds and landing sites. Research is also responsible for some extraction, which normally is not incorporated in national databases of total catches probably due to the low figures in relation to other fisheries. There is also a growing concern with the magnitude of catches from illegal, unreported and unregulated fishing (IUU) and its impact on the sustainability of fish stocks (FAO, 2002c). This indicates that the most basic data required to access the health of stocks, i.e. total catches, are underestimated in many countries.

The goal of the present chapter was to analyze the catch data available for marine Brazilian fisheries and to assess the possibility of its use to indicate the state of the stocks. The following specific objectives were addressed:

1) to compile and to document annual landing data originating from Brazilian marine fisheries per State and per fishery type for the period 1978-2000;
2) to compare the database compiled in (1) with other existing databases at a national scale;
3) to assess the occurrence of 'fishing down the food web' in Brazil;
4) to identify some sources of underestimation in order to lead to further improvement of the database compiled here.

3.2. Material and methods

Annual landing data from Brazilian commercial marine fisheries were compiled and encoded in Microsoft Access for the period 1978-2000 by State, by fishery type (artisanal and industrial), and by species or group of species (Tables 3.1 and 3.2).

Table 3.1: Structure of the ACCESS database of landing statistics originating from Brazilian marine fisheries.

VARIABLE	DESCRIPTION
1. Year	1978-2000
2. State	Amapá, Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Espírito Santo, Rio de Janeiro, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul
3. Fishery	Artisanal or Industrial
4. Species	By common name
5. Landings	Tonnes
6. Source	All sources are listed in Table 3.2

Table 3.2: Sources used to compile landing statistics from Brazilian marine fisheries.

PERIOD	FREQUENCY	FORMAT	SOURCES
1978-1979	Annual	Paper	(SUDEPE, 1980; 1981)
1980	Annual	Paper	(IBGE, 1980)
1981-1989	Semi-annual	Paper	(IBGE, 1981; 1982a; b; 1983a; b; 1984a; b; 1985a; b; 1986a; b; 1987a; b; 1988a; b; 1989a; b)
1990-1997	Annual	Paper	(CEPENE, 1995a; b; c; d; e; 1997a; b; 1998)
1998	Annual	Electronic	IBAMA (G.C. dos Santos, pers. comm.)
1999	Annual	Paper	(CEPENE, 2000b)
2000	Annual	Electronic	IBAMA (S. Bezerra, pers. comm.)

After encoding the database (called CATCHDAT hereafter), the correspondence between the common names presented in the original source and the scientific name was established, using the decision diagram illustrated in Figure 3.1. The general database of common and scientific names (I in Fig. 3.1) was created only for this study and includes molluscs, crustaceans, fishes, turtles, and whales. The database of fish names (II in Fig. 3.1) includes 4,172 common names associated with 725 species of marine and estuarine species, and represents an extension of the database presented in Freire and Pauly (2003) and discussed in Chapter 2. After applying the process illustrated in Figure 3.1, seven species remained unknown: 'ubaroba' and 'miracú' (Rio de Janeiro State), 'papa fina' and 'papuda' (Bahia), 'sagra' (Paraná), and 'tapa pomba' (Santa Catarina).

The database compiled here was compared with the FAO database (www.fao.org; FISHSTAT) and with ICCAT databases TASK I, TASK II, and CATDIS (www.iccat.es), all of them available online. TASK I includes all catches of tunas, tuna-like fishes, and sharks, by gear, region, and flag (no effort data); TASK II presents catch (both number and weight) and effort data for the main species and includes spatial information (latitude and longitude); and CATDIS raises landings originating from TASK II to total landings and also includes spatial information (latitude and longitude; no effort).

The mean trophic level ($\overline{TL}$) of the catches was estimated based on the information on the diet of each species, as compiled in Chapter 4 and complemented with data from FishBase (www.fishbase.org) and Opitz (1996):

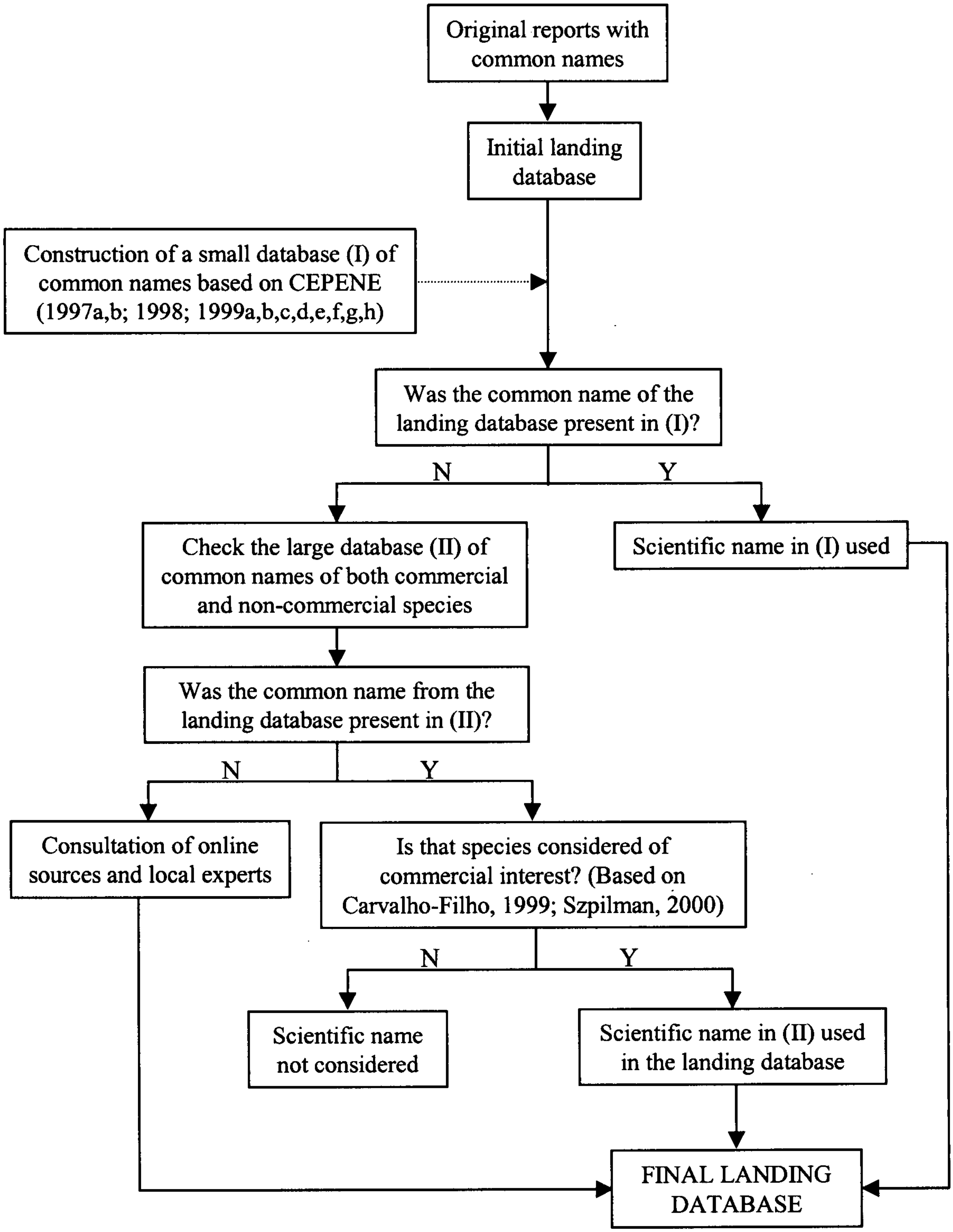

Figure 3.1: Decision diagram on the correspondence between common and scientific names for commercial species to obtain the final landing database. The database of common names (II) is available in FishBase (www.fishbase.org).

$$TL_i = 1 + \sum_{j=1}^{n} DC_{ij} \cdot TL_j$$

$$\overline{TL}_k = \sum_{i=1}^{m} Y_{ik} \cdot TL_i / \sum_{i=1}^{m} Y_{ik}$$

where DC_{ij} represents the diet composition of predator *i*, *j* is the prey, Y_{ik} are landings of species *i* in year *k*, and *m* is the number of species or group of species caught in year *k* (Pauly *et al.*, 2001). Note that categories such as 'outros peixes', 'caíco' and 'mistura', all representing unidentified fishes, were not included in this analysis due to the impossibility of assigning them a precise trophic level.

A Fishing-in-Balance (FiB) index (Pauly *et al.*, 2000) was calculated in order to assess if changes in the mean trophic level were compensated by changes in catches:

$$FIB_k = \log(Y_k \cdot (1/TE)^{TL_k}) - \log(Y_0 \cdot (1/TE)^{TL_0})$$

where *k* refers to year, *0* = baseline year (1978), Y = catch, TL = mean trophic level in the catch, and TE = transfer efficiency between trophic levels = 0.1 (based on Pauly and Christensen, 1995).

3.3. Results and discussion

a) Commercial fisheries

Comparing databases

Total landings obtained from the database compiled in this chapter represent the sum of data related to the seventeen States that record marine landings from artisanal and industrial fisheries in Brazil and were similar to data available from the FAO database for the period

1980-1988 (Fig. 3.2). The latter showed a peak of 756,000 tonnes landed in 1985 and a decline after that year, reaching a total of 567,687 tonnes in 2000. This pattern follows the declining trend of global catches discussed in Pauly *et al.* (2002). The database compiled in this chapter is also able to detect this declining trend, even though there was an increased discrepancy between the landings from these two sources after 1988. This discrepancy is partially associated with higher landings of large pelagics (tuna, swordfish, billfishes) recorded by FAO after revising catches for this group in collaboration with ICCAT; the national bulletins used in the compilation of the landings database compiled here contain underestimates of catches from longline fisheries. Most of the discrepancy is explained by catches of 'marine fishes nei' (nei = not elsewhere identified), as FAO has included, since 1995, 100,000 tonnes of estimated subsistence and recreational catches under this category (FAO, 2002a). However, neither the basis for such estimate nor the reasons for differences in previous years (1989-1994) are stated.

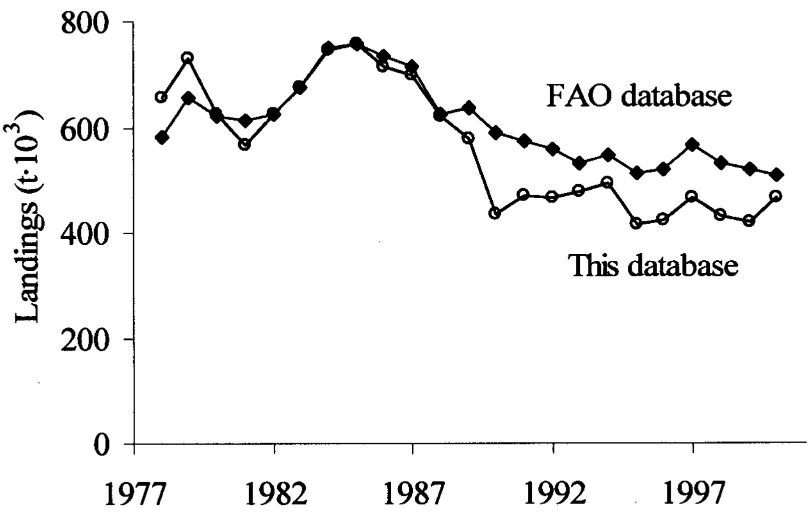

Figure 3.2: Landing data for Brazilian marine fisheries from this database and from FAO database - FISHSTAT (www.fao.org) for 1978-2000.

The database presented here has some advantages in relation to the FAO database: the breakdown per State, allowing for the allocation of landings to the three Brazilian large marine ecosystems (North, East, and South), the distinction between landings originating from industrial and artisanal fisheries, and more detailed information per species. Some problems were detected in the linkage between landings recorded in the FAO database and landings recorded using Portuguese common names in national bulletins compiled here. Landings for 1995 were analyzed in detail and indicate that most differences are related to the loss of detailed information, but in some cases, catches are attributed to the wrong species. Some of these differences are highlighted as follows:

- 'agulha' (halfbeak) landings were attributed only to ballyhoo halfbeak (*Hemiramphus brasiliensis*), when in fact more species are caught; 'agulha branca' landings were not included;
- Atlantic bonito landings are lower than those presented in national bulletins;
- 'Lagosta' (lobster) catches were attributed to Caribbean spiny lobster (*Panulirus argus*), when in fact only 80% is expected to be *P. argus* and 20% would be *P. laevicauda* (Smoothtail spiny lobster) (Dias Neto and Dornelles, 1996). More recently a third species has been caught around oceanic islands, *Panulirus echinatus*, but catch rates are very low (Lins-Oliveira and Vasconcelos, 2004).
- 'barbigão', 'chubinho', 'sarnambi', and 'vieira' were combined with 'outros moluscos' (other molluscs) in the category 'marine molluscs', thus eliminating information on actual species caught;

- landings for Patagonian grenadier (*Macruronus magellanicus*) were included, even though this species is not recorded for Brazil (www.fishbase.org);
- landings for Scyllaridae were not recorded;
- 'caçonete' and 'machote' landings were not included in shark landings;
- 'betara', 'batera', 'goete', 'Maria Luíza', 'tortinha' and 'pescadinha' were not included in croakers or drums (Sciaenidae), which implies accuracy loss; the same loss was observed for groupers, snappers, and clupeoids.

The comparison with ICCAT database is restricted to tuna and tuna-like fishes and requires an analysis of the three subsets made available through the ICCAT webpage (TASK I, TASK II, and CATDIS). Landings originating from all vessels that carry Brazilian flag (national and leased) and recorded in TASK I are the highest and close to those recorded in CATDIS (Fig. 3.3). However, TASK II only contains 22 to 69% of the landings recorded in TASK I and its use poses problems when catch and effort data are required in a spatial scale. ICCAT data provided in TASK I was chosen to be compared with FAO and my database due to the highest degree of coverage. With the exception of swordfish, the database compiled in this chapter presents the highest landing values for all large pelagics covered by ICCAT for most of the years (Fig. 3.4). FAO landing values were corrected based on ICCAT databases and thus are equivalent, except for 2000, when ICCAT landings are slightly higher, and for sharks, as ICCAT coverage is rather poor and landings from national sources were used instead by FAO. The pitfall of this approach is that landings originating from artisanal fisheries are not included in the FAO database, and leads to an underestimation of catches of tunas, bonitos, mackerels, and billfishes (Fig. 3.4). Considering that several of these stocks are either fully or over exploited, there is reason for concern if this is an approach used for many other countries.

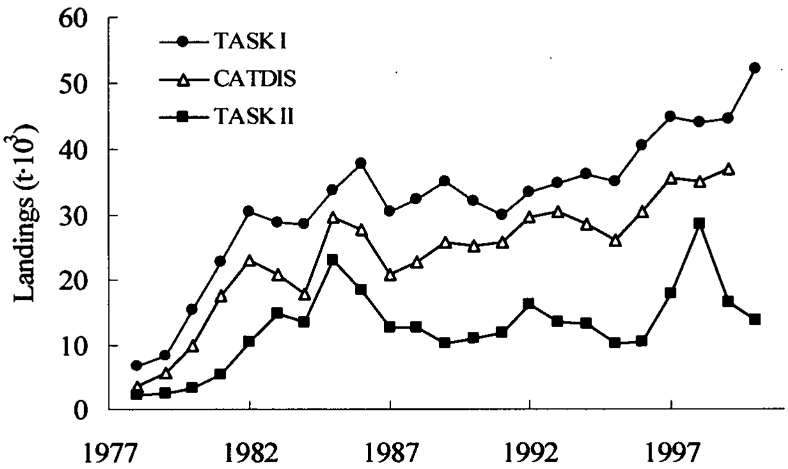

Figure 3.3: Comparison amongst landings recorded in three databases compiled by ICCAT for vessels using Brazilian flags (national and leased) for 1978-2000 (Source: www.iccat.es).

Landing trends

The decline in overall Brazilian landings is accounted for mainly by the massive decline in landings of sardine (*Sardinella brasiliensis*), from 300,000 in 1988 to less than 50,000 tonnes in 1990 (Figs. 3.5). Fishes represent the highest landings, followed by crustaceans, molluscs, and mammals (Fig. 3.6). Note that whaling was completely banned in 1985, although a ban on successive species had occurred since 1981. Minke whales, *Balaenoptera acutorostrata*, continued to be exploited until 1985 (Singarajah, 1997). Turtles were a minor component of the total landings: 60 tonnes in 1980 (not shown). A gradual process to ban turtle fisheries also occurred in Brazil from 1967 onwards, until the complete ban of 1986 (Marcovaldi and Marcovaldi, 1999). However, contrary to the whales, some turtles were still caught in 1987-88 and are recorded in this database (< 5 tonnes). After that year, there were no landing data for turtles, although they are still caught as by-catch in swordfish and other pelagic longline fisheries (Weidner and Arocha, 1999), in lobster gillnets (Sales and Lima, 2002), and for self consumption.

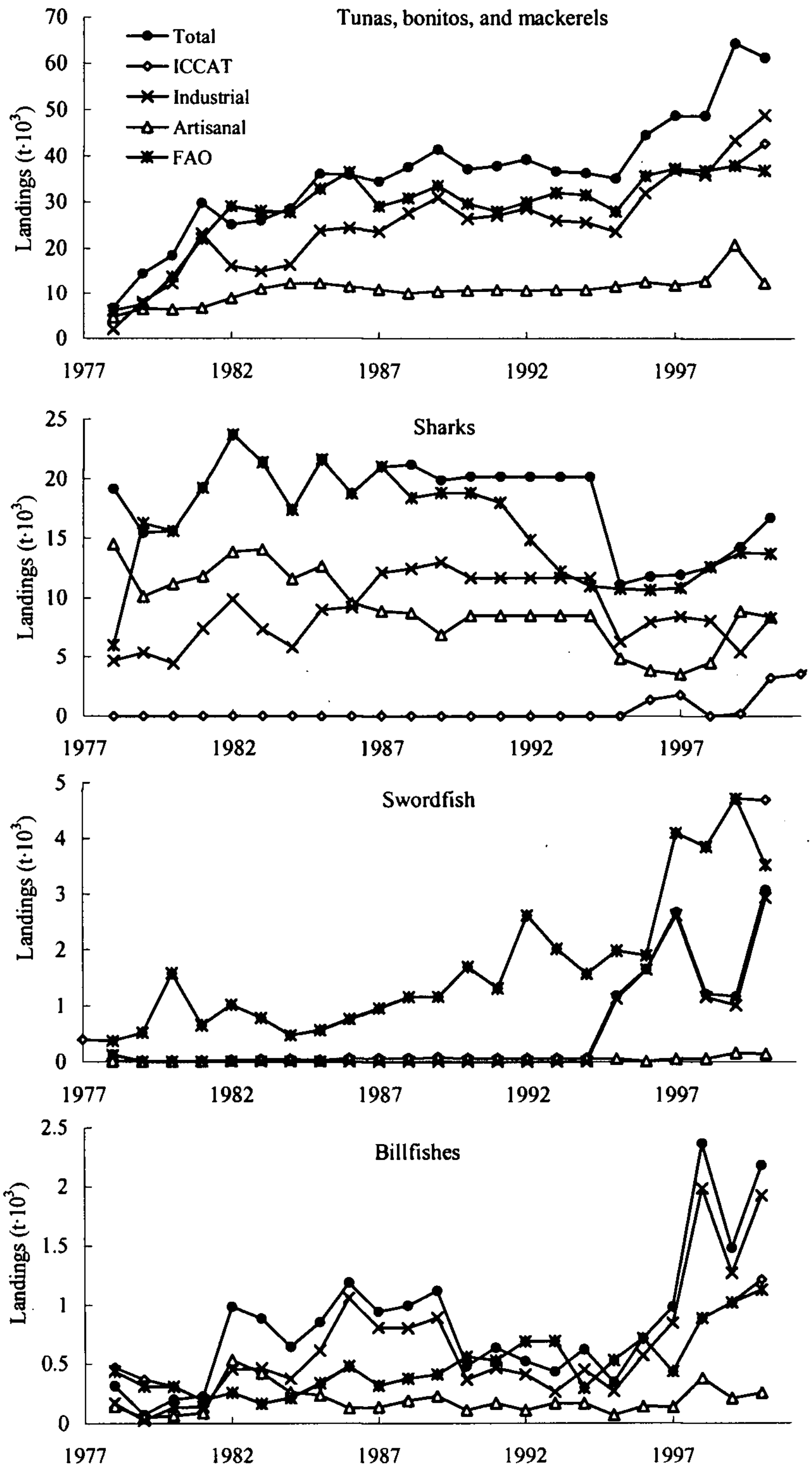

Figure 3.4: Landings of tunas, bonitos and mackerels, swordfish, billfishes, and sharks originating from all vessels carrying Brazilian flags for 1978-2000 recorded in TASK I database (www.iccat.es), my database (total, industrial, and artisanal), and in FISHSTAT (www.fao.org).

The majority of Brazilian marine landings come from Rio de Janeiro, Santa Catarina, and São Paulo, although landings from Pará have increased in 2000 (Fig. 3.7). The drastic decline in landings from Rio de Janeiro is mainly associated with the decline in sardine fisheries. The first three States are located in the southeastern and southeast regions, where most of the landings originate (Fig. 3.8). The decline in landings from the industrial sector is evident in both regions, although it is also noted in the artisanal sector. This reflects the typical development of the fishing sector, where the introduction of a new fishery (in this case, the industrial fishery) leads to an initial increase in landings and then to oscillations and collapse (Pauly, 1997).

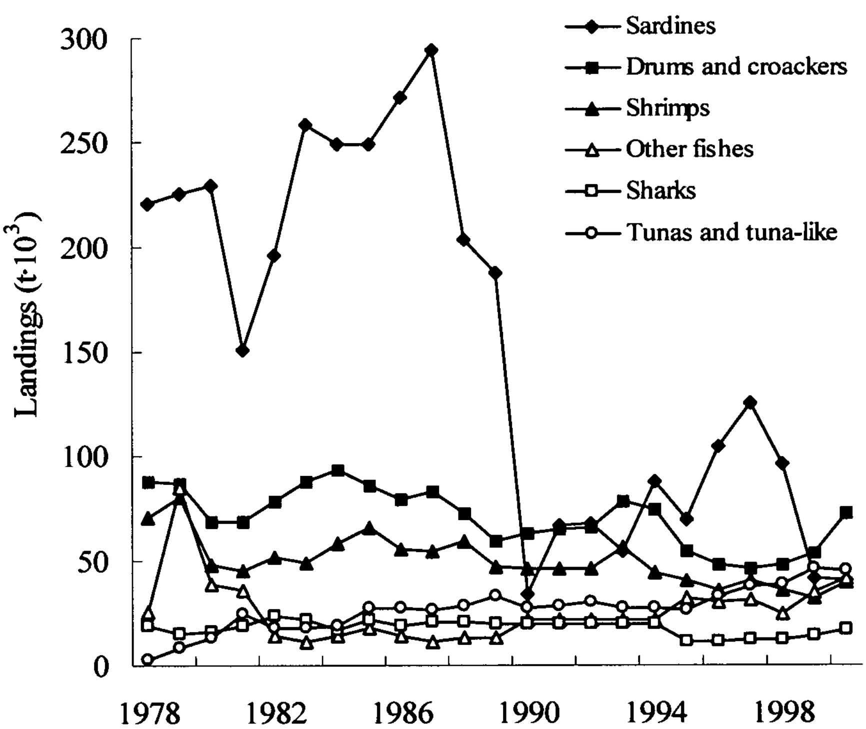

Figure 3.5: Main species caught by Brazilian marine commercial fisheries (1978-2000).

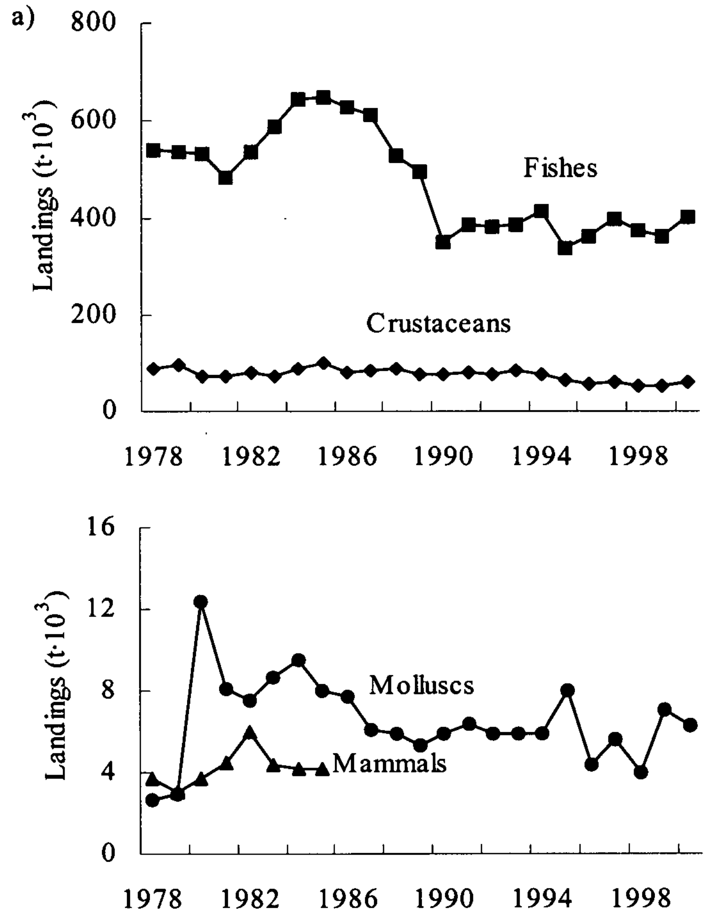

Figure 3.6: Groups represented in landings from Brazilian marine commercial fisheries (1978-2000): a) Fishes and crustaceans; b) Molluscs and mammals.

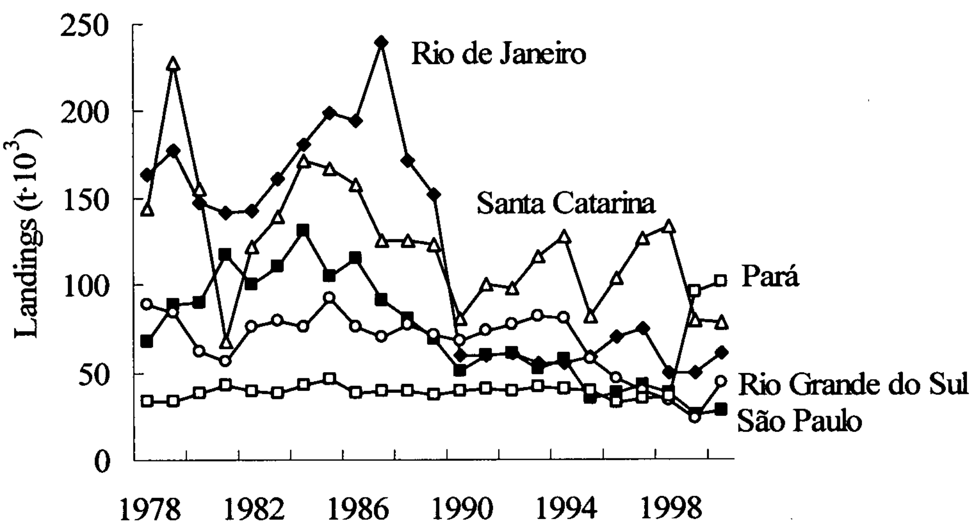

Figure 3.7: States with the highest landings in Brazil (industrial and artisanal fisheries combined).

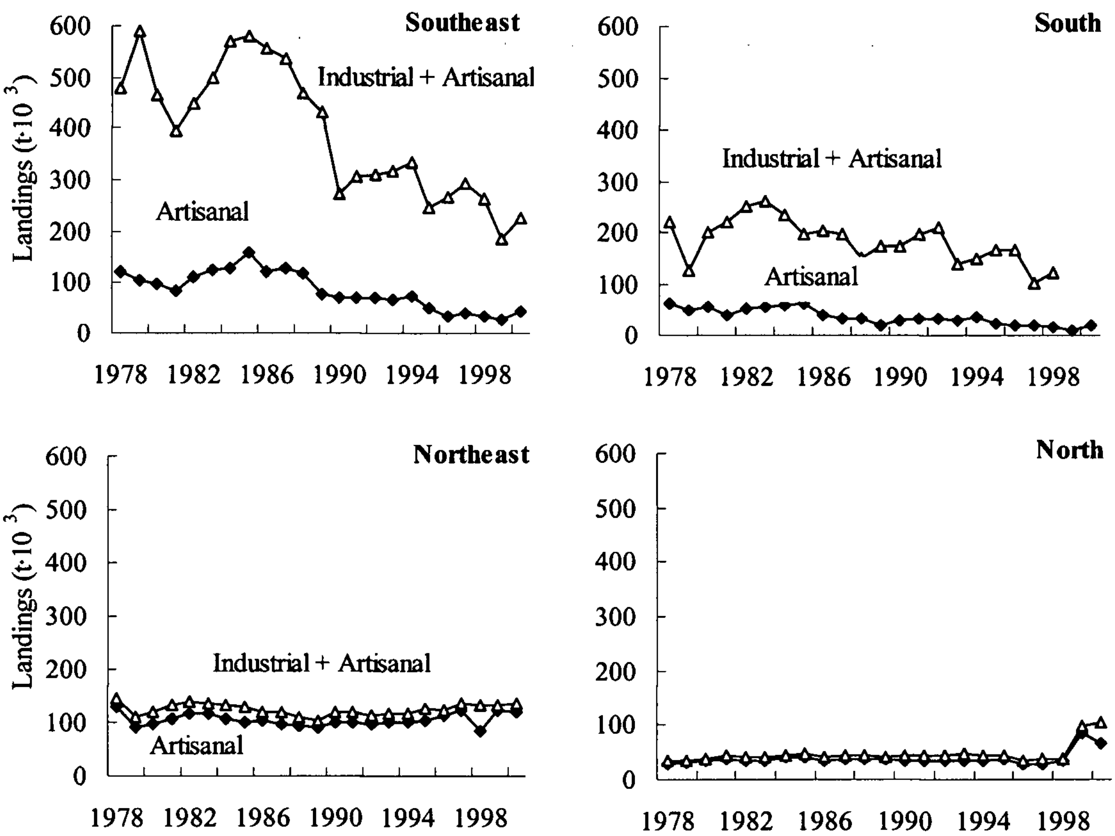

Figure 3.8: Landings of the industrial and artisanal marine fisheries off the southeastern, southern, northeastern, and northern regions of Brazil (1978-2000).

Landings from the northeastern and northern regions combined accounted for about 200,000 tonnes, with most landings originating with artisanal fisheries (Fig. 3.8). In this case, the introduction of a limited industrial fishery seems to have had little impact on the artisanal sector, as they both remained stable for the last 20 years. When this study is extended to include the period 1950-1979, a better analysis may be performed as most of the industrial fleet began to operate in the 1960s, although a new expansion occurred in the mid 1990s. Additionally, the analysis of individual fisheries would allow for a better understanding of the impact of industrial over artisanal fisheries.

The main group of species landed in northeastern Brazil were marine shrimps, other marine fishes, tunas, catfishes, drums and croakers, and lobsters (descending order of landings for 2000) (Fig. 3.9). Shrimps were responsible for the highest landings during the whole period, with the exception of the first year when drums and croakers dominated the catches. The proportion of other marine fishes increased in the last six years, reflecting a rather poor system of data collection or reporting. Although the database compiled here is not the best resource for analyzing tuna landings, it is able to indicate increasing landings for this group in the late 1990s. Lobster landings oscillated during the whole period with a decline of 42% in the last six years. Shrimps dominated the landings from artisanal fisheries and lobsters, southern red snapper, and shrimps dominated those from industrial fisheries, with a strong decline in landings of these three groups in the latter years.

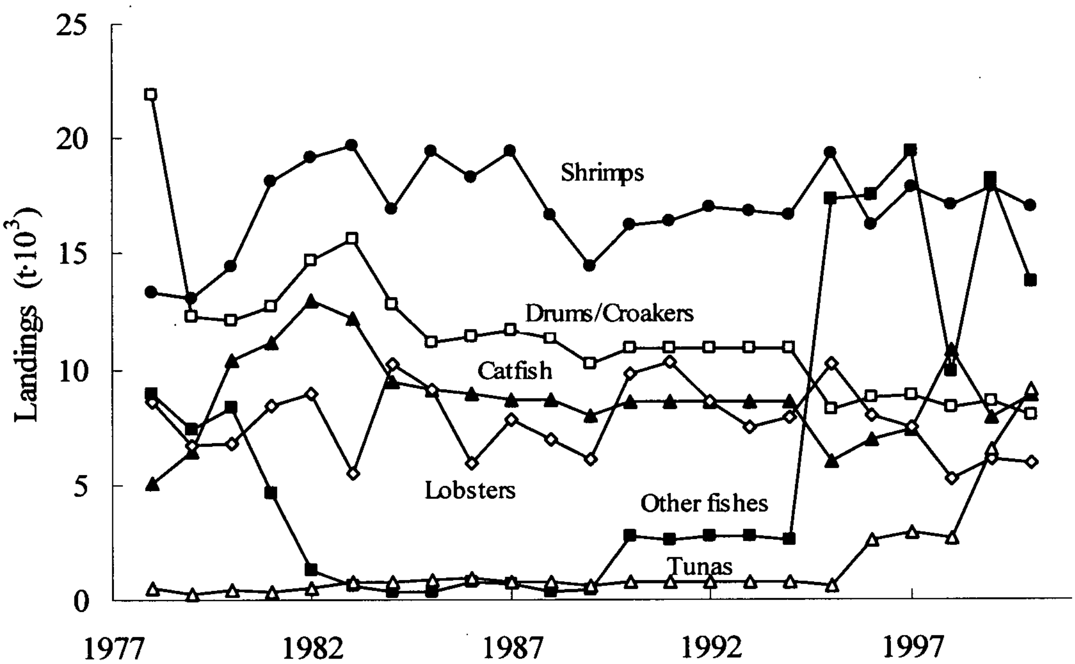

Figure 3.9: Landings of the main groups of species originating from marine commercial fisheries in northeastern Brazil (1978-2000; artisanal and industrial).

Fishing down the food web

The mean trophic level of all Brazilian landings originating from marine waters presents a trend upwards for the period 1978-2000 (Fig. 3.10a). A similar trend was observed by Vasconcellos and Gasalla (2001) when analyzing data from Brazilian fisheries provided by FAO. In order to assess the impact of fishing in local habitats, landings of large pelagic species were eliminated, as these species are largely migratory and affected by changes in other habitats, for example, the whole Atlantic for yellowfin and bigeye tunas. Landings from artisanal and neritic industrial fisheries were combined as they are targeting the same stocks (Fig. 3.11). A slight decreasing trend in the mean trophic level of these landings was observed after 1984 (Fig. 3.10a). However, this analysis combines landings from large marine ecosystems (LMEs) as diverse as North, East, and South Brazil.

Landings originating only from northeastern Brazil (East Brazil LME) showed a stable mean trophic level for the whole period. However, there was a downward trend when large pelagics were excluded (Fig. 3.10b). The downward trend in mean trophic level was even clearer when the analysis of landings was performed at a finer spatial scale. Fishing down the food web was detected in landings originating from five out of the seven States for which landing data was properly collected using the ESTATPESCA program (Fig. 3.12). About 0.16 trophic levels were lost every ten years in those States, with the exception of Paraíba State, which recorded a lower rate. The decreasing trend in mean trophic level was not compensated by increasing catches for most States (Fig. 13.3), which would have justified a deliberate choice of moving down the food web, towards the more productive, lower components of the trophic web. The FiB index in fact declined indicating that these ecosystems had already been impacted during

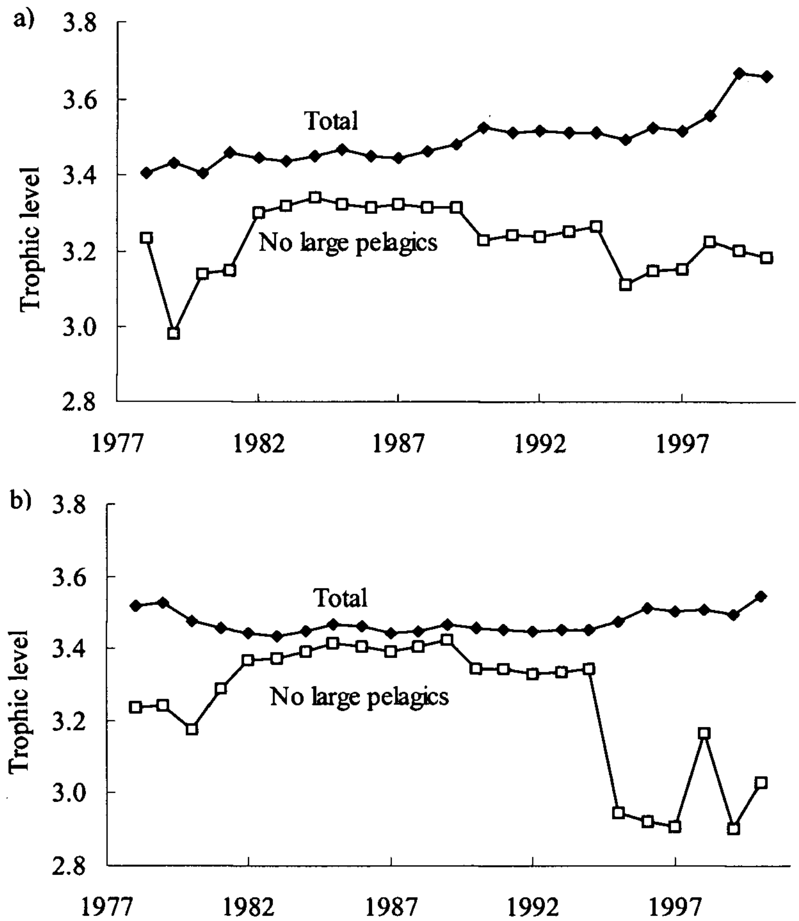

Figure 3.10: Mean trophic level of landings for Brazil (a) and northeastern Brazil (b) for the period 1978-2000. Both total landings and landings excluding large pelagic species are presented.

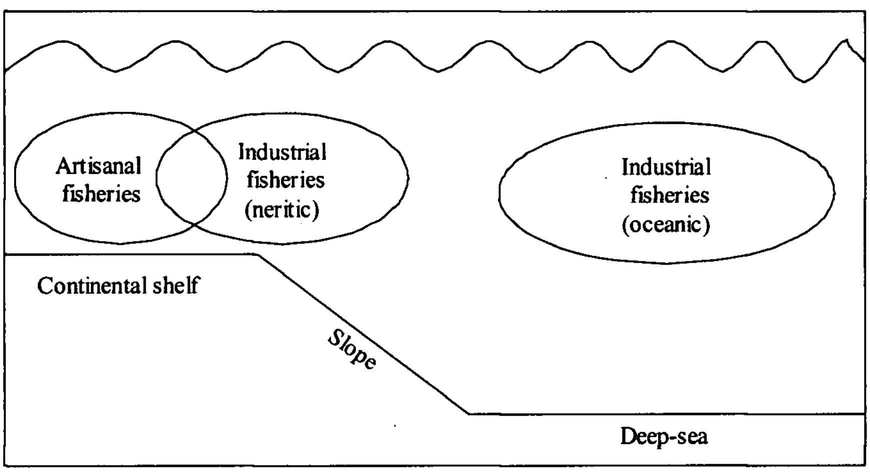

Figure 3.11: Schematic drawing indicating the overlapping of resources targeted by artisanal and industrial fisheries on shelves (neritic), and the oceanic fisheries further offshore.

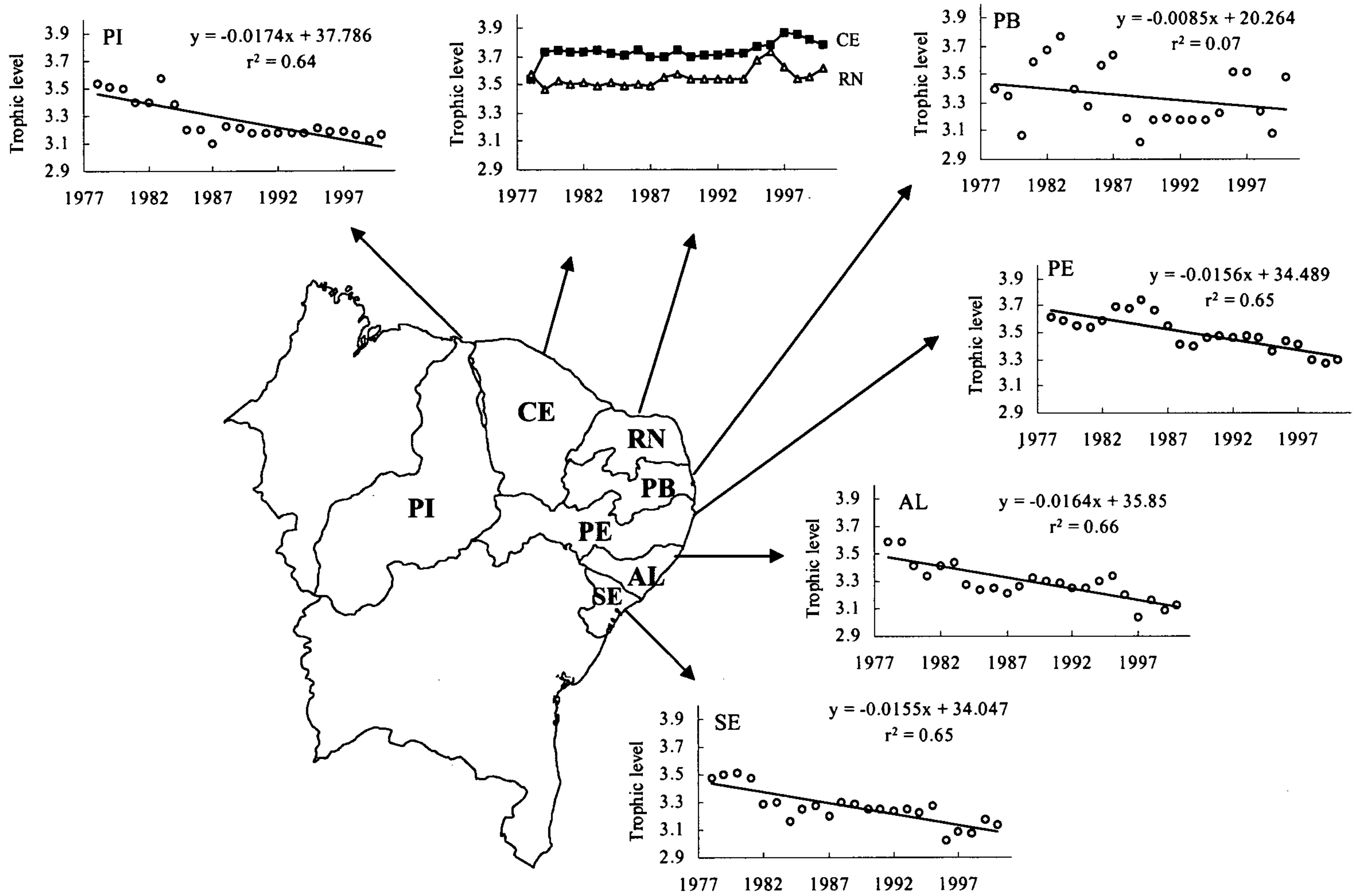

Figure 3.12: Changes in mean trophic level for landings from northeastern Brazil in 1978-2000. PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, and SE = Sergipe. Maranhão and Bahia States are not shown due to the lack of a proper system of data collection.

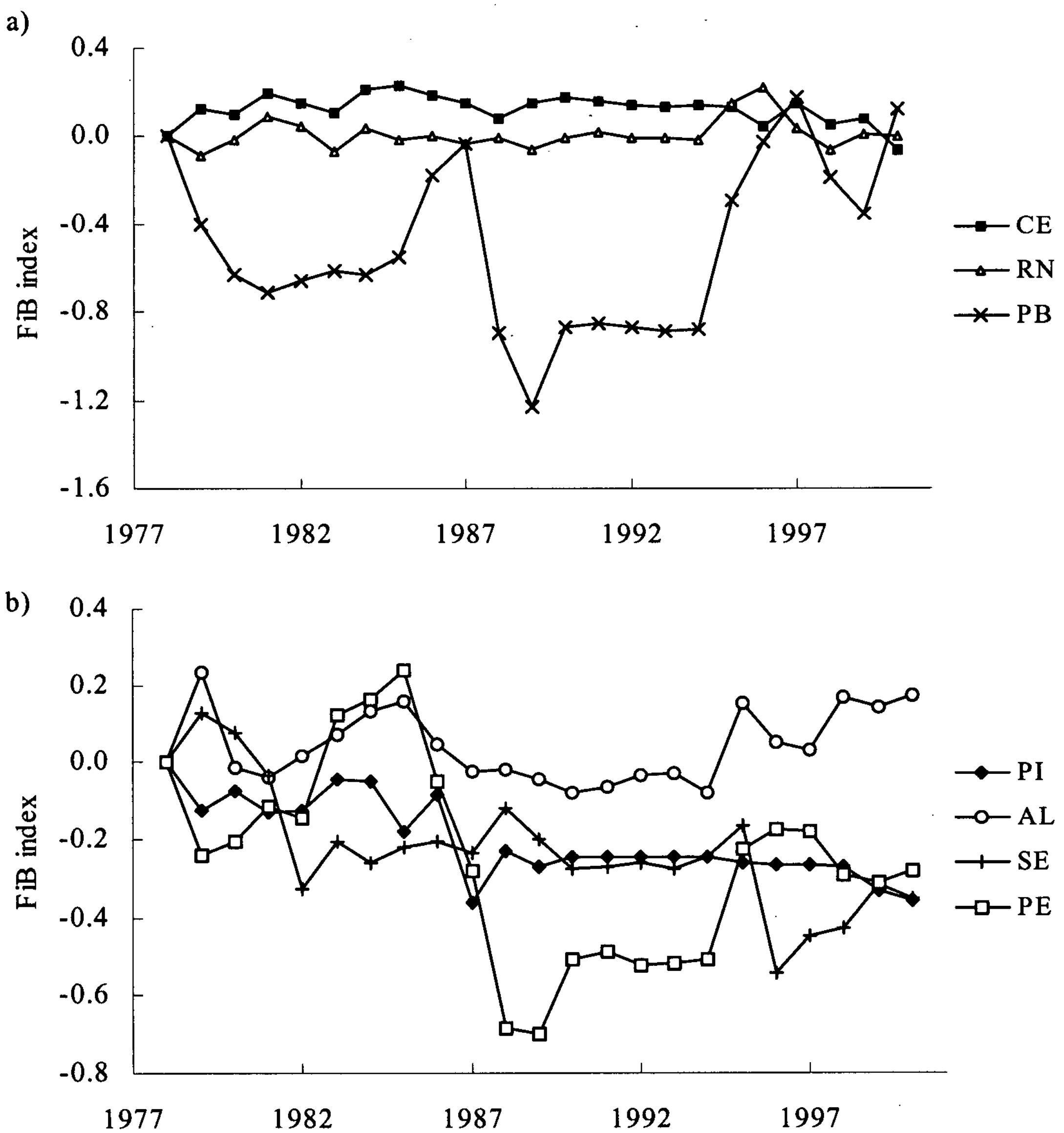

Figure 3.13: Fishing-in-balance (FiB) index for northeastern Brazil during 1978-2000. CE = Ceará, RN = Rio Grande do Norte, and PB = Paraíba; b) PI = Piauí, AL = Alagoas, SE = Sergipe, and PE = Pernambuco.

this period (1978-2000). The use of longer time series would clarify this hypothesis. Overall, decline rates of mean trophic level of landings in northeastern Brazil were greater than those observed in Gulf of Thailand, Canada, and India (Christensen, 1998; Pauly *et al.*, 2001; Bhathal, 2004).

Ceará and Rio Grande do Norte States present a stable mean trophic level throughout the period (Fig. 3.12). It seems that these areas have been affected by the high mobility of the industrial fleet from Ceará, which operates mainly in the coast of other states (CEPENE, 2000a). Thus, landings originating from other States would mask any trends in the local ecosystem. Moreover, it is worth pointing out that there is a high degree of correspondence between catches originating from both artisanal and industrial fisheries in Ceará and Rio Grande do Norte States (Fig. 3.14). This indicates that both fleets are fishing the same stocks or possibly there are flaws in the data collection system leading to the extrapolation of data from one state to the other.

There is also a possibility that overaggregation of categories such as 'outros peixes', 'caíco', and 'mistura', all representing other fishes, may be affecting this analysis, as they reach high proportions (0.3-15% of total catch), particularly in the beginning and in the end of the period studied (Fig. 3.15). The breakdown of these groups into species is required, based on data from neighbour States and from anterior/posterior years, to elucidate this issue. However, there is evidence that taxonomic detail only exacerbates the downward trend observed based on overaggregated landing data (Pauly and Palomares, 2001).

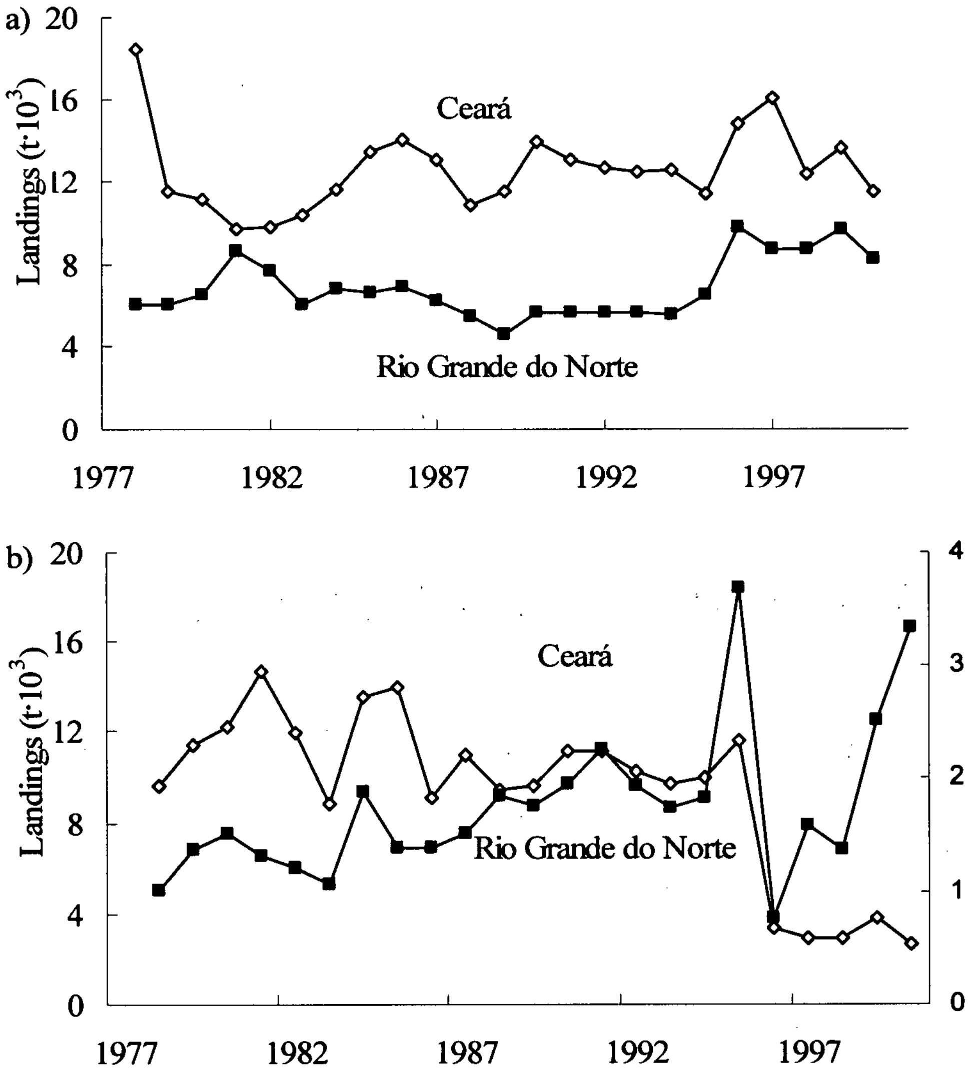

Figure 3.14: Landings originating with marine fisheries off Ceará and Rio Grande do Norte: a) artisanal and b) industrial (1978-2000).

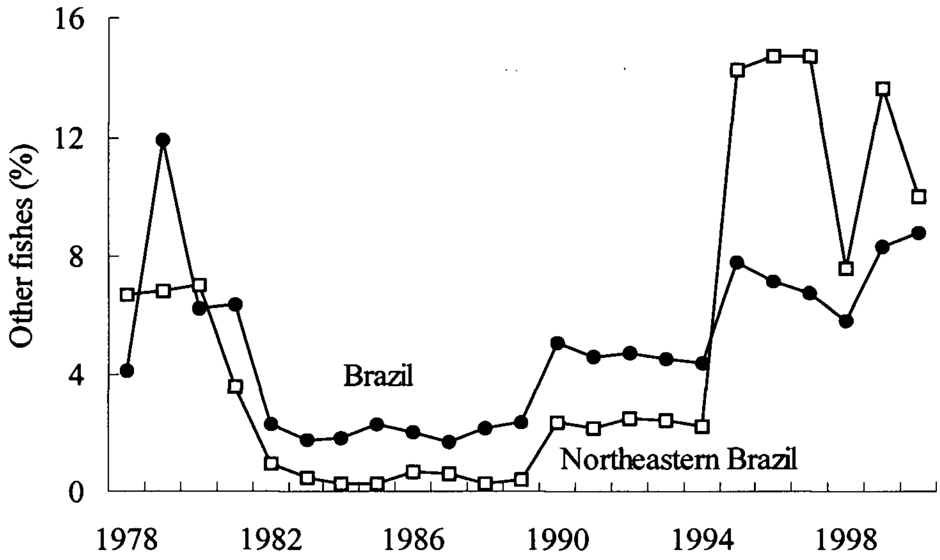

Figure 3.15: Proportion of other fishes in relation to total landings in Brazil and northeastern Brazil.

b) Recreational fisheries

Although FAO has added an estimate of 100,000 tonnes to Brazilian landing data provided by local agencies in order to account for catches originating from recreational and subsistence fisheries (FAO, 2002a), neither the basis for such estimate nor the proportion of each component was recorded. All catches were added as 'marine fishes nei' (not elsewhere identified) and as such were not incorporated in the database compiled here.

Freire (2005) indicates that preliminary estimates of catches from recreational fisheries off northeastern Brazil are very low (about 1,150 tonnes in 2001). Eighty-six species or group of species are caught by anglers and the main ones are: catfish (Ariidae), threadfins (*Polydactylus* spp.), rays (unidentified), jacks (*Caranx* spp.), pompanos (*Trachinotus* spp.), southern kingcroaker (*Menticirrhus americanus*), puffers (unidentified), snooks (*Centropomus* spp.), king mackerel (*Scomberomorus cavalla*), sharks (unidentified), weakfish (*Cynoscion* spp.), banded croacker (*Paralonchurus brasiliensis*), tarpon (*Megalops atlanticus*), jenny mojarra (*Eucinostomus gula*), dolphinfish (*Coryphaena hyppurus*), mutton snapper (*Lutjanus analis*), serra mackerel (*Scomberomorus serra*), groupers (*Epinephelus* spp.), yellowtail snapper (*Ocyurus chrysurus*), sailfish (*Istiophorus albicans*), tunas (*Thunnus atlanticus*, *T. obesus* and *T. alalunga*), and barracuda (*Sphyraena barracuda*). However, catches were not separated into species and would have to be included in the category 'marine fishes nei'. There is no estimate for other regions in Brazil, with the exception of an indication that about 33 tonnes·year^{-1} were caught in oceanic tournaments promoted by the Rio de Janeiro Yatch Club in 1969-1992 (Paiva and Pires-Júnior, 1983; Arfelli *et al.*, 1994) and an extra four tonnes caught off Espírito Santo State in 1990 (Arfelli *et al.*, 1994). Preliminary analysis of shore-based fishing tournaments off northeastern Brazil indicates that total catches amounted to an average of three tonnes·year^{-1} in 1995-1999 (Freire, in press).

None of the estimates presented above were added to the database compiled here as the series are either too short or do not contain enough detail in terms of species composition. This does not imply that this activity is not important at a national scale, but rather indicates that the available data up to now do not allow for the proper assessment of this activity.

c) Subsistence fisheries

As previously noted, FAO has added 100,000 tonnes to catches provided by Brazilian fisheries agencies to account for recreational and subsistence fisheries, but does not give any ratio between them. Some local sources indicate that 15-30% of the catches originating from artisanal fisheries off northeastern Brazil in the 1970s (Piauí, Ceará, and Rio Grande do Norte States) were probably not accounted for, but subsistence fisheries were not mentioned (SUDENE/UFRN, 1975; SUDEPE/PDP, 1978; 1979). Artisanal fisheries also include a subsistence component as some fishers keep some fish for consumption or for paying the transport of fishes from the boat to landing sites (pers. obs.), which are not accounted in local statistics. Diegues (1996) and Glaser (2003) indicate that mangroves areas are particularly exploited for subsistence purposes.

d) Research fisheries

Catches originating from research vessels are not usually included in national databases. Several large-scale research programs were performed along the Brazilian Exclusive Economic Zone (EEZ) to assess the potential of exploitation of some species and later on to assess the state of some exploited stocks. In southern Brazil, projects such as PDP, AREPE, and ECOPEL were developed in order to study the anchovy-centered pelagic ecosystem off southern Brazil in 1976-1977, 1980-1982, and 1987-1991 (Castello, no year). Fishing hauls were involved in all these projects, but total catch was not incorporated in the national database. ECOSAR was a similar large-scale project designed to study the sardine-based pelagic system off southeastern Brazil and the resulting catches were not incorporated either (Rossi-Wongtschowski *et al.*, 1996). In the same region, a project to analyze tuna fisheries using live-bait was developed in 1980-1991. This project alone produced a total catch of 495 tonnes, with *Katsuwonus pelamis* representing 94% of this total (Ávila da Silva and Vaz dos Santos, undated).

In northeastern Brazil, several projects were developed by SUDENE (Institute for the Development of Northeastern Brazil) and SUDEPE during the 1960s and 1980s, and ECOTUNA Project (Ecology of Tuna and Tuna-like fishes) was set up during the 1990s (Hazin *et al.*, 1999), followed by REVIZEE (Assessment of the Living Resources off the Brazilian Exclusive Economic Zone - EEZ), which in fact encompassed the whole Brazilian EEZ.

Although total catches resulting from research activities are low in relation to commercial catches, it would be interesting to quantify its magnitude in relation to unreported catches from other sectors such as recreational fisheries. Catch data may be recovered through an extensive literature review of reports produced by the projects listed here and by many others not listed.

e) Ornamental fisheries

Brazilian ornamental fisheries began on a commercial scale in Brazil by 1959 (Denis, 1985), but were mainly based on freshwater species with an average of about 10.6 million fishes exported annually in 1970-1976 (Welcomme *et al.*, 1979). Marine species have been targeted more recently. IBAMA is responsible for controlling ornamental fisheries, but the control is performed only through a system of forms for trade permits. However, monitoring of this activity is rather poor, with coverage restricted to only some coastal states (Monteiro-Neto *et al.*, 2003). Moreover, underreporting is a common practice aiming at lowering taxes and avoiding quotas. A total of 143 species and about 60-80 thousand individuals of marine ornamental fishes were traded by Ceará State alone in 2000 (Monteiro-Neto *et al.*, 2003). This is the only record of trade of marine ornamental species found for Brazil.

f) Discards

Global estimates of by-catch and discards were found to be very high, accounting for 27 million tonnes per year in 1980-1992 (Alverson *et al.*, 1994) and somewhat lower in 1992-2003 (7.3 million, according to Kelleher, 2004). There is no estimate of by-catch and discards at a national level in Brazil. Some discarding practices will be highlighted, but there is little attempt to quantify the effect of such practices, with the exception of localized estimates:

- Finning: common practice amongst leased longliners targeting tuna and tuna-like fishes off northeastern Brazil (Lessa *et al.*, 2004) – not quantified;
- Longline: Cramer (2003) indicates that in 2001 about 15.3, 2.0 and 0.1 tonnes of undersized swordfish, billfishes, and pelagic sharks, respectively, were discarded dead by US pelagic longliners targeting tuna and swordfish in ICCAT areas 93 and 96, which include Brazilian waters. No other document was found addressing discards other than finning practices in this region by national or leased vessels.
- Shrimp trawling: by-catch and discard rates vary amongst States due to differences in target species and location of fishing grounds in relation to the coast. In southern Brazil, 812 tonnes of juveniles of drums and croakers, flatfishes, and rays were discarded in 1992-1993 by beam trawlers, with an average of 0.3 kg of fish discarded per kilogram of shrimp landed (Haimovici and Mendonça, 1996). Shrimp trawlers in this region discard not only fishes, but also squids such as *Loligo sanpaulensis* (Perez and Pezzuto, 1998). In northeastern Brazil, discard rates of 2.5:1 kg of fishes and crabs were recorded for Piauí State. Moreover, large-scale trawlers targeting *Penaeus subtilis* in Bahia State discard *Xiphopenaeus kroyeri*, a shrimp species targeted by artisanal

fishers (CEPENE, 2000c). By-catch rates of 3.2:1 were observed in Paraíba State (Nunes and Rosa, 1998), although no indication about discard rates was given.

- Other bottom trawling: estimates of discards by fish trawlers are available mainly for southern Brazil, where these fisheries are very important. Haimovici and Habiaga (1982) found a discard proportion of 0.26 for pair-trawlers and pointed out that beside juveniles of the commercial species, other potential commercial species such as *Trichiurus lepturus* and *Prionotus punctatus* are discarded due to poor storage methods. A total of 5,641 tonnes of juveniles of drums and croakers, flatfishes, and rays were discarded in 1992-1993 by beam trawlers, with an average of 1.1 kg of fish discarded per kilogram of fish landed (Haimovici and Mendonça, 1996). More recently, Vasconcellos *et al.* (in press) estimated that 9,740 and 4,000 tonnes of croakers and drums were discarded in the late 1970s and 1990s, respectively. Overall, discards by trawlers can reach 17-25 thousand tonnes in this region (Haimovici, 1998).
- Lobsters: Ivo *et al.* (1996) indicate that 54 species of fishes and crustaceans are caught by trap and gillnet lobster fisheries in Ceará State, even though no discard rate was mentioned; FAO/WECAFC (2001) indicates that 10% of the lobster fleet continues fishing during the closed season in Ceará State. Lobster diving (with compressor - hookah) and gillnets are illegal (IBAMA, 1994) and their catches are likely to be underestimated in national databases.
- Turtles: caught as by-catch in swordfish and other pelagic longline fisheries (Weidner and Arocha, 1999; Pinedo and Polacheck, 2004). There is also some indication that 60 turtles were caught per month by shrimp trawlers in Alagoas State and 100-130 per year in Sergipe State (both in northeastern Brazil) (IBAMA, 1994). There is also

evidence of increasing number of turtles entangled in gillnets targeting lobsters in Ceará and Bahia States (Sales and Lima, 2002).

- Mammals: even though there was a ban of whaling activities in Brazil and no marine mammal is currently allowed to be killed in Brazilian waters, incidental catch has been a serious problem. Monteiro-Neto *et al.* (2000) indicate that in Ceará State alone an average of 7-13 *Sotalia fluviatilis* and *Steno bredanensis* were caught annually in 1992-1998 (with a maximum of 31 in 1996). *Sotalia fluviatilis* (tucuxi) was also caught by gillnets in Alagoas State. In Rio Grande do Sul State (southern Brazil), the franciscana *Pontoporia blainvillei* is caught by bottom gillnets targeting sciaenids, which killed 919 fransciscanas in 1976-1987 (Pinedo, 1994). However, the list of marine mammals incidently caught in fisheries activities is much longer and includes bottlenose, Atlantic spotted, striped, spinner and common dolphins, and the long-finned pilot, false killer, killer, and minke whales (Siciliano, 1994).

g) Distant water fleets

US and other distant water fleets fished illegally for shrimp in Brazilian waters during the 1980s (Weidner and Hall, 1993), almost leading to the collapse of shrimp stocks off Amapá State (Chimanovitch, 2001). In the 1990s, vessels from Japan, Korea, Spain, and Taiwan frequently called Brazilian ports in the northeastern region for services and it is suspected that such vessels were targeting tuna in Brazilian waters (Weidner and Hall, 1993). Saint Peter and Saint Paul Archipelago is particularly vulnerable due to its distance from mainland (Chimanovitch, 2001). Currently, there is no estimate of catches by distant water fleets, but they probably represent an annual loss of US$ 500 million for Brazil (Chimanovitch, 2001).

The database compiled here presents trends for landing data from marine commercial fisheries off Brazil as recorded in national reports, but it has several flaws inherited from the original sources. For the period between 1990 and 1994, for example, the entries were calculated based on the mean of landings for the period 1986-1989 and corrected only for those species that were dealt with in the context of study groups (CEPENE, 1997a). Catch data for shrimps and sardines from São Paulo are probably underestimates (Gasalla and Tomás, 1997). And finally, catches from other fishing activities, i.e, the abovementioned (a-f), are not incorporated in the national database.

This study will be extended to include, in a first phase, data from the period 1970-1977. For those cases where landing data are available from sources other than the national sources, they will be incorporated in the present database, together with the original information. Furthermore, this database will be gradually corrected for discards and other unreported catches, including those from recreational and ornamental fisheries, two sectors that have been growing in the last few years. In addition, the breakdown of the categories 'outros peixes', 'caíco', and 'mistura', all of which representing unidentified fishes, will be performed based on the catch composition of different years and on that from neighbouring States. In a second phase, the database will be expanded to include the period 1950-1969. This phase will be more problematic as some sources available present landing data combined in broad categories such as 'fish', 'crustaceans', 'mammals', and do not distinguish between catch from marine and freshwaters.

The objective here was to assemble basic data needed for assessments, which are scattered in documents that are usually not readily available. Several researchers have likely already undergone the process of data collection and encoding, and others would have to repeat this process, if data are not made easily available in an electronic version. This is also an opportunity to collaborate to create a more complete national database as soon as more accurate data from specific study groups are incorporated.

All potential users should be aware that the State associated with a given landing record does not imply that this landing came from waters along the coast of that State due to the high mobility of some large motorized boats. Additionally, the correspondence between common and scientific names remains incomplete. Landing data compiled in this chapter was used in the simulations run in chapters 4 and 5 for northeastern Brazil, in conjunction with ICCAT data for tuna and billfishes. This was possible only owing to the breakdown of catches by State and posterior grouping for the nine States included in this region.

3.4. Conclusions

Brazilian landings data compiled in this chapter indicate a decreasing trend in landings after the mid 80s, mainly associated with the collapse of sardine fisheries off southeastern Brazil. This database fails in recording tuna and tuna-like fish catches (with the exception of sharks) originating from industrial fisheries and have to be corrected using ICCAT database. However, ICCAT data cannot completely substitute landings from this database, as Brazil has not been reporting catches from artisanal fisheries to this commission. Moreover, several other sources of catches such as recreational, subsistence, research, ornamental, and distant-water fleet fisheries, and discards are not accounted for, resulting in underestimated catches. The use of Brazilian landings available from FAO implies a loss in taxonomic detail as many species are grouped in taxonomic levels higher than recorded in national bulletins and, in some cases, landings are attributed to the erroneous species.

Even though catches are underestimated, fishing down the food web is observed in Brazilian ecosystems, particularly when a finer spatial scale is used. East Brazil Large Marine Ecosystem has seen an average loss of 0.016 trophic levels per year since 1978, based on information from landings. However, problems with the underestimation of catches, correspondence between common and scientific names, and overaggregation of categories such as 'other fishes' remain to be resolved.

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CHAPTER 4. Description of the marine ecosystem off northeastern Brazil using a trophic model

4.1. Introduction

Models are representations of complex systems that attempt to depict their main components and the interrelations amongst these components. These representations, which can be physical, verbal, graphical or mathematical, reflect the interest of the modeller, if only because of their partial character (Haddon, 2001). In this study, the interest is the effect of fisheries on the marine ecosystem off northeastern Brazil, i.e., on its major functional groups, here defined as groups of species that share similar population parameters, diet composition, distribution area, and behaviour.

Modelling requires that the ecosystem to be studied is properly defined. This is a difficult task, particularly in the marine realm, due to the absence of fixed boundaries. Longhurst (1998) proposed a hierarchical classification for the oceans, where the most general levels are the biomes (coastal, westerly winds, trade wind, and polar), subdivided in fifty-seven provinces based on physical forcing and the response of phytoplankton to this forcing. One of these provinces is the Guianas Coastal Province (a part of the Atlantic Coastal Biome), which extends from Trinidad to Cape de São Roque (Rio Grande do Norte State). However, this province encompasses two sub-regions that are influenced by the Amazon River in a completely different fashion, and hence the division provided by Matsuura (1995) and presented in Chapter 1 is more realistic.

Matsuura (1995) proposed the division of the Brazilian coast into five sub-regions (north, northeast, east, southeast, and south) based on bathymetry, oceanographic structure, fauna, flora, and major fisheries. The north sub-region is characterized by high primary production due to the discharge of the Amazon River, and has a sandy or muddy bottom and a rich benthic community. Bottom trawling is the most important fishery. In contrast, the northeast sub-region, the object of this study, is characterized by rocky substrates and low primary production due to the influence of the warm North Brazil and Brazil currents. This sub-region corresponds to the East Brazil Large Marine Ecosystem (Sherman *et al.*, 2002) and it is distinguished from other large marine ecosystems (LMEs) by criteria such as bathymetry, hydrography, and productivity. LMEs have been proposed as a conceptual framework for ocean management and their use should facilitate the comparison of the results obtained here with the ones obtained in multi-country projects to recover marine biomass that have been developing worldwide (Sherman and Duda, 2001).

Many models have been built to describe marine ecosystems around the world (see e.g. contributions in Christensen and Pauly, 1993). In Brazil, Vasconcellos (2000) and Vasconcellos and Gasalla (2001) modelled the Brazilian southeast and south sub-regions, which are characterized by wide continental shelf and sandy or muddy bottoms that allowed for the development of an important bottom trawl fishery for drums and croakers. In the pelagic realm, sardines are dominant in the southeast (and they used to support the major Brazilian fishery), while anchovies are very abundant in the south, although not yet exploited (Castello and Castello, 2003). Gasalla and Rossi-Wongtschowski (2004) developed a model for southeastern Brazil where the effects of changes in fishing patterns were assessed. Two other areas in Brazil were also modelled in terms of trophic interactions: one to the north of the area modelled in this thesis (Wolff *et al.*, 2000) and one to the south (Telles, 1998). The present study will allow for the comparison between the East Brazil Large Marine Ecosystem and the other previously modelled regions.

The objective of this chapter is to describe the East Brazil Large Marine Ecosystem (off northeastern Brazil) and the main trophic interactions between the functional groups occurring in this ecosystem. This model will be the basis for the exploration of fishing policies for the main resources exploited that will be presented in Chapter 5.

4.2. Methods

4.2.1. ECOPATH model

A model was constructed for the East Brazil Large Marine Ecosystem for the 1970s using Ecopath with Ecosim (EwE version 5.1; www.ecopath.org), a computer package based on an early version of Ecopath (Polovina, 1984). The Ecopath module represents a mass-balance model based on two master equations (Christensen *et al.*, 2004; Christensen and Walters, 2004):

(1) $$P_i = Y_i + E_i + BA_i + M0_i \cdot B_i + M2_i \cdot B_i$$

where: P_i = total production rate for each functional group *i*; $P_i = B_i \cdot (P_i/B_i)$; Y_i = catch rate of *i*; E_i = net migration rate for group *i* (emigration minus immigration); BA = bioaccumulation rate of *i*; $M0_i$ = non-predation mortality rate for *i* = $P_i \cdot (1-EE_i)/B_i$; B_i = biomass of group *i*; EE_i = ecotrophic efficiency (proportion of the production used in the system); $M2_i$ = total predation rate for $i = \sum_{j=1}^{n} Q_j \cdot DC_{ji}$; Q_j = consumption by predator j = $B_j \cdot (Q_j/B_j)$; and DC_{ji} = diet composition = fraction of the diet of predator j that is made up of prey i, and

$$Q_i = P_i + R_i + UF_i \quad (2)$$

where: Q_i = consumption by functional group i; R_i = respiration by i; and UF_i = food of i that remains unassimilated.

Values of B_i, P_i/B_i, Q_i/B_i, EE_i, and DC_{ji} for each functional group were provided to the model, allowing equations (1) and (2) to be solved (Christensen *et al.*, 2004). These data were gathered from scientific papers, reports, theses, and unpublished sources related to this ecosystem and similar ecosystems, as well as from FishBase, a global database on fishes (Froese and Pauly, 2002, see also www.fishbase.org). Catch data were obtained from Chapter 3. Details about the source of each data type are provided below.

4.2.2. Habitat area

The total area modelled here (Large Marine Ecosystem 16 – East Brazil) encompasses 1,074,984 km^2 and corresponds to the Exclusive Economic Zone (EEZ) off northeastern Brazil. The shelf is usually narrow, reaching down to 20 km, but can reach up to 220 km at the Abrolhos Bank, the southernmost region included in the study area (Ekau and Knoppers, 1999). A total of 1,200 km^2 of coral reefs are found in the region (Spalding *et al.*, 2001). Creed (2003) estimates that Brazil has a seagrass coverage of 200 km^2, 70-80% of which located in northeastern Brazil (Joel Creed, pers. comm.; Laboratory of Benthic Marine Ecology, Rio de Janeiro, Brazil). The habitat area (fraction) for each group was estimated based on information available in the literature. For those groups for which no information was available, a 'guesstimate' was calculated based on the extension of the habitat (e.g., coral, mangrove, seagrass) they are associated with.

4.2.3. Functional groups

Forty-one functional groups were used to describe the marine ecosystem off northeastern Brazil, including marine mammals, fishes, crustaceans, molluscs, other invertebrates, zoo- and phytoplankton, benthic producers, and detritus (Table 4.1). Details of the species included in each group are presented in Appendix 2. More groups could have been used, but this would have led to data requirements that would be hard to meet due to unavailability of data.

The functional groups were chosen based on the distribution area of each species, their maximum body size, trophic level, and consumption rates, in combination with information provided from previous models built for similar habitats. This division was intended to encompass all exploited groups in such a way that allowed for the analysis of the effect of fisheries on the biomass of the stocks. Groups were kept generic to include all catches that are recorded by common name and incorporate various species. Finally, one group (dolphinfish) was split into stanzas (juveniles and adults) in order to properly represent the complex trophic ontogeny of this group (Christensen *et al.*, 2004).

4.2.4. Basic input

The basic input data were: Biomass (B), Production/Biomass (P/B), Consumption/Biomass (Q/B), and/or Ecotrophic Efficiency (EE). The values used for each species to calculate an average for each functional group in the 1970s model are presented in Appendix 3. All biomass values were expressed in wet weight density (tonnes·km^{-2}), using habitat area as reference, and all rates were put on an annual basis. For each functional group, only one of those parameters could be missing and was estimated by the model. Usually, the model estimates ecotrophic efficiency, as it cannot be empirically calculated. However, as biomass estimates were not readily available for several groups, they were estimated by the model, after ecotrophic efficiency values obtained from similar ecosystems were used as input. Details of calculations of basic input for each group are presented below:

Biomass (B)

Estimates of biomass for northeastern Brazil are absent in most cases and thus they were mostly estimated by the model or obtained from models of similar regions. The biomass of manatees was estimated based on a total population of 400 individuals (Medeiros *et al.*, 2000) and an individual mean weight of 400 kg (Edwards, 2000). In the absence of other information and considering that these species have been protected since 1967, the estimate of total population for 1978 was considered the same as estimated by Medeiros *et al.* (2000), even though other factors beside hunting may have affected the population such as accidental catch, and agricultural and industrial pollution (Borobia and Lodi, 1992).

For baleen whales and toothed cetaceans, estimates of biomass for the East Brazil LME were obtained from updated estimates by Kristin Kaschner (pers. comm., Fisheries Centre, UBC, Vancouver, Canada), based on Kaschner *et al.* (2001). These estimates are based on a model predicting global distributions of marine mammals and as such are likely to be only gross estimates of local abundance. Moreover, these estimates represent annual means while seasonal abundance may vary as observed for humpback whales (Kinas and Bethlem, 1998; Zerbini *et al.*, 2004), the only species for which abundance has been estimated in local studies.

Total biomass for tunas and tuna-like fishes were obtained from ICCAT assessments for each specific stock. As recommended by ICCAT, the hypothesis of one single stock was considered for yellowfin and bigeye tunas and two stocks for albacore (northern and southern). Biomass estimates were divided by the total distribution area of the species following the latitude limits defined in Collette and Nauen (1983): between 40°N and 35°S for yellowfin tuna, 40°N-40°S for bigeye tuna, and 5°N-45°S for albacore. For the first two tuna species, total biomass was available in ICCAT documents. For albacore, total biomass was calculated using a conversion factor (CF_1) based on an estimate of spawning biomass (ICCAT, 2004b), considering an age-at-maturity of 5 years and 8 years of longevity:

(3) $$CF_1 = (\sum_{a=j}^{k} S_a \cdot W_a / \sum_{a=1}^{k} S_a \cdot W_a)$$

(4) $$TB = SSB / CF_1$$

where: S = survival, a = age, j = age-at-maturity, k = longevity, TB = total biomass, and SSB = spawning biomass. For all three tuna species, biomass per area were estimated to the East Brazil LME using mean catches for the period between 1995 and 2000 as a correction factor (CF_2):

(5) $$CF_2 = (\text{Catch}_{LME} \cdot \text{Area}_{TOTAL}) / (\text{Catch}_{TOTAL} \cdot \text{Area}_{LME})$$

Mean catches for 1995-2000 were used in the correction factor instead of catches for 1978 as tuna fisheries developed in Brazil in the last few years and thus, earlier catches would not be considered an adequate index of local abundance (Walters, 2003). CPUE-based indexes were not used, as the coverage of the TASK II-ICCAT database containing effort data for East Brazil was rather limited, as discussed in the previous chapter.

The resulting biomass of this group in the East Brasil LME (B_{LME}) was calculated as follows:

(6) $$B_{LME} = TB \cdot CF_2$$

The same procedure described above was applied to the southern stock of swordfish, which is distributed between 15°N and 45°S. The total biomass was estimated based on the spawning biomass (ICCAT, 2004b), considering an age-at-maturity and maximum age of 5 and 15 years, respectively. For other large pelagics, biomass was estimated using the same procedure, considering one single Atlantic stock of white and blue marlins. Two stocks of sailfish are recognized by ICCAT, but the absence of biomass for the western stock precluded the consideration of such division. The resulting biomass for other large pelagics is likely to be underestimated, as biomass data for other pelagic species such as *Acanthocybium solandri* and *Scomberomorus* spp. are not available.

For spotted goatfish, the value of biomass available in Opitz (1996) seems to be overestimated when compared to Southern red snapper, a species that has been sustaining an intense industrial fishery off northeastern Brazil since the 1960s. Thus, a biomass of 1/10 the original value was used. For squids, an arbitrary ratio of 1/100 of the average value of the biomass estimated by Vasconcellos (2002) for the Southern Atlantic in the 1950s and 1990s was used. The rationale behind this ratio is that local squid annual catches are very low ($\leq$ 1 tonne) when compared with, e.g., southern/southeastern Brazil (about 1,200 tonnes; based on the database compiled in Chapter 3) and with the entire southern Atlantic Ocean (85,000 tonnes in 1978; www.fao.org). Lower catches were used as an indicator of low local biomass due to the lack of local information of biomass.

The biomass of detritus was calculated by the equation:

(6) $$\log_{10}D = -2.41 + 0.054 \log_{10}PP + 0.863 \log_{10}E$$

where: D = detritus standing stock ($gC{\cdot}m^{-2}$), PP = primary production ($gC{\cdot}m^{-2}{\cdot}year^{-1}$), and E = euphotic depth (m) (Pauly *et al.*, 1993). Primary production was obtained by multiplying B by P/B from the basic input in Ecopath and dividing by a factor of 16.7 in order to convert carbon weight to wet weight (Opitz, 1996).

The biomass values for all other functional groups are as in the original sources cited in Appendix 3. For groups with no estimate of biomass available, an estimate of ecotrophic efficiency for similar groups from similar areas was used, and biomass was estimated by EwE using the mass balance constrained by equations (1) and (2) mentioned above.

Production/Biomass (P/B)

The values and references used to calculate P/B for each group are presented in Appendix 3. For exploited fish groups, the instantaneous rate of total mortality (Z) was used as an estimate of P/B (Allen, 1971), where Z is the sum of natural (M) and fishing (F) mortality rates. Groups such as tunas and other large pelagics, for which biomass estimates where available for each species, had a Z value estimated using biomass as a weighting factor. As much as possible, estimates were obtained from local studies. Some estimates were calculated using length-frequency distributions from the REVIZEE Program-Score NE (Assessment of the Living Resources of the Brazilian Economic Exclusive Zone – Northeastern Score), converted to age-frequency using growth parameters obtained from local studies or from FishBase (www.fishbase.org).

For most of the species there was no historical trend of total mortality rates. In these cases, when only more recent estimates were available (as for example in Lessa *et al.*, 2004), the trend available for similar species was used to estimate mortality rates in 1978. Thus, for reef fishes, the trend available for the southern red snapper was used, while for dolphinfish, trends from other large pelagics were used. For shrimps, the trend for *Farfantepenaeus subtilis* (Ehrhardt *et al.*, 1999) was assumed for the group as a whole. For the remaining species, estimates were used as presented in the original source.

Consumption/Biomass (Q/B)

Studies related to annual consumption of food by the groups included in the model built here are lacking in northeastern Brazil. The exceptions are those presented in Wiedemeyer (1997), whose study is restricted to estuarine areas. For almost all groups, Q/B was obtained from similar models for same or similar species, including the models constructed for northern and southeastern Brazil, or from FishBase. Most of these estimates are based on an equation that predicts consumption in relation to mortality, growth parameters, temperature, and caudal morphometrics (Palomares and Pauly, 1998). P/Q values resulting from this estimates are expected to be between 0.1 and 0.3, a limit considered physiologically realistic for most groups (Christensen *et al.*, 2004). Q/B was changed when necessary in order to produce P/Q values within this range.

4.2.5. Diet composition

The diet matrix for each functional group was obtained as the percentage of each group in terms of total wet weight (or volume) in the diet of the predator, based on the sources presented in Appendix 4. However, some sources presented only frequency of occurrence or numerical importance of various food items and these data required translation into an appropriate format, based on information available for other areas and some indication of the individual prey weights. In the absence of any other information besides frequency of occurrence, all items were assumed to contribute equally to the diet of the predator.

The mixed trophic impact – MTI (*sensu* Leontief, 1951) was estimated using diet information. MTI allows for the assessment of the impact of changes of biomass of each group on other groups included in the model (Christensen *et al.*, 2004). The resulting impacts are relative and may be compared amongst groups.

4.2.6. Landing data

Landing data used in the model were mostly obtained from the data compiled in Chapter 3 – CATCHDAT for 1978 (see sources therein), with the exception of landings of tuna and tuna-like fishes (*Thunnus alalunga, Thunnus albacares, Thunnus obesus, Istiophorus albicans, Katsuwonus pelamis, Makaira nigricans, Tetrapturus albidus,* and *Xiphias gladius*) originating from industrial fisheries, which were retrieved from the CATDIS-ICCAT database due to its completeness. CATCHDAT provides landing data for all whales combined, not allowing for the split between the two groups considered in this model (baleen whales and toothed cetaceans). Thus, the landings were split according to the number of minke (baleen) and sperm whales (toothed) caught in 1978 (Singarajah, 1985), considering their mean individual weight (Trites and Pauly, 1998).

Landing data for 1978 were used as representing the 1970s as this is the earliest year for which landing data is separately recorded by fishery type in national sources (industrial and artisanal). Moreover, no complete list of species caught is available for the period between 1960 and 1977; landings were recorded only for those species that made up to 75-80% of total landings in each State. For earlier years, no species detail is provided and landings are recorded by very broad categories (fishes, crustaceans, molluscs, whales, and turtles). All values were expressed in tonnes·km^{-2}, considering the total study area as basis and not only the fishing ground area.

In order to establish the correspondence between common name and the group used in the model, the database compiled in Chapter 2 was used. Catches recorded by broad categories such as 'outros peixes', 'mistura', 'caíco', and 'outras espécies' were not included. They all represent unidentified species, which together accounted for about 6% of the total landings.

Catch data included in the model are restricted to landings and no estimate of discards or catches from other fishing activities such as recreational, subsistence, research, and illegal was added due to the absence of quantitative studies in the region, mainly through large areas and related to the period being modelled (1970s). As such, landings represent an underestimation of the total extractions from the East Brazil LME.

4.2.7. Balancing the model

The procedure of connecting such diverse data into one single framework such as Ecopath with Ecosim is expected to show some incompatibilities, which are indicated by ecotrophic efficiencies greater than one (i.e., mortality is higher than production). Thus, some changes were incorporated in the original data from the sources presented in Appendices 3 and 4 in order to obtain an initial version of a balanced flux of biomass between functional groups and to make the data more appropriate to northeastern Brazil. Main changes were incorporated in the diet matrix, as this is one of the most uncertain input data in the model. In some cases, changes in the diet composition did not suffice and extra changes were required, which are described below. The following was based on ecotrophic efficiency largest to smallest:

a) In order to decrease the high ecotrophic efficiency of 'large carnivorous reef fishes', the proportion of this item in the diet of 'southern red snapper' was decreased by 80% (from 0.15 to 0.03); this was a plausible change as there was no indication of weight (or volume) of each prey item in the original source used. Adittionally, the proportion of cannibalism was reduced by 50% (from 0.04 to 0.02). These changes did not suffice and P/B was increased by 100% (from 0.18 to 0.37), as data presented in Lessa *et al.* (2004) for this group are probably underestimated considering the commercial fishery for this group;
b) A 50% reduction of the proportion of 'bathypelagic fishes' in the diet of 'benthopelagic fishes' and 'squids' was needed (from 0.019 to 0.008 and from

0.284 to 0.114, respectively); the consumption by biomass for this group had to be decreased to 1/3 of its original value (from 9.5 to 3.2), with a resulting estimate compatible with other models;

c) The proportion of 'seagrass' in the diet of 'needlefishes' was decreased by 50% (from 0.068 to 0.034); the same change was applied to the diet of 'omnivorous reef fishes' (from 0.023 to 0.011). The consumption of 'needlefishes' was reduced by 50%, resulting in a value similar to the estimate used by Mohammed (2003) for Grenada and the Grenadines, and to the estimate for 'small pelagics'. The estimate of seagrass production available for Pernambuco State was not able to support the grazing impact of all consumers in the larger area. This was accommodated by increasing the biomass of this group by 100% (from 100 to 200 tonnes·km^{-2});

d) A 50% reduction of the proportion of zooplankton in the diet of shrimps and other molluscs was applied (from 0.336 to 0.168 and from 0.156 to 0.078, respectively); most of the original sources of diet data were from southern Brazil where zooplankton production is much higher than in the study area. The estimate of biomass from a local study in northeastern Brazil (9.62 tonnes·km^{-2}; Schwamborn, 1997) seems to be too low. Thus, the original estimate was taken out and an ecotrophic efficiency of 0.95 was entered, leaving the biomass to be estimated by the model;

e) P/B for microfauna was increased by 10% (from 280 to 308 year^{-1});

f) Phytoplankton biomass was increased by 30% (from 9.29 to 12.08), resulting in an estimate consistent with other models for the tropical western Atlantic;

g) The biomass value for squids, corresponding to 1/100 of the value provided by Vasconcellos (2002) for the South Atlantic (0.0042 tonnes·km^{-2}), seemed to be too low for the study area. Thus, this value was set to be estimated by the model, given an ecotrophic efficiency of 0.9 available from the same source.

The resulting model is expected to be able to reproduce observed trends in the time series of abundance, natural, fishing or total mortality, or catches available for any of the groups included in the model. In order to check for this correspondence, the Ecosim module of EwE was used and will be described in the next section.

4.2.8. Time-dynamic simulation using Ecosim

The Ecosim module allows for time-dynamic simulation of changes in biomass for each functional group based on the following equation (Walters *et al.*, 1997; Christensen *et al.*, 2004):

$$\frac{dB_i}{dt} = g_i \sum_{j}^{n} Q_{ji} - \sum_{j}^{n} Q_{ij} + I_i - (M0_i + F_i + e_i) \cdot B_i \quad (7)$$

where: dB_i/dt = change in biomass of group i; g_i = net growth efficiency; Q_{ji} = consumption of group j by group i; n = number of functional groups; Q_{ij} = consumption of group i by group j; I_i = immigration of group i; $M0_i$ = non-predation natural mortality rate of group i; F_i = fishing mortality rate of group i; e_i = emigration of group i; and B_i = biomass of group i.

One of the pillars of Ecosim is the 'foraging arena theory', which states that prey are not always available to predators, but they interchange between vulnerable and unvulnerable pools based on the trade-off between the risks of being eaten or starving (Walters and Juanes, 1993; Christensen *et al.*, 2004). The rate at which prey move from one pool to another is called vulnerability. This assumes high values if the ecosystem is dominated by a top-down control and low values if a bottom-up control is dominant (Christensen *et al.*, 2004). Thus, the amount of a prey i consumed by predator j (Q_{ij}) depends on the vulnerability (v_{ij}) and is defined by:

$$Q_{ij} = \frac{a_{ij} \cdot v_{ij} \cdot B_i \cdot B_j}{2v_{ij} + a_{ij} \cdot B_j}$$

where a_{ij} = effective search rate of predator j feeding on prey i; B_i = prey biomass; and B_j = predator biomass.

Vulnerabilities (v_{ij}) cannot be directly estimated, so they were evaluated by changing the default values (2) in order to fit the predicted Ecosim simulations to the observed time series of relative or absolute biomass, using times series of fishing mortality or fishing effort to drive changes in biomass for those groups for which data were available. The sum of the squares between the observed and the predicted time series was used to decide which vulnerability value produced the best fit (Christensen *et al.*, 2004).

All available time series were simultaneously incorporated into the model through the use of a comma-delimited file (CSV). However, changes in the vulnerability settings were made in one group at a time, beginning with those groups better rooted in local data: spiny lobsters, southern red snapper, baleen whales, and toothed cetaceans. These were followed by tuna and tuna-like fishes for which ICCAT time series were used as a proxy for local data. All time series used are as follows:

a) Spiny lobsters

Catch per unit of effort (CPUE) of spiny lobsters (*Panulirus argus* and *P. laevicauda*) was used as an estimate of abundance as no direct estimate was available. These data were obtained from Ivo and Pereira (1996) for 1978-1994 and complemented by an estimate for 2000 available in Castro e Silva (2003). A linear trend for CPUE between 1994 and 2000 was assumed in order to estimate missing values of CPUE (1995-1999). The resulting series was then used to back-calculate the effort in trap-days required to produce the spiny lobster catches compiled in Chapter 3. This effort series was used as a driving function for this group in Ecosim and, as such, had to be complete (Christensen *et al.*, 2004). CPUE trend was converted into biomass trend using the biomass estimated by the model as the starting point.

b) Southern red snapper

Similarly to spiny lobsters, CPUE of *L. purpureus* was used as a proxy for the trend in biomass changes, based on Paiva (1997) for the period 1978-1992. No estimate of CPUE was found for later years, with the exception of an indication that it has been in average 3 kg·hook-day^{-1} (Fonteles Filho, undated). This was used for 1993-2000 and the effort required to obtain the catch data for this species compiled in Chapter 3 was estimated. The resulting effort series was used to drive changes in biomass of *L. purpureus* in the EwE simulations.

c) Whales

Times series of catch data (in weight) for baleen whales (minke whale) and toothed cetaceans (sperm whale) were obtained from catches in number presented by Singarajah (1997), using a mean individual weight of 6.6 and 18.5 tonnes, respectively (Trites and Pauly, 1998). The resulting values were adjusted to the total catch recorded in the national fishery statistical bulletins and compiled in Chapter 3. Fishing effort was considered constant until 1980 for toothed cetaceans and until 1985 for baleen whales, as only one vessel was involved in whaling in this area (Rabay, 1985). For the remaining years, fishing effort was considered zero due to the ban of whaling activities in Brazilian waters.

d) Tunas

Trends in biomass for the whole Atlantic Ocean were used for yellowfin and bigeye tunas, based on the hypothesis of one stock for the whole Atlantic (ICCAT, 2004b; 2005a). Fishing mortality (F) trends for both species were obtained from ICCAT (2004b). For albacore, the trend in biomass available for the Southern Atlantic (south to 5°N) was used, based on the hypothesis of two stocks (ICCAT, 2004a). No time series of fishing mortality was found for this species. The trends in biomass and fishing mortality were translated into absolute values for the study area using Ecopath values as starting points. An average for all species for which information was available was considered as representative of the whole group.

e) Swordfish

For swordfish, a time series of B/B_{MSY} (MSY = maximum sustainable yield) was obtained from ICCAT (2003) for the Southern Atlantic stock. This trend was translated into absolute biomass using the biomass at the Ecopath level as the starting point. A time series of fishing mortality for this stock was obtained from the same source and was used to drive changes in biomass for this group in EwE.

f) Sharks

ICCAT (2005b) presents very preliminary information about the abundance of sharks based on the ratio of shark to tuna catches. These estimates are available only for blue shark *Prionace glauca*, which corresponds to about 60% of the sharks caught by longliners in Brazilian waters (ICCAT, 2005b), and for shortfin mako (*Isurus oxyrinchus*). An average trend in biomass was obtained using the biomass estimated by Ecopath for 1978 and the trend in

CPUE available for blue shark and of absolute biomass for shortfin mako for the Southern Atlantic.

g) Other large pelagics

A trend in B/B_{MSY} was used for blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*), assuming the existence of one single Atlantic stock for both species (ICCAT, 2004b). For skipjack, a series of absolute biomass for the whole Atlantic was obtained from ICCAT (1999). Sailfish (*Istiophorus albicans*) and longbill spearfish (*Tetrapturus pfluegeri*) have been historically caught and assessed together. Although this has changed in the last years, the assessment for Western Atlantic is still based on this composite. A trend in CPUE was used for the composite (ICCAT, 2004b) and combined with the trend for other species, using the biomass defined in the Ecopath model as the starting point to obtain a time series of biomass. Trends in F/F_{MSY} were obtained for blue marlin, white marlin, and sailfish/spearfish from ICCAT (2004b). For skipjack, a series of fishing mortality was available in ICCAT (1999). These trends were combined for the whole group and expressed based on the value of fishing mortality estimated for 1978 at the Ecopath level. The resulting trend was used to drive changes in biomass for 'other large pelagics'.

After the adjustments of vulnerabilities were made, changes in biomass for the period 1978-2000 were assessed for some groups using Ecopath with Ecosim.

4.3. Results

The basic input matrix obtained in the balanced trophic model of the 1970s for the marine ecosystem off northeastern Brazil is presented in Table 4.1. Forty-one functional groups were assumed to describe the main trophic relationships, with a total biomass (excluding detritus) of 222 tonnes·km^{-2} estimated for this ecosystem.

The diet matrix for the northeastern Brazil marine ecosystem obtained in this study for the 1970s model is presented in Table 4.2. The mixed trophic impact (MTI) analysis allows a better understanding of the impact of one group over the others. Most of the impacts are quite modest, probably due to the highly reticulated diet matrix. However, seagrass and macroalgae exert a strong positive impact on manatee and herbivorous reef fishes, respectively (Fig. 4.1). A high negative impact of omnivorous reef fishes is observed over spiny lobsters. Sharks have a negative impact, as a predator, over swordfish.

A model is considered a reasonable representation of one system if it is able to reproduce with some degree of confidence some observed patterns. The model was not able to reproduce the observed changes in biomass available for spiny lobsters, southern red snapper, and tuna and tuna-like fishes, unless adjustments in the vulnerability were made from the default (2.0). Thus, for spiny lobsters and southern red snapper, the vulnerabilities that resulted in the best fit were 1.2 and 1.3, respectively (Fig. 4.2). For swordfish and other large pelagics, low values (1.3 and 1, respectively) produced the best fit as well (Fig. 4.3). For tunas, a vulnerability of 8 was able to produce a good fit between the ICCAT series of biomass and the value predicted by the model. For sharks, changes in vulnerability did not result in much difference in the predicted values; the model was still able to capture some of the decline of sharks observed in the Atlantic, but not at the level indicated by ICCAT (2005b). No changes in the original basic input were incorporated at this stage.

After the vulnerabilities adjustments were made, the final changes in biomass for many of the groups could be assessed. The largest changes were observed for spiny lobsters and swordfish (Fig. 4.4), which declined to 12 and 14% of the biomass in the beginning of the period (1978), respectively. Tunas, other large pelagics, and sharks presented intermediate decline rates of biomass, reaching 52%, 72%, and 85% of the original biomass, respectively. A slight increase in biomass was observed for toothed cetaceans, large carnivorous reef fishes, and dolphinfish (1.7 to 6.9%). Southern red snapper (*L. purpureus*) presented a decline in biomass until 1996 and seemed to recover to levels above the observed in the Ecopath level. For the remaining species, changes in biomass (positive or negative) were very low and are not shown.

EwE provides a series of system statistics that allow for the comparison amongst different ecosystems and details about the equations used to obtain each estimate are available in Christensen *et al.* (2004, available at www.ecopath.org). In order to compare these statistics, an analysis of the sensitivity of the system statistics provided by EwE to the aggregation of the 41 functional groups included in the model was performed after aggregating the original groups into 31 and 21 groups. This procedure indicated that all the statistics provided remained within the range between +20 and –20% of the original value, with the exception of the connectance index, the throughput cycled (excluding detritus), and the predatory cycling index (Fig. 4.5). Thus, these statistics should not be used in the comparison of the characteristics of the ecosystem studied here with other ecosystems in Brazil or in other tropical shelves.

Table 4.1: Basic input for the 1970s Ecopath with Ecosim model for the marine ecosystem off northeastern Brazil. B = biomass in the habitat area (wet weight); P/B = production/biomass; Q/B = consumption/biomass; and EE = ecotrophic efficiency*.

Group name	B (tonnes·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	Catches (tonnes·km^{-2})
1. Manatee	0.0002	0.06	27.38	0.00	0
2. Baleen whales	0.3852	0.03	4.62	0.30	0.003130
3. Toothed cetaceans	0.1427	0.08	10.85	0.50	0.000307
4. Seabirds	0.0150	5.40	80.00	(0.38)	0
5. Sea turtles	0.1630	0.15	22.00	0.50	0.000006
6. Tunas	0.0350	0.82	8.00	0.99	0.003420
7. Other large pelagics	0.0257	0.64	9.60	0.72	0.005786
8. Dolphinfish	0.0005	4.36	20.44	(0.43)	0.000872
9. Dolphinfish juveniles	0.0013	13.08	59.21	(0.31)	0
10. Swordfish	0.0090	0.29	4.00	0.99	0.000190
11. Sharks	(0.0324)	0.27	4.00	0.60	0.004471
12. Rays	(0.1013)	0.50	3.50	0.41	0.001871
13. Small pelagics	(0.6045)	4.41	12.45	0.99	0.004061
14. Needlefishes	(0.1150)	5.42	18.95	0.99	0.000656
15. Southern red snapper	0.0143	0.73	5.30	(0.90)	0.005490
16. Large carnivorous reef fishes	(0.2338)	0.37	6.34	0.81	0.015600
17. Small carnivorous reef fishes	(0.9726)	1.57	9.22	0.86	0.002100
18. Herbivorous reef fishes	(1.1164)	0.55	23.13	0.39	0.000052
19. Omnivorous reef fishes	(1.1400)	0.44	10.57	0.95	0.005680
20. Demersal fishes	(1.3468)	1.93	10.27	0.95	0.041052
21. Mullets	(0.7631)	1.03	22.60	0.86	0.008000
22. Spotted goatfish	0.0500	0.82	10.80	(0.24)	0.000045
23. Benthopelagic fishes	(0.0746)	0.78	3.18	0.80	0.000768
24. Bathypelagic fishes	1.1710	1.90	5.44	(0.71)	0
25. Spiny lobsters	(0.0138)	1.28	7.40	0.99	0.007960
26. Other lobsters	(0.6111)	0.35	7.40	0.90	0
27. Shrimps	(3.9006)	2.73	13.45	0.99	0.012430
28. Crabs	(1.5077)	5.23	10.82	0.99	0.005300
29. Squids	(0.1767)	6.40	36.50	0.90	0
30. Octopus	(0.1510)	1.90	6.76	0.85	0.000005
31. Other molluscs	(2.5310)	3.30	18.87	0.95	0.001580
32. Other crustaceans	(1.5906)	19.58	50.77	0.95	0.000003
33. Other invertebrates	(6.9979)	2.34	6.74	0.91	0
34. Zooplankton	(2.1656)	26.04	165.00	0.95	0
35. Corals	(0.0631)	1.09	4.23	0.98	0
36. Microfauna	5.9890	308.00	560.00	(0.09)	0
37. Phytoplankton	12.0860	157.04	NA	(0.08)	0
38. Macroalgae	98.4060	13.25	NA	(0.09)	0
39. Mangroves	77.7620	66.46	NA	(0.004)	0
40. Seagrasses	0.0520	100.00	NA	(0.09)	0
41. Detritus	201.9130	NA**	NA	(0.33)	0

* Values in parentheses were estimated by Ecopath with Ecosim. **NA = not applicable.

Table 4.2: Diet matrix for the 1970s Ecopath with Ecosim model for the marine ecosystem off northeastern Brazil*.

Prey / Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Manatee																		
2. Baleen whales																		
3. Toothed cetaceans			0.0035								0.0018							
4. Seabirds			0.0177								0.0250							
5. Sea turtles																0.0082		
6. Tunas							0.0086			0.0264	0.1702							
7. Other large pelagics							0.0126	0.0251		0.0264	0.0351							
8. Dolphinfish										0.0019								
9. Dolphinfish juv.						0.0029	0.0105	0.1783										
10. Swordfish											0.0194							
11. Sharks																		
12. Rays												0.0084				0.0107		
13. Small pelagics		0.2500	0.0834	0.0976		0.4568	0.1626	0.3247	0.2273	0.0153	0.0835	0.1239	0.0302	0.0877	0.3944	0.0100	0.0649	
14. Needlefishes							0.0334	0.0059	0.0041						0.1972		0.0649	
15. Southern red snapper						0.0034	0.0001	0.0001		0.0003	0.0114					0.0010		
16. Large carnivorous reef fishes						0.0310	0.0009	0.0009		0.0030	0.1030				0.0295	0.0193		
17. Small carnivorous reef fishes						0.0247	0.1089	0.3023	0.3023	0.1235	0.1158	0.0158			0.0986	0.1915	0.0942	
18. Herbivorous reef fishes						0.0019	0.0012	0.0003	0.0003	0.0003	0.0402	0.0071				0.0404	0.0188	
19. Omnivorous reef fishes						0.0377	0.1245	0.0535	0.0535	0.2989	0.0553	0.0014			0.0986	0.0267	0.0188	
20. Demersal fishes		0.0720	0.2890	0.1331	0.0163		0.0003	0.0003	0.0003		0.0734	0.3537				0.0392		
21. Mullets				0.0000										0.0015				
22. Spotted goatfish															0.0295	0.0051		
23. Benthopelagic fishes				0.0001			0.0069			0.0046	0.0605						0.0002	
24. Bathypelagic fishes		0.0300	0.0845	0.0063		0.2978	0.3547	0.0659	0.0659	0.3602	0.0376							
25. Spiny lobsters																0.0002		
26. Other lobsters						0.0034				0.0001	0.0002					0.1129		
27. Shrimps			0.0043	0.0001	0.0014					0.0092	0.0038	0.0680	0.0103	0.1081	0.0457	0.2012	0.1353	
28. Crabs				0.2209	0.0739	0.0022	0.0003	0.0001	0.0001	0.0001	0.0209	0.1443	0.0859	0.0074	0.0457	0.2563	0.1349	
29. Squids		0.0060	0.4790	0.0192		0.0968	0.1552	0.0281	0.2809	0.1272	0.0766	0.0005			0.0101	0.0032	0.0009	
30. Octopus			0.0043			0.0126	0.0186	0.0022	0.0022	0.0022	0.0567	0.0018			0.0101	0.0323		
31. Other molluscs			0.0300	0.0048	0.0328			0.0003	0.0003	0.0002		0.1433	0.0374		0.0406	0.0055	0.1923	
32. Other crustaceans				0.0057		0.0229	0.0003	0.0118	0.0118	0.0002	0.0016	0.0617	0.1432	0.0143		0.0306	0.0643	
33. Other invertebrates	0.0135		0.0043	0.2969	0.2200						0.0077	0.0350	0.0283	0.1195		0.0030	0.0732	
34. Zooplankton		0.6420		0.1057	0.4539	0.0060	0.0004	0.0002	0.0510		0.0001	0.0348	0.3935	0.6100		0.0026	0.1373	
35. Corals					0.0118													
36. Microfauna																		
37. Phytoplankton													0.2077					
38. Macroalgae	0.0436				0.1569								0.0436	0.0173				1.0000
39. Mangroves	0.1465																	
40. Seagrasses	0.7964				0.0302							0.0003		0.0342				
41. Detritus				0.1095	0.0028								0.0199					

Table 4.2: Diet matrix for the 1970s Ecopath with Ecosim model for the marine ecosystem off northeastern Brazil* (continued).

Prey / Predator	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. Manatee																		
2. Baleen whales																		
3. Toothed cetaceans																		
4. Seabirds																		
5. Sea turtles																		
6. Tunas																		
7. Other large pelagics																		
8. Dolphinfish																		
9. Dolphinfish juv.																		
10. Swordfish																		
11. Sharks																		
12. Rays																		
13. Small pelagics	0.0004	0.0016			0.0929	0.0954												
14. Needlefishes					0.0465													
15. Southern red snapper																		
16. Large carnivorous reef fishes	0.0001																	
17. Small carnivorous reef fishes	0.0071					0.0002												
18. Herbivorous reef fishes	0.0002					0.0003												
19. Omnivorous reef fishes	0.0019			0.0440		0.0218												
20. Demersal fishes	0.0599	0.0500			0.0443	0.0003						0.0164						
21. Mullets	0.0314				0.0446						0.0392	0.0228						
22. Spotted goatfish																		
23. Benthopelagic fishes					0.0443						0.0011	0.0147						
24. Bathypelagic fishes					0.0076	0.0564					0.1271	0.0106						
25. Spiny lobsters	0.0008																	
26. Other lobsters	0.0008					0.0001						0.0141						
27. Shrimps	0.0405	0.2587		0.2250	0.2210	0.0255				0.1934	0.1612	0.0730						
28. Crabs	0.2336	0.0718		0.3110	0.0036		0.4785			0.0422		0.2049			0.0008			
29. Squids	0.0004					0.0051					0.0123	0.0110						
30. Octopus	0.0045					0.0003					0.0003	0.1113						
31. Other molluscs	0.1749	0.0084	0.0024	0.0770	0.0412	0.0309	0.2930	0.5000	0.0021	0.0090		0.1856	0.0087		0.0006			
32. Other crustaceans	0.2791	0.1729	0.0050	0.1530	0.3046	0.0839			0.3689	0.0726	0.0615	0.1961			0.0032			
33. Other invertebrates	0.0849	0.2021	0.0024	0.1900	0.0887	0.0371	0.1075	0.5000	0.0398	0.0905		0.1144	0.0172	0.0113	0.0159			
34. Zooplankton	0.0074	0.1567	0.0050		0.0607	0.6429			0.1682	0.0054	0.5975	0.0251	0.0779	0.0273	0.0438	0.0500	0.1625	
35. Corals							0.0054							0.0001	0.0003			
36. Microfauna	0.0001		0.0188							0.0018			0.1985	0.1182	0.0696	0.4000	0.5875	
37. Phytoplankton		0.0010	0.1930							0.0009			0.5020		0.0339	0.3300		
38. Macroalgae	0.0470	0.0407	0.1050				0.1022		0.0710	0.1179			0.0752	0.3086	0.1429			0.0134
39. Mangroves										0.2624								0.0045
40. Seagrasses	0.0114						0.0134			0.0013				0.000069	0.000001			0.00004
41. Detritus	0.0137	0.0361	0.6685						0.3499	0.2026			0.1204	0.5344	0.6889	0.2200	0.2500	0.9821

* Functional groups 37-40 and 41 do not require predator column as they refer to primary producers and to the product of the degradation of all groups included in the model, respectively.

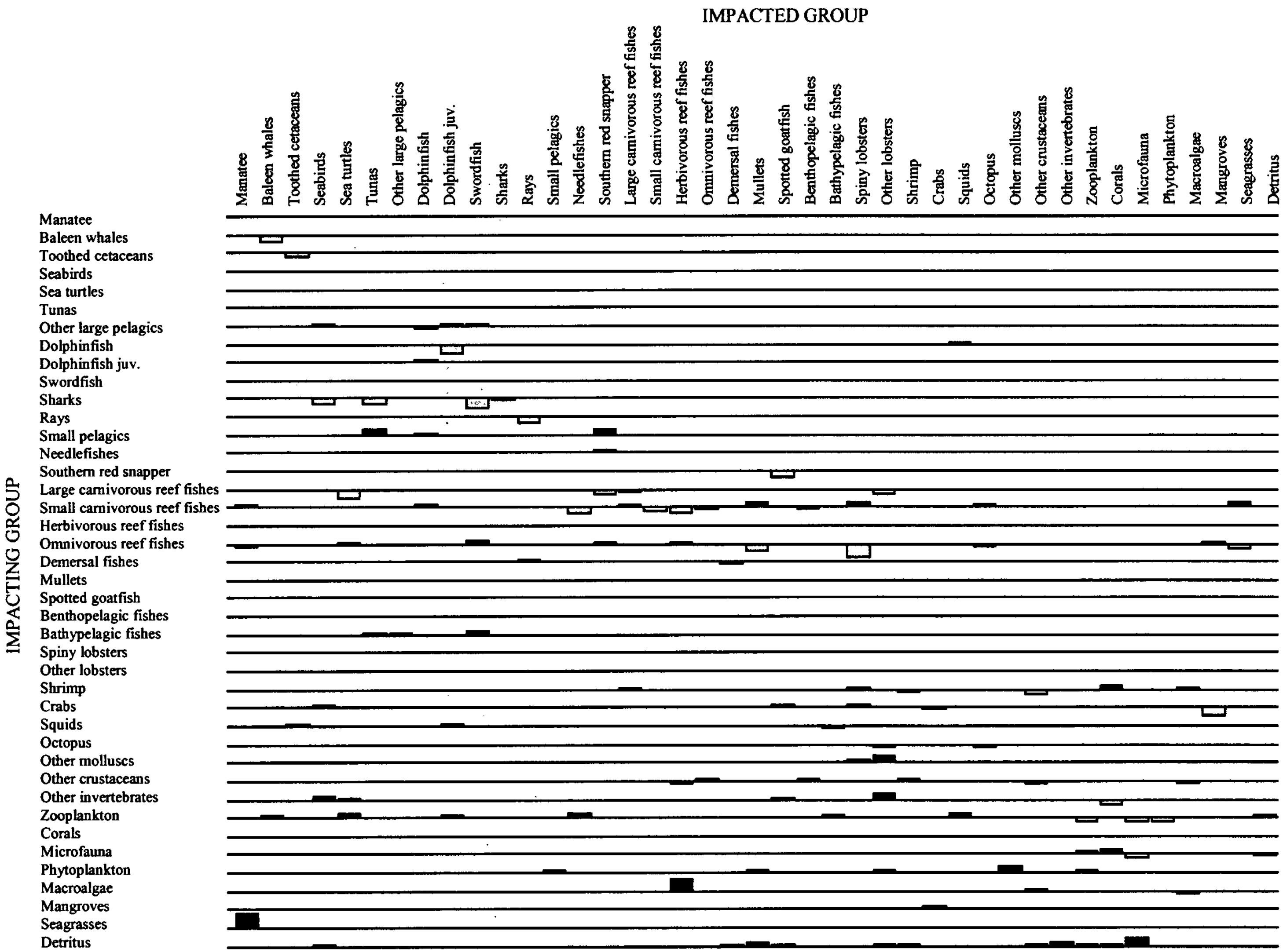

Figure 4.1: Mixed trophic impact in northeastern Brazil marine ecosystem for the 1970s. The impact in each group is positive when placed above the line and negative when below.

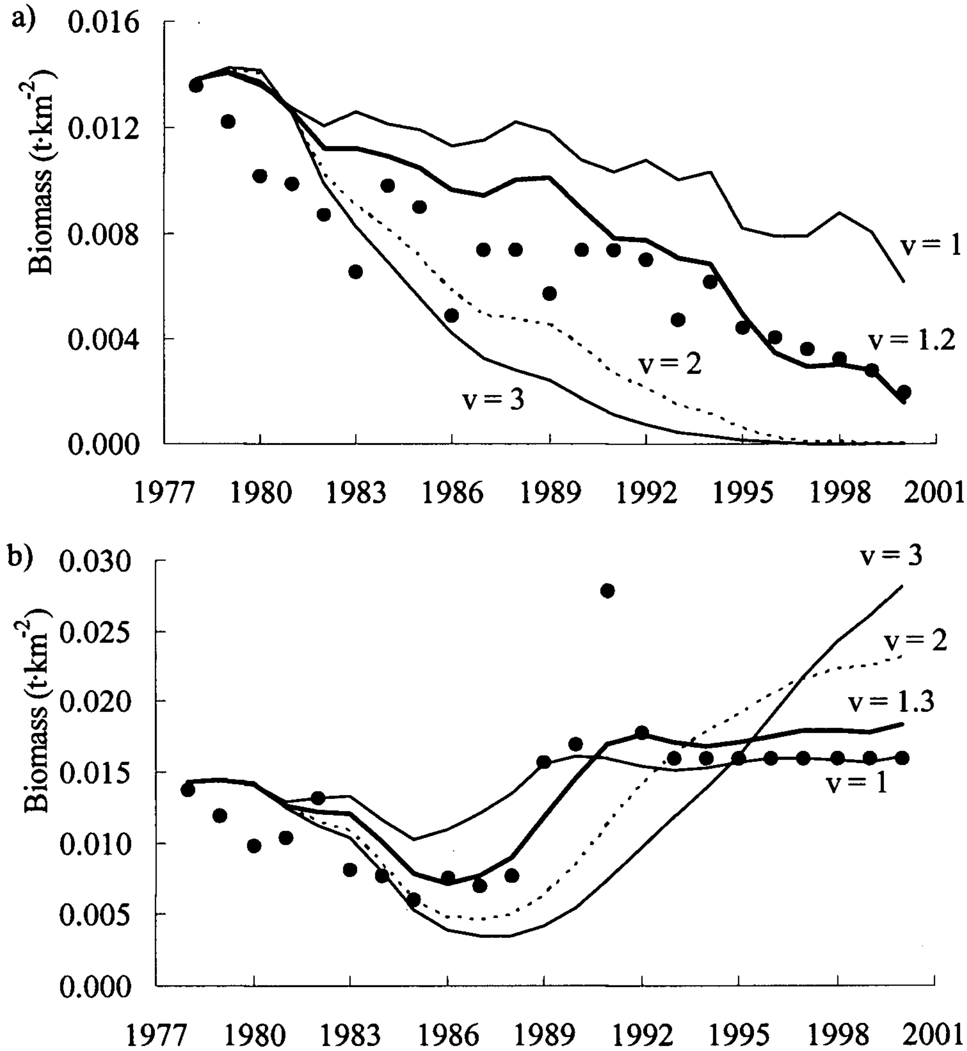

Figure 4.2: Verification of the model: observed time series (dots) of biomass for spiny lobsters (a) and southern red snapper (b) off northeastern Brazil and estimated values from Ecopath with Ecosim under four values of vulnerability 'v' (lines) for the period from 1978 to 2000. The thicker line is associated with the vulnerability value used in the final version of the model.

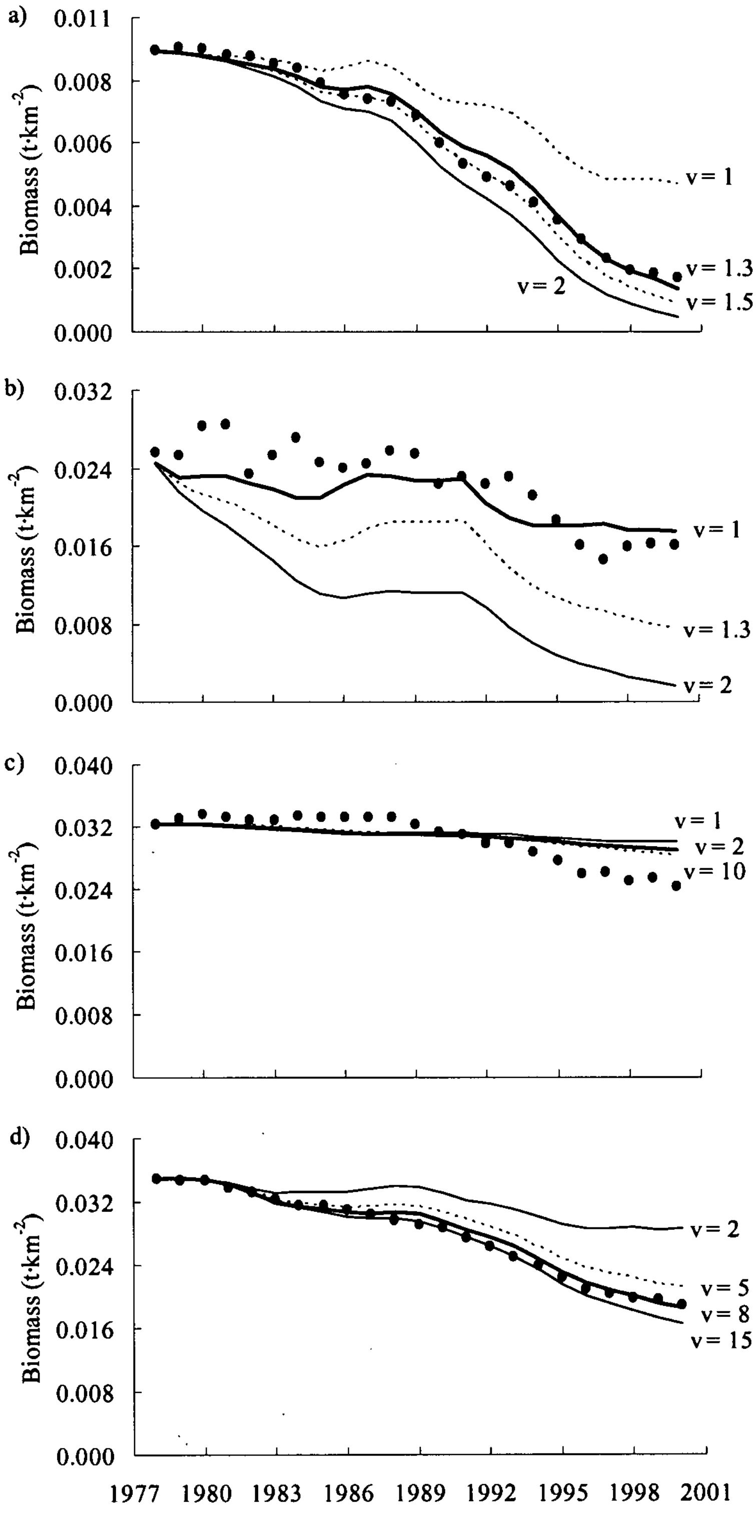

Figure 4.3: Verification of the model: observed time series of biomass (dots) and estimated values (lines) from Ecopath with Ecosim under different settings of vulnerability (v) for swordfish (a), other large pelagics (b), sharks (c), and tunas (d) off northeastern Brazil in 1978-2000.

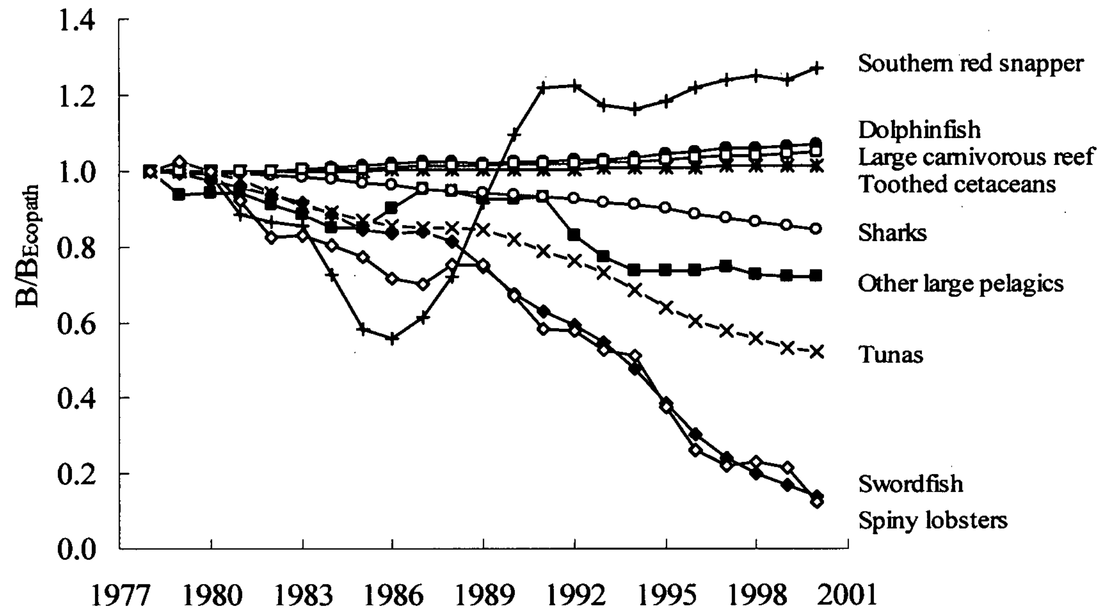

Figure 4.4: Changes in biomass in relation to the Ecopath level (1.0) for some groups included in the 1970s model of the marine ecosystem off northeastern Brazil (1978-2000). The remaining groups did not show any significant changes.

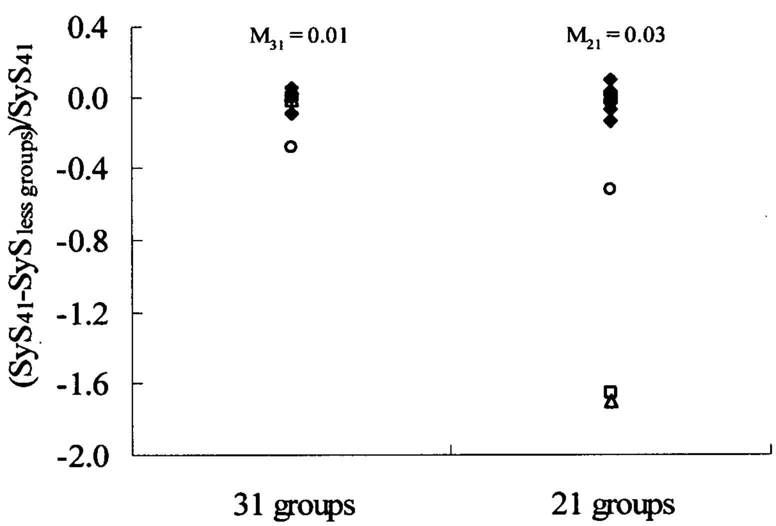

Figure 4.5: Variation of the system statistics (SyS) for the East Brazil Large Marine Ecosystem obtained with Ecopath with Ecosim models using 31 and 21 groups ($SyS_{less\ groups}$) in relation to the original 41 groups model (SyS_{41}). Open circles correspond to the connectance index, open squares to the throughput cycled (excluding detritus), and open triangles to the predatory cycling index. M_{31} and M_{21} indicate the mean absolute variation of the system statistics using 31 and 21 groups in relation to the baseline (41 groups).

Northeastern Brazil marine ecosystem, as represented in this model, presents a total system throughput of 23,042 $t \cdot km^{-2} \cdot year^{-1}$ (Table 4.3). This value is equal to the sum of all flows in this system, including consumption, export, respiration, and flow to detritus, and indicates the size of the system in terms of flows (Ulanowicz, 1986). Of this total, 18% represents consumption by predators, 30% is exported, 6% is lost via respiration, and a very high proportion flows into the detritus group (46%). Total primary production is 8,375 $t \cdot km^{-2} \cdot year^{-1}$, with 22% originating from phytoplankton and the remaining from mangroves, macroalgae, and seagrass. Only 3.4% of this production is consumed and the rest goes into the detritus. The primary production of this system exceeded the respiration (P/R=1.5) and the total biomass (P/B=15.4) of all functional groups included in the model.

In terms of catches, they added up to 0.13 $t \cdot km^{-2} \cdot year^{-1}$ (Table 4.3), with demersal fishes accounting for 33%, reef fishes for 17%, shrimps for 10%, spiny lobsters for 6%, and tuna and tuna-like fishes for 5% of this total. The mean trophic level of the catch was 3.4, and the primary production required was 1.3%. The gross efficiency of catches in this area, defined as the ratio of catch to primary productivity (Christensen *et al.*, 2004) was 0.00002.

The trophic aggregation analysis indicated the existence of ten discrete trophic levels (*sensu* Lindeman, 1942). The ninth trophic level encompasses only dolphinfish, swordfish, and sharks (Table 4.4). Microfauna and herbivorous reef fishes are the only functional groups besides primary producers that operate at one single trophic level. All the other groups operate through a range of two to seven trophic levels, but concentrate at levels II to IV. The mean transfer efficiency between trophic levels (geometric mean weighted by flows for trophic levels II-IV) was estimated at 11.4%. Transfer from level I to II was low (6.4%), increasing to a maximum

Table 4.3: System statistics obtained from Ecopath with Ecosim for the 1970s model of East Brazil Large Marine Ecosystem (off northeastern Brazil), for other models of marine ecosystems off Brazil, and for models representing shelf ecosystems in tropical areas.

Statistic/Ecosystem	Brazil					Other shelves					Units
	This study	Mangrove[1]	Coral reef[2]	Shelf[3]	Shelf[4]	SE US[5]	Yucatan[6]	Venezuela[7]	SW GOM[8]	Grenada[9]	
	Northeast	North	Northeast	Southeast	South						
Total system throughput	23042	10559	43394	9098	5584	14518	2049	7621	7713	14332	t·km⁻²·year⁻¹
Sum of all production	10364	3555	13119	4178	2274	5420	692	3699	5029	3755	t·km⁻²·year⁻¹
Calculated total net primary production	8375	3134	9150	2988	1670	4336	454	3290	4668	3115	t·km⁻²·year⁻¹
Phytoplankton biomass	12.1	6	16	18	16.7	5.6	7.9	45	45.5	36.2	t·km⁻²
Phytoplankton production	1900	1080	1920	2988	1670	1865	356	3150	4687	2534	t·km⁻²·year⁻¹
Zooplankton biomass	2.2	1.5	28.9	10.5	9	36.5	1.7	8.2	5.7	2.5	t·km⁻²
Zooplankton production	57	150	1156	945	584	475	30	328	124	100	year⁻¹
Total primary production/total respiration	6.6	3.3	0.6	1.2	0.9	1.7	0.8	1.8	4.1	1.0	dimensionless
Total primary production/total biomass	37.6	0.2	5.6	20.5	37.2	9.2	7.0	27.0	44.4	24.3	dimensionless
Total biomass/total throughput	0.01	1.24	0.04	0.02	0.01	0.03	0.03	0.02	0.01	0.01	dimensionless
Total biomass (excluding detritus)	222.5	13132	1640	146	45	470	65	122	105	128	t·km⁻²
Omnivory Index	0.21	0.11	0.16	0.28	0.26	0.22	0.28	0.32	0.36	0.26	dimensionless
Prop. total flux originating from detritus	0.62	0.45	0.68	0.31	0.37	NP	0.43	0.27	0.53	NP	dimensionless
Mean transfer efficiency between TL	11.4	9.3	10.4	12.6	6	NP	17.6	6.6	9.2	NP	%
Total catches	0.13	268.30	NA	1.67	0.99	0.79	0.09	5.20	0.31	0.08	t·km⁻²·year⁻¹
Mean trophic level of the catch	3.4	2.1	NA	2.6	3.7	3.0	4.1	2.8	3.5	4.3	dimensionless
Gross efficiency (catch·10⁴/net pp.)	0.2	86000	NA	5.6	5.9	1.8	1.8	16.0	0.7	0.3	dimensionless
Primary production required (catches)	1.3	30.7	NA	2.5	22.0	NP	53.6	7.9	6.7	NP	%
Study area	1074984	220	7	97000	28661	174300	100000	30000	65000	25957	km²
Number of groups	41	19	22	25	13	42	21	16	19	51	groups

1. From Wolff *et al.* (2000); 2. From Telles (1998); 3. From Gasalla and Rossi-Wongtschowski (2004); 4. From Vasconcellos and Gasalla (2001); 5. Southeastern United States, from Okey and Pugliese (2001); 6. From Arreguín-Sánchez *et al.* (1993); 7. From Mendoza (1993); 8. Southwestern Gulf of Mexico, from Manickchand-Heileman *et al.* (1998); 9. Grenada and the Grenadines, from Mohammed (2003). Note that some statistics were not provided in the original source and were obtained after re-entering the data, wherever the completeness of the basic input allowed. NA = not applicable and NP = not provided.

Table 4.4: Relative flows by discrete trophic level for the marine ecosystem off northeastern Brazil in the 1970s model. Flows through the trophic level X are too low to be shown. TL represents the fractional trophic level *sensu* Odum and Heald (1975).

Group\Trophic level	TL	I	II	III	IV	V	VI	VII	VIII	IX
Manatee	2.02	0	0.9865	0.0119	0.0013	0.0003	0	0	0	0
Baleen whales	3.72	0	0	0.4475	0.4517	0.0906	0.0090	0.0011	0.0001	0
Toothed cetaceans	4.45	0	0	0.0759	0.5299	0.3330	0.0561	0.0048	0.0003	0
Seabirds	3.45	0	0.1095	0.5045	0.2694	0.0990	0.0164	0.0012	0	0
Sea turtles	3.15	0	0.1899	0.5298	0.2579	0.0192	0.0030	0.0002	0	0
Tunas	4.31	0	0	0.1564	0.5007	0.2991	0.0381	0.0052	0.0005	0
Other large pelagics	4.50	0	0	0.0588	0.5434	0.3358	0.0548	0.0066	0.0006	0
Dolphinfish	4.58	0	0	0.1057	0.4383	0.3326	0.1048	0.0169	0.0016	0.0001
Dolphinfish juv.	4.42	0	0	0.1078	0.5206	0.3065	0.0583	0.0063	0.0005	0
Swordfish	4.56	0	0	0.0304	0.5524	0.3348	0.0719	0.0096	0.0009	0.0001
Sharks	4.65	0	0	0.0990	0.4055	0.3445	0.1301	0.0188	0.0020	0.0002
Rays	3.88	0	0.0003	0.3950	0.4164	0.1596	0.0265	0.0021	0.0001	0
Small pelagics	3.05	0	0.2796	0.4710	0.2313	0.0153	0.0027	0.0001	0	0
Needlefishes	3.43	0	0.0515	0.5465	0.3620	0.0376	0.0022	0.0003	0	0
Southern red snapper	4.21	0	0	0.2073	0.4979	0.2528	0.0369	0.0047	0.0003	0
Large carnivorous reef fishes	4.01	0	0	0.3323	0.4466	0.1781	0.0390	0.0037	0.0002	0
Small carnivorous reef fishes	3.68	0	0	0.5683	0.3267	0.0937	0.0104	0.0008	0	0
Herbivorous reef fishes	2.00	0	1	0	0	0	0	0	0	0
Omnivorous reef fishes	3.33	0	0.0722	0.6346	0.2180	0.0631	0.0113	0.0006	0	0
Demersal fishes	3.36	0	0.0819	0.6040	0.2594	0.0508	0.0038	0.0001	0	0
Mullets	2.04	0	0.9664	0.0297	0.0037	0.0002	0	0	0	0
Spotted goatfish	3.50	0	0	0.6389	0.2644	0.0826	0.0132	0.0009	0	0
Benthopelagic fishes	3.58	0	0	0.5958	0.3032	0.0929	0.0075	0.0006	0	0
Bathypelagic fishes	3.58	0	0	0.5693	0.3895	0.0370	0.0036	0.0006	0	0
Spiny lobsters	3.30	0	0.1156	0.5953	0.2068	0.0677	0.0140	0.0006	0	0
Other lobsters	3.25	0	0	0.7924	0.1801	0.0272	0.0002	0	0	0
Shrimps	2.73	0	0.4209	0.4450	0.1285	0.0055	0.0001	0	0	0
Crabs	2.61	0	0.6124	0.2423	0.1150	0.0291	0.0012	0	0	0
Squids	3.64	0	0	0.5097	0.4115	0.0724	0.0058	0.0005	0.0001	0
Octopus	3.58	0	0	0.6663	0.2503	0.0714	0.0114	0.0006	0	0
Other molluscs	2.35	0	0.7038	0.2610	0.0348	0.0003	0	0	0	0
Other crustaceans	2.17	0	0.8431	0.1440	0.0127	0.0002	0	0	0	0
Other invertebrates	2.16	0	0.8810	0.0992	0.0196	0.0002	0	0	0	0
Zooplankton	2.47	0	0.5789	0.4211	0	0	0	0	0	0
Corals	2.83	0	0.2500	0.6816	0.0684	0	0	0	0	0
Microfauna	2.00	0	1	0	0	0	0	0	0	0
Phytoplankton	1.00	1	0	0	0	0	0	0	0	0
Macroalgae	1.00	1	0	0	0	0	0	0	0	0
Mangroves	1.00	1	0	0	0	0	0	0	0	0
Seagrasses	1.00	1	0	0	0	0	0	0	0	0
Detritus	1.00	1	0	0	0	0	0	0	0	0

from level III to IV (16.6%) and decreasing thereafter to 4.3% at level IX. The estimated omnivory index, calculated as the average omnivory index of all predators weighted by the logarithm of each predator's food intake (Christensen *et al.*, 2004), was 0.21.

4.4. Discussion

This study represents the first attempt to model the trophic components of the whole marine ecosystem off northeastern Brazil. Two previous studies dealt with a small reef area off Bahia State (Telles, 1998, using EwE) and a mangrove area off Pernambuco State (Wiedemeyer, 1997, not using EwE) (Table 4.3). As a first attempt, this required a considerable effort to gather information for an area that is much less studied than the southeastern and southern regions for which trophic models have already been constructed using EwE (Rocha *et al.*, 1998; Vasconcellos, 2000; Gasalla and Rossi-Wongtschowski, 2004).

The characteristics of the ecosystem modelled in this study will be discussed here and at the same time compared with other models constructed for Brazilian marine ecosystems and for tropical continental shelves along the western Atlantic (see Table 4.3). The models presented for comparison were chosen due to the use of similar methodology, but all of them refer to more recent periods. Telles (1998) found much higher biomass for most of the functional groups in the Abrolhos region (southernmost part of my study area). However, Telles modelled a very small (7 km^2) reef area, which has been protected since 1983, and which therefore is expected to harbour a higher biomass per unit of area. Wiedemeyer (1997) restricted the analysis to a small mangrove subsystem embedded in an estuarine system (35 km^2) and dealt only with the benthic food web. Wolff (2000) also analyzed a small mangrove area (220 km^2) to the north of the area studied in this thesis and found extremely high total system biomass per unit of area, mainly of mangrove vegetation. Part of the results of all these models were used in the model of northeastern Brazil constructed here, and may be seen as representing different subsystems embedded in a larger ecosystem. Thus, most of the comparisons below will be restricted to shelves areas both in Brazil and other countries.

The total system throughput (23,042 $t \cdot km^{-2} \cdot year^{-1}$) indicates that this system is similar in size to the Southeastern United States and Grenada and Grenadines in terms of amount of flows. The total primary production off the northeastern coast of Brazil was the highest amongst the shelves cited here. However, we must consider that some of these models were built to analyze specific subsystems such as the one for south Brazil, which aimed to assess the pelagic subsystem and did not include coastal systems. Thus, they did not include all primary production generated by benthic producers in these areas. The biomass originating from phytoplankton off northeastern Brazil (12.1 $t \cdot km^{-2}$) was lower than in Venezuela, Southwestern Gulf of Mexico, and Grenada and Grenadines (36-46 $t \cdot km^{-2}$), but higher than southeastern United States and Yucatan.

Vasconcellos and Gasalla (2001) and Gasalla and Rossi-Wongtschowski (2004) worked with large shelf ecosystems in southern and southeastern Brazil. The phytoplankton biomass in those areas was higher than in the marine ecosystem off northeastern Brazil (Table 4.3), as also reported by Matsuura (1995). However, the P/B ratio for phytoplankton may be slightly overestimated in the northeastern region (157 $year^{-1}$), as it results in a production level that surpasses the value for southern Brazil, a system dominated by *Engraulis anchoita*. That value is also very close to the P/B for southeastern Brazil (166 $year^{-1}$), an area associated with upwelling processes and highly influenced by small pelagics (in this case, *Sardinella brasiliensis*).

One important system statistic of an ecosystem is the omnivory index, which measures the degree to which a system exhibits weblike characteristics, i.e., how the interactions are spread amongst trophic levels. Pauly *et al.* (1993) suggested the use of this index as an alternative to the connectance index, which is highly affected by the number of functional groups included in the model. The omnivory index was 0.21, very similar to all other shelf systems considered (Table 4.3), which indicates that the functional groups are specialized, consuming food items over a few trophic levels. If we consider that the omnivory index is correlated with maturity in the same fashion as the connectance index (Odum, 1969), then one would say that northeastern Brazil would be on the immature side of the maturity spectrum. This hypothesis is supported by the high ratio of system primary production to respiration (6.6), but not by the high ratio between system primary production and biomass (37.6). The latter is one of the highest amongst the shelf systems presented in Table 4.3, and is very similar to the ratio observed in southern Brazil.

Detritus seems to have an important role in the marine ecosystem off northeastern Brazil considering that only about 3% of the total primary production is consumed and the remaining flows to the detritus, and 62% of the total flow in this system originates from detritus. Pace *et al.* (1984) points out that failure to properly consider different components of the zooplankton may lead to an overestimation of the detritus originating from phytoplankton. However, this is not expected to produce a large effect on this model as most of the primary production originates from benthic producers. Of all inflows to detritus, about 29% is derived from recycling, the highest percentage amongst the shelves analyzed here. The understanding of the recycling capacity of a system is important, as it is closely related to its ability to recover from perturbations (Vasconcellos *et al.*, 1997).

Petersen and Curtis (1980) suggest that an efficient system of recycling between phyto- and zooplankton would decrease the amount of nutrients available to benthic communities in tropical areas, which would be characterized by important pelagic fisheries in detriment of demersal fisheries and short food chains. The system analyzed here indicated that the biomass of demersal fishes was high and did support high catches (probably underestimated due to the non-inclusion of discards). This would reveal the importance of coastal vegetation and the detritus resulting from its decay to support a benthic community.

Total extractions (catches) from the marine ecosystem off northeastern Brazil were 0.13 $t \cdot km^{-2}$, a level very similar to southeastern US, Yucatan, and Grenada and the Grenadines. The mean trophic level (TL) of the landings was 3.4, which was higher than the model representing the northern mangrove area (2.1) where mangroves were by far the most exploited resource, followed by mangrove crabs (*Ucides cordatus*). In southeastern Brazil, where sardine is the main fish resource (Paiva, 1997), Gasalla and Rossi-Wongtschowski (2004) found a mean trophic level of catches of 2.6. As these authors constructed a model for 1998-1999, after the collapse of sardine fisheries in that region, the difference between the mean trophic of catches originating from northeastern and southeastern Brazil is expected to be higher in the late 1970s, when catches of sardine (TL = 2.8) were about 7 times higher than in 1999 (according to the database compiled in Chapter 3). In southern Brazil, the mean trophic level of catches was higher (3.7) than in northeastern Brazil. Even though sardines dominate fisheries in southern Brazil, demersal fishes such as drums, croakers, and hakes (TL = 3.5 to 4.1) are also heavily targeted, leading to an increased trophic level. The mean trophic level of landings in the Caribbean was higher than in northeastern Brazil, as a result of the greater importance of tuna fisheries in the Caribbean and the deficient coverage of inshore fisheries for lobsters and reef species (Mohammed, 2003).

The gross efficiency of the fisheries (catch divided by net primary production) in northeastern Brazil (0.00002) was the lowest amongst the systems compiled in Table 4.3 and also lower than the weighted global average of 0.0002 (Christensen *et al.*, 2004). It is reasonable to assume that the low gross efficiency was related to the underexploitated state of most of the resources in the 1970s. The value of primary production required (PPR) for catches originating from northeastern Brazil was very low (1.3%) compared to the values estimated by Pauly and Christensen (1995) for global catches (8%), for tropical shelves (16.1-48.8%), and for the shelf models compiled in Table 4.3. Primary production required (primary production required to sustain catches·100/observed primary production) is seen as an indication of the ecological footprint of human activities and would imply that catches in northeastern Brazil were having a very low impact on the marine ecosystem. However, one has to consider that only landings were included in the model, not considering any discards. Additionally, landings recorded in very broad categories such as 'outros peixes', 'outras espécies', 'caíco', and 'mistura' (all representing other species) were not incorporated in the model. Finally, estimates of primary production estimate for mangroves from Wiedemeyer (1997) may be overestimated. Thus PPR, as calculated here, underestimates the overall impact of fisheries on this ecosystem.

The mean transfer efficiency between trophic levels of 11.4% was very close to the mean calculated by Pauly and Christensen (1995) over 48 trophic models (10%), with the highest value observed between trophic levels III and IV (16.6%). Pace *et al.* (1984) consider that trophic efficiency is highly variable and the use of a standard value of 10% may be misleading. Note that the values of transfer efficiency for the models presented in Table 4.3 oscillate between 6.6 and 17.6%, within the range indicated by Pauly and Christensen (1995), and in fact bracket their mean value of 10%.

All the comparisons of system statistics may be affected by the definition of the system and its functional groups, and by the origin of the input data. More insight would be gained if a model for the current time is built for the same system and the system statistics for both periods are compared. However, because of the scarcity of basic data for northeastern Brazil, both models (early and current period) may be based on the same data and systems statistics would not differ much (see, e.g., Araújo *et al.*, 2005, available online at www.cefas.co.uk/news.asp). The original setting of the 1970s model is limited as biomass estimates for most groups were not available due to the lack of biomass surveys for this region. Biomass was estimated by the model using ecotrophic efficiency from models of similar areas. Mortality rates for some groups were also borrowed from similar areas and may not reflect the actual fishing pressure occurring off northeastern Brazil.

Several papers dealing with the diet of species in northeastern Brazil present only the frequency of occurrence or numerical frequency of prey in the gut of their predators (Alves and Fernandes, 1973; Rodrigues, 1974; Vasconcelos Filho, 1979; Vasconcelos Filho *et al.*, 1984; Cunha and Furtado, 1985; Macedo Costa *et al.*, 1987; Vasconcelos Filho and

Cavalcanti, 1993). Gasalla and Soares (2001) reviewed the evolution of diet studies in Brazil and pointed out the 1990s as a benchmark in terms of the studies of trophic relationships in Brazilian ecosystems. However, these authors did not mention changes in the nature of the basic data of diet composition provided by these studies. For northeastern Brazil, for example, several past diet studies cannot be properly incorporated in food webs studies owing to the absence of proportion in weight (or volume) of prey items. Thus, results from other regions had to be considered instead. Moreover, there is the persistent problem of combining several species into one single functional group, a procedure that can mask important linkages in terms of predation or competition (Paine, 1988).

Even though these constraints limit the interpretation of the results presented here, the model is still able to capture some of the generalities of the system and some inconsistencies in the data. Thus, the biomass of 0.5 tonnes·km^{-2} estimated for southern red snapper (in the habitat area), based on the information available in Ivo (1982), seemed to be overestimated and was replaced by a value estimated by the EwE model (0.01 tonnes·km^{-2}). On the other hand, the biomass of phytoplankton calculated based on Medeiros *et al.* (1999) was probably underestimated and an estimate 30% higher was considered more realistic (12 tonnes·km^{-2}). Additionally, the model indicated a high sensitivity to the vulnerability of swordfish to sharks and of bathypelagic fishes and omnivorous reef fishes to swordfish. Thus, it is worth to invest more in understanding the dynamics of the swordfish stock in Brazilian waters, especially if we consider Brazil's position at ICCAT that its swordfish fishing quotas in the Atlantic should be increased (Evangelista *et al.*, 1998).

The model presented here was able to closely reproduce the biomass trends for all species for which times series were available. However, there are several other groups that did not show any changes in biomass levels during the simulated period. These trends have to be looked at with reservation as some reef species, e.g., have shown signs of overexploitation (*Lutjanus analis*, *L. jocu*, and *Ocyurus chrysurus*) or have been exploited at their maximum level (*Lutjanus vivanus* and *L. synagris*) (Lessa *et al.*, 2004). Another important issue to be addressed in future developments of the model is the effect of changes on the basis of this trophic web. Even though Creed (2003) indicates that there is little information about changes in seagrass biomass for South America (Brazil included), in the Abrolhos region (south of the studied area), a national marine park, 0.5% of seagrass area is lost per year due to anchor damage. A total of 40% of Brazilian seagrass beds are considered threatened (Creed, 2003). Another extraction not accounted for in catch statistics is the extraction of macroalgae. According to Oliveira (2000), macroalgae (*Gracilaria cornea*, *G. caudate*, and *Hypnea musciformis*) have been exploited since the 1960s along the area between Ceará and Paraíba States, with *Gracilaria* spp. showing signs of overexploitation.

Mangroves have also shown ominous symptoms, with their cover area shrinking from 25,000 km^2 in 1983 to 13,400 km^2 in 1997 (Valiela *et al.*, 2001). In northern Brazil, mangroves are extracted for house construction, fishing traps, and as firewood (Wolff *et al.*, 2000) and similar uses are likely to occur in northeastern Brazil (see, e.g., Botelho *et al.*, 2000). Additionally, mangroves are destroyed by the pollution caused by chemical and petro-chemical industries, infrastructure development, and agriculture (Diegues, 1996). These practices are likely to affect other benthic primary producers as well. More recently, there is some indication of the destruction of mangrove areas for the establishment of shrimp ponds (WRM, 2004), even though some consider that the 83% annual increase in shrimp production of northeastern Brazil complies with 'sustainability principles' and no conversion of mangrove areas is currently observed (Roubach *et al.*, 2002).

This chapter allowed for the description of the flows amongst trophic components in the marine ecosystem off northeastern Brazil and some of its general features. Indices generally used as indicators of maturity of ecosystems did not allow for conclusive answers about the maturity of the East Brazil Large Marine Ecosystem. On the other hand, results indicated that recycling is an important feature of this ecosystem, which is characterized by low phytoplankton-originated primary production supplemented by high production from coastal vegetation. There was some indication that omnivory in shelves (at least tropical shelves) may be lower than in other ecosystems. Some inconsistencies in isolated estimates of biomass were found, as well as gaps in basic information required to better understand this system, even for commercial species. Catch rates were low in comparison with other shelf systems in Brazil and along other tropical shelves in the western Atlantic, which serves many times as driving force for initiatives by the federal government towards policies aiming at increasing catches from Brazilian waters. The results presented here serve as basis for the exploration of future fishing policies for the marine ecosystem off northeastern Brazil within a multi-species and ecosystem approach.

4.5. Bibliography

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CHAPTER 5. Assessing fishing policies for northeastern Brazil

5.1. Introduction

There is a growing interest in ecosystem-based fisheries management (EBFM) in the last few years resulting from a better understanding of the incompatibility of getting maximum sustainable yield from a number of target stocks (a common management goal) that are trophically linked. There is also an increased concern with the effect of fisheries on the habitats and on non-target species, mainly those long-lived and with low reproductive rates such as cetaceans, seabirds, sea turtles, and sharks (see, e.g., Hall *et al.*, 2000). The importance of ecosystem considerations was recognized as early as the mid-1950s, even though a low priority was assigned to them (Schaefer, 1956). As an example, Holt (1978) advocated that moving from managing yellowfin tuna fisheries from maximum sustainable yield (MSY) to maximum economic yield (MEY) would benefit dolphins incidentally caught by purse seiners.

Although EBFM is not a new idea from the theoretical point of view, there is much to be learned about how to make it operational and ultimately how to measure its success. Link (2002b) suggests that one can expand on the few approaches already available in Fishery Management Plans that consider ecosystem effects of fishing in conjunction with the traditional single species approaches. The same author lists several issues to be ranked by priority in specific ecosystems as a starting point, which are related to the geography of the system, abiotic factors, key species, species interactions, aggregate and system level properties, and fisheries (Link, 2002a). The analysis of each of these issues requires the establishment of an open dialogue amongst all stakeholders involved in ecosystem-related activities in order to decide on goals, objectives, strategies, indicators of performance at the ecosystem level (both traditional and innovative), monitoring system, and feedback mechanisms.

High complexity of ecosystems often leads to responses to management measures that are not always foreseen in single species management plans. In attempts to protect stocks from the direct impact of fisheries, technical measures such as the use of nets with larger mesh sizes are one of the most traditional measures recommended since the establishment of fisheries science in the late 1800s. In a search for a better understanding of the trophic links between species in an ecosystem, it was found that larger meshes may decrease the impact on non-target species that act as competitors of target species, and thus have a deleterious effect on the latter. This is one of the reasons that led the Organization for Economic Co-operation and Development to consider this measure inefficient unless used in conjunction with another management measures (OECD, 1997). Along these lines, Walters and Kitchell (2001) postulated a phenomenon of 'cultivation/depensation': high fishing pressure leads to low population abundance; after a reduction in fishing effort, the population may be unable to recover due to the predation release of some prey of the target species that act as competitors (or predators) of juveniles of the target species. Testing for this effect is possible using multi-species models, and the results have profound policy implications.

Another current issue related to trophic relationships within ecosystems is the proposal of resuming whaling activities as a way of improving the state of fisheries worldwide. The rationale behind this proposal is the increasing consumption by marine mammals of species targeted by commercial fisheries as a result of increasing abundance of mammals. A cull has even been proposed for a few marine mammals that are perceived as important competitors of fisheries (Yodzis, 2001). Besides the ethics involved in culling, the effects of such measures in highly complex environments are not direct and guaranteed, as culling can result in increasing abundance of competitors or predators of other target species. Additionally, Kaschner and Pauly (2004) found that the trophic and spatial overlap between fisheries and mammal consumption is lower than usually assumed and restricted to specific areas. Thus, culling of marine mammals would have only minimal effects on global catches.

Fisheries are not only about 'fishes' and their competitors and/or predators. Fisheries are supposed to generate profit and employ people. With a growing world population, particularly in developing countries, and increasing demand for fish protein (Delgado *et al.*, 2003), there is a need to consider different ecological, economic, and social goals under a much higher pressure than earlier. One way this can be accommodated is through multi-objective functions that include these three dimensions of fisheries to identify an 'optimum' use of a natural resource (see, e.g., Healey, 1984).

Fisheries management schemes around the world have evolved to a very high degree of complexity in order to try to optimize gains obtained from fishing activities, which in most cases require a decrease in fishing capacity. Some developing countries such as Brazil are still striving to boost their fisheries through programs to increase fishing capacity. The Special Secretary of Aquaculture and Fisheries (SEAP) launched the 'Profrota Pesqueira' in 2004, a program aiming to increase and modernize the Brazilian fishing fleet (Anon., 2004). The objective of this program is to give incentives to build, buy, or adapt a total of 370 vessels for oceanic fisheries targeting tuna and tuna-like fishes, and to build another 150 medium and large vessels to catch laulao catfish (*Brachyplatystoma vaillanti*), southern red snapper (*Lutjanus purpureus*), and southern brown shrimp (*Farfantepenaeus subtilis*) off northern and northeastern Brazil. Simultaneously, the Brazilian government has put in place a national campaign to increase the *per capita* consumption of seafood in Brazil to above the current 7 $kg \cdot year^{-1}$. Both these programs require a heavy system of subsidies, which Brazil considers essential to the development of fisheries in developing countries. They should be therefore included in a 'green box' of allowed subsidies, as part of a special treatment by the World Trade Organization (WTO) towards developing countries aiming at the development of their fisheries (Anon., 2005).

In northeastern Brazil, fisheries targeting tunas and tuna-like fishes, lobsters, southern red snapper, shrimps, and demersal fishes are very important as a result of their bulk catch or the revenue generated by their exports. Many of the stocks in this region are considered overexploited. Lobster is one of the most valuable resources in northeastern Brazil due to its very high price in the international market. Catches are mainly exported to the US, where 21% of the spiny lobster commercialized originates from Brazil (Cascorbi, 2004). Swordfish, shrimps, and southern red snapper catches are also, at least partially, exported.

In this chapter, the effect of current fishing practices over these stocks will be analyzed in the light of the information available for each fishing sector. Also, the degree in which the current information allows for increasing fishing effort as proposed by national plans will be assessed.

Some scenarios for future fishing policies will be investigated, with emphasis on the lobster fishery for which long time series of catch and effort are available.

5.2. Material and Methods

The Ecopath model constructed in Chapter 4 for the marine ecosystem off northeastern Brazil was used as the basis for the simulations of fishing policies presented in this chapter. Some additional fisheries-related data were required and are presented in the following subsections. Temporal changes in biomass were assessed through the Ecosim module included in the Ecopath with Ecosim (EwE) software, version 5.1 (Walters *et al.*, 1997; Christensen *et al.*, 2004):

$$\frac{dB_i}{dt} = g_i \sum_{j}^{n} Q_{ji} - \sum_{j}^{n} Q_{ij} + I_i - (M0_i + F_i + e_i) \cdot B_i \qquad (1)$$

where: dB_i/dt = change in biomass of group *i*; g_i = net growth efficiency; Q_{ji} = consumption of group *j* by group *i*; *n* = number of functional groups; Q_{ij} = consumption of group *i* by group *j*; I_i = immigration of group *i*; $M0_i$ = non-predation natural mortality rate of group *i*; F_i = fishing mortality rate of group *i*; e_i = emigration of group *i*; and B_i = biomass of group *i*.

All simulations were performed for a fifty years period through changes in fishing effort for each fleet or fishing mortality for each exploited species (according to data availability) amongst the 41 groups included in the model (Table 5.1; see also Chapter 4). During the simulations, fishing effort and mortality were allowed to change only for the 2001-2028 period.

Table 5.1: Groups used in the simulations of fishing policies and their respective trophic level and biomass in the total area of the East Brazil Large Marine Ecosystem (After Chapter 4).

Group name	Trophic level	Biomass ($t \cdot km^{-2}$)
1. Manatee	2.02	0.000004
2. Baleen whales	3.72	0.385200
3. Toothed cetaceans	4.45	0.142700
4. Seabirds	3.45	0.015000
5. Sea turtles	3.15	0.163000
6. Tunas	4.31	0.035000
7. Other large pelagics	4.50	0.025700
8. Dolphinfish	4.58	0.000500
9. Dolphinfish juveniles	4.42	0.001280
10. Swordfish	4.56	0.009400
11. Sharks	4.65	0.032400
12. Rays	3.88	0.101300
13. Small pelagics	3.05	0.604500
14. Needlefishes	3.43	0.115000
15. Southern red snapper	4.21	0.014300
16. Large carnivorous reef fishes	4.01	0.233800
17. Small carnivorous reef fishes	3.68	0.972600
18. Herbivorous reef fishes	2.00	1.116400
19. Omnivorous reef fishes	3.33	1.140000
20. Demersal fishes	3.36	1.346800
21. Mullets	2.04	0.763100
22. Spotted goatfish	3.50	0.050500
23. Benthopelagic fishes	3.58	0.074600
24. Bathypelagic fishes	3.58	1.170600
25. Spiny lobsters	3.30	0.013800
26. Other lobsters	3.25	0.611100
27. Shrimps	2.73	3.900600
28. Crabs	2.61	1.507700
29. Squids	3.64	0.176700
30. Octopus	3.58	0.151000
31. Other molluscs	2.35	2.531000
32. Other crustaceans	2.17	1.590600
33. Other invertebrates	2.16	6.997900
34. Zooplankton	2.47	2.165600
35. Corals	2.83	0.063100
36. Microfauna	2.00	5.989000
37. Phytoplankton	1.00	12.085900
38. Macroalgae	1.00	98.405500
39. Mangroves	1.00	77.761600
40. Seagrasses	1.00	0.052000
41. Detritus	1.00	201.912800

5.2.1. Fleet definition and landing data

The fishing fleet operating in northeastern Brazil was divided into twelve groups: large pelagic artisanal, small pelagic artisanal, manual collection, demersal artisanal, longline, reef, lobster, demersal industrial, turtle, whaling toothed, whaling baleen, and snapper. This division was chosen to represent some of the basic dynamics of the fleet operating off northeastern Brazil under the limitation of data availability for several more specific fisheries. Landing data compiled in Chapter 3 were used here after being divided amongst the twelve fleet types based on the knowledge about the dynamics of each species and fleet/gear. As in Chapter 4, catches recorded by any broad category indicating 'other fishes' and originating from subsistence, recreational, ornamental, and research fisheries were not considered here.

5.2.2. Ex-vessel prices of 'fish' products

Ex-vessel prices of 'fish' products (at dockside) were obtained from SUDEPE (1980) (Table 5.2). No distinction was made for price of products originating from artisanal and industrial fisheries, as prices are estimated by the ratio of total value to total catch (after combining both fisheries) in the original sources. Non-market value was not considered in this analysis.

5.2.3. Fishing costs and profits

Fishing costs (fixed and variable) and profits were obtained from local studies for those fleets for which data were available. Thus, data for crab capture were considered as representative of manual collection fisheries (Glaser and Diele, 2004). For demersal artisanal and lobsters fisheries, data were obtained from Carvalho *et al.* (1996; 2000). No local data was found for the other fleet types. For large pelagic artisanal and industrial demersal fisheries, the

Table 5.2: Price[1] per kilogram of each group caught by each fleet[2] operating off northeastern Brazil in 1978[3].

Group name / Fleet	LPelArt	SPelArt	Manual	DemArt	Longline	Reef	Lobster	DemInd	Turtle	Whaling Toothed	Whaling Baleen	Snapper
Baleen whales	–	–	–	–	–	–	–	–	–	–	4.6	–
Toothed cetaceans	–	–	–	–	–	–	–	–	–	4.6	–	–
Sea turtles	–	–	–	–	–	–	–	–	10.8	–	–	–
Tunas	20.3	–	–	–	20.3	–	–	–	–	–	–	–
Other large pelagics	22.4	–	–	–	22.4	–	–	–	–	–	–	22.4
Dolphinfish	26.8	–	–	–	26.8	–	–	–	–	–	–	–
Swordfish	–	–	–	–	21.4	–	–	–	–	–	–	–
Sharks	10.9	–	–	–	10-.9	–	–	–	–	–	–	–
Rays	–	–	–	11.05	–	–	–	11.0	–	–	–	–
Small pelagics	–	12.7	–	–	12.7	–	–	–	–	–	–	–
Needlefishes	–	16.9	–	–	–	–	–	–	–	–	–	–
Southern red snapper	–	–	–	–	–	–	–	–	–	–	–	23.4
Large carnivorous reef fishes	–	–	–	–	–	21.6	–	–	–	–	–	21.6
Small carnivorous reef fishes	–	–	–	–	–	16.9	–	–	–	–	–	16.9
Herbivorous reef fishes	–	–	–	–	–	19.9	–	–	–	–	–	–
Omnivorous reef fishes	–	–	–	–	–	17.9	–	–	–	–	–	17.9
Demersal fishes	–	–	–	16.1	–	–	–	16.1	–	–	–	16.1
Mullets	–	–	–	24.8	–	–	–	–	–	–	–	–
Spotted goatfish	–	–	–	–	–	22.4	–	–	–	–	–	–
Benthopelagic fishes	14.2	–	–	–	14.2	–	–	–	–	–	–	–
Spiny lobsters	–	–	–	–	–	–	116.4	–	–	–	–	–
Shrimps	–	–	–	25.0	–	–	–	25.0	–	–	–	–
Crabs	–	–	11.7	–	–	–	–	–	–	–	–	–
Octopus	–	–	25.9	–	–	–	–	–	–	–	–	–
Other molluscs	–	–	29.3	–	–	–	–	–	–	–	–	–
Other crustaceans	–	–	–	35.0	–	–	–	–	–	–	–	–

1. Price in cruzeiros (Cr$), the Brazilian currency in 1978 (US$ 1 = Cr$ 17.98 in 1978; www.bcb.gov.br); 2. In this thesis, for convenience, the names of the fleets are derived either from their size ("small scale pelagic artisanal"), their gear ("longline") or their target organisms ("lobsters"); and 3. Dashes indicate no catch. Source: SUDEPE (1980).

information available in Arreguín-Sanchéz (2002) was used as an indication of potential costs and benefits for these fleets. For small pelagic artisanal fisheries, estimates provided by Trinidad *et al.* (1993) were used. Pedrosa and Carvalho (2000) analyzed the cost of longline fisheries harbored in Rio Grande do Norte State. However, it was not possible to incorporate their results in this model due to the lack of a revenue value for comparison. Similarly, results from Mattos and Hazin (1997) for shark longline could not be used due to limitations imposed by the use of research vessels (as also pointed out by these authors). Costs and benefits from longline fisheries were then obtained for a combination of foreign fisheries targeting tuna and swordfish (O'Malley and Pooley, 2003).

Burke and Maidens (2004) provide an estimate of cost of reef fisheries in relation to gross revenue, but do not mention the relation between variable and fixed costs; this partition was based in Arreguín-Sánchez (2002). For turtle fisheries, the estimate for crab fisheries was used considering that individuals are collected by the beach, when laying eggs during the reproduction season, and are sold or consumed locally. Even though southern red snapper is considered an important target of fisheries in northeastern Brazil, no local data on the economics of this fishery was found. It was assumed that the breakdown of costs and benefits are similar to the lobster fisheries, as both fisheries target the external market (export), use traps (although not exclusively), and the stocks are considered overexploited.

Finally, for whaling activities, data from Conrad and Bjorndal (1993) were used, complemented with information on number of whaling vessels available in Statistics Norway (2005), correcting costs for the time spent in whaling activities in opposition to other fishing activities (38-41%). However, these authors did not provide any ratio between fixed and variable costs and thus, an average value of the fixed cost for all industrial fleets (longline, demersal, and lobster) was used. Details of the breakdown of fishing costs and profits are presented in Table 5.3.

Table 5.3: Cost of each fishing fleet operating off northeastern Brazil for the simulation performed based on the 1970s Ecopath model.

Fleet	Abbreviation	Fixed cost (%)	Variable cost (%)	Profit (%)
1. Large pelagic artisanal	LPelArt	2.0	33.0	65.0
2. Small pelagic artisanal	SPelArt	0.6	80.0	19.4
3. Manual collection	Manual	0.0	32.9	67.2
4. Demersal artisanal	DemArt	8.3	75.0	16.7
5. Longline	Longline	18.6	73.0	8.4
6. Reef	Reef	2.9	47.1	50.0
7. Lobster	Lobster	7.3	92.5	0.2
8. Demersal industrial	DemInd	4.5	45.5	50.0
9. Turtle	Turtle	0.0	32.9	67.2
10. Whaling toothed	Toothed	10.0	70.0	20.0
11. Whaling baleen	Baleen	10.0	70.0	20.0
12. Snapper	Snapper	7.3	92.5	0.2

5.2.4. Optimum fishing policy search

The first simulation was run considering the maintenance of the 2000 level of fishing effort or mortality for all exploited fishing groups. Secondly, an optimum fishing policy for all fleets operating off northeastern Brazil was assessed based on economic, social, and ecological criteria using the 'fishing policy search' routine available in Ecosim. The optimum policy search was based on a non-linear search procedure for maximizing the following multi-criterion function:

(2) $$Max_{output} = w_1 \sum_{i=1}^{k} \sum_{j=1}^{l} NPV_{ij} + w_2 \sum_{j=1}^{l} NJ_j + w_3 \sum_{i=1}^{k} B_i \times \left(\frac{P}{B} \right)_i^{-1}$$

where NPV_{ij} = net present value of the catches of functional group i by fleet j; l = number of fleets = 12; k = number of exploited groups = 26; NJ_j = number of jobs generated by unit of monetary value of catches; B_i = biomass; $(P/B)_i$ = production over biomass ratio, obtained from the basic input of Ecopath; and w_1, w_2 and w_3 are weights (see below). A nonlinear optimization method known as Fletch was used in this search (Fletcher, 1970). Changes in fishing effort and mortality were applied to the levels observed in 2001 and onwards for all fleets used in the model, except for turtle fisheries and whaling (toothed and baleen), as they were banned during the 1980s.

The economic criterion was assessed through the net present value (NPV) of the resources exploited in the future, partially based on the opportunity cost of the capital. NPV was calculated as follows:

$$NPV = \sum_{t=o}^{T} V_t W_t$$

where: T = simulation period (2000-2028); V_t = net benefit in year t = gross revenue minus cost; W_t = weight used to discount the benefit (V_t) = d^t; d = 1/(1+r); and r = conventional discount rate. In order to consider future generations, an intergenerational discount factor (d_{fg}) was added to the simulations, through changes in the weight W_t (Sumaila and Walters, 2005):

$$W_t = d^t + \frac{d_{fg} d^{t-1} t}{G}$$

where d_{fg} = intergenerational discount factor in year t and is equal to $1/(1+r_{fg})$; r_{fg} = intergenerational discount rate and it was assumed equal to r; and G = generation time (assumed equal to 20 years). Discount rates (r and r_{fg}) of 10% were used as Sathaye *et al.* (cited in Van Vliet *et al.*, 2003) considers that 8-12% is the usual rate for developing countries.

Gross revenue was calculated as the product between catch and price per kilogram for each functional group. Catch was obtained for 1978 as shown in section 5.2.1 and price was obtained from SUDEPE (1980) (Table 5.2).

The social criterion was defined through the number of jobs provided per catch value for each fleet. The estimated number of jobs provided by fishery type in northeastern Brazil is presented in Table 5.4.

Table 5.4: Estimated number of jobs provided by each fishery type in northeastern Brazil.

Fishery	No. jobs per R$10,000 of catch*	Sources
1. Large pelagic artisanal	1.9	CEPENE (2000a), Database in Chapter 2
2. Small pelagic artisanal	7.6	CEPENE (2000a), Database in Chapter 2
3. Manual collection	7.1	Costa-Neto and Lima (2000), Alves and Nishida (2003)
4. Demersal artisanal	0.8	CEPENE (2000a), CEPENE (2000b)
5. Longline	0.1	Evangelista *et al.* (1998), Database in Chapter 2
6. Reef	1.4	CEPENE (2000a), Database in Chapter 2
7. Lobster	3.2	Castro e Silva *et al.* (2003), CEPENE (2000a)
8. Demersal industrial	7.4	CEPENE (2000a), CEPENE (2000b)
9. Turtle	3.4	Based on manual collection, considering the price/kg for turtle
10. Whaling toothed	2.1	SUDEPE (1979), Singarajah (1985), Rabay (1985)
11. Whaling baleen	0.4	SUDEPE (1979), Singarajah (1985), Rabay (1985)
12. Snapper	0.6	Based on lobsters, considering the price/kg for snapper

* In 'reais' = Brazilian currency from 1994 on; US$ 1 = R$ 2.47 (May 2005).

The ecological criterion intended to maximize the biomass of long-lived animals, i.e., the biomass of each functional group was weighted by the inverse of its production/biomass ratio. The rationale behind this approach is that the presence of long-lived organisms with low P/B ratios is associated with the maturity of an ecosystem (Christensen *et al.*, 2004).

The partial effect of each criterion was assessed through four scenarios depending on the management objectives assumed for the study area:

(a) Economic: maximization of the economic rent (net benefit = revenue-cost); w_1 was set to 1; w_2 and w_3 were set to zero;

(b) Social: maximization of number of jobs; w_2 was set to 1; w_1 and w_3 were set to zero;

(c) Ecological: maximization of ecological benefits; w_3 was set to 1; w_1 and w_2 were set to zero.

(d) Compromise: in this scenario, all three components (economic, social, and ecological) were considered equally important and w_1, w_2, and w_3 were set to 1.

(e) Mandated rebuilding: in this scenario, w_1 and w_2 were equal to 1; w_3 was set to 5 and the model was forced towards a policy aiming to increase the biomass of sharks. The mandated relative biomass of sharks was set to 1, indicating that the biomass of this group should maintain the value estimated for the year of the base model (1978).

5.2.5. Lobster fishery and future fishing policies

A simulation was run in Ecosim for 50 years (1978-2028) in order to analyze the effect of changes in the effort employed by lobster fisheries in relation to the 2000 effort level under four scenarios: (a) same constant effort level as observed in 2000 (*status quo*); (b) decrease of 50% in effort over the first year and constant thereafter (1/2 effort); (c) ban of lobster fisheries; (d) recovery plan (to the 1978 biomass level). For all other fleets, effort was considered constant at 2000 levels for the period 2000-2028.

5.3. Results

The simulation of the performance of the main functional groups in the marine ecosystem off northeastern Brazil under the current fishing regime indicates that spiny lobsters will be extirpated from the system in a short time (Fig. 5.1). Biomass of swordfish would also decrease to unsustainable levels in a short time. Groups such as sharks and other large pelagics will continue to decline slightly with their biomass stabilizing at 81% and 69% of the 1978 level, respectively. Decreasing biomass of sharks may lead to a slight increase in tunas' biomass due to the decreasing predation pressure. An increase in biomass would be expected for baleen whales. Southern red snapper biomass would stabilize at the 2000 level.

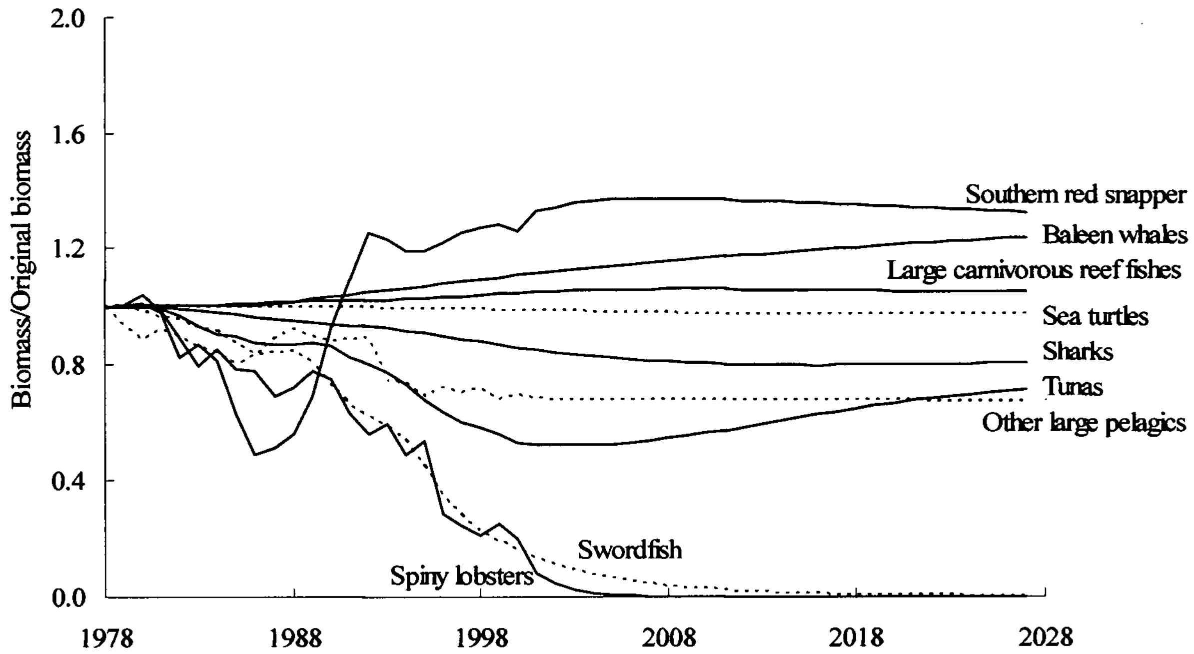

Figure 5.1: Biomass of functional groups that showed variation in relation to the original biomass (1978) for northeastern Brazil during the simulations for 50 years. Fishing rates for 2000-2028 were set at levels observed in 2000.

The simulations for the optimum configuration of the fleet of northeastern Brazil as a whole indicated that very similar configurations would result when trying to maximize rent, number of jobs, and the compromise (rent, jobs, and biomass of less productive groups, all equally weighted). In all three cases, the effort of manual collection for crabs and other molluscs could be increased to more than 100 times the current level (Fig. 5.2). The effort of demersal industrial fisheries could also be largely increased, although to an extent less than the effort of manual collectors. One important difference amongst these three scenarios is that small pelagic artisanal fisheries are recommended to increase in order to produce jobs under the social and compromise scenarios, but not from the economic point of view. In terms of maximizing number of jobs per catch value and profit, fisheries such as lobsters and reef fisheries would have to be shut down. In order to maximize the ecological structure of the system, five fisheries could maintain their current fishing pressure: small pelagic artisanal, manual collection, artisanal and industrial demersal, and reef fisheries (Fig. 5.2). Longline and lobster fisheries would have to be practically shut down. On the other hand, large pelagic artisanal and snapper fisheries could increase the fishing pressure to 6 and 2 times the 2000 level, respectively.

The recommended configuration of the fleet would result in changes in biomass very similar amongst the four scenarios. Particularly, one can note that the biomass of swordfish, tunas, and spiny lobsters would increase in all scenarios, with higher rates in the ecological scenario (Fig. 5.3). Most of the remaining groups would have their biomass constant during the simulated period or slightly decreased. Note that lesser groups in the ecological scenario reach lower biomass than in 2000.

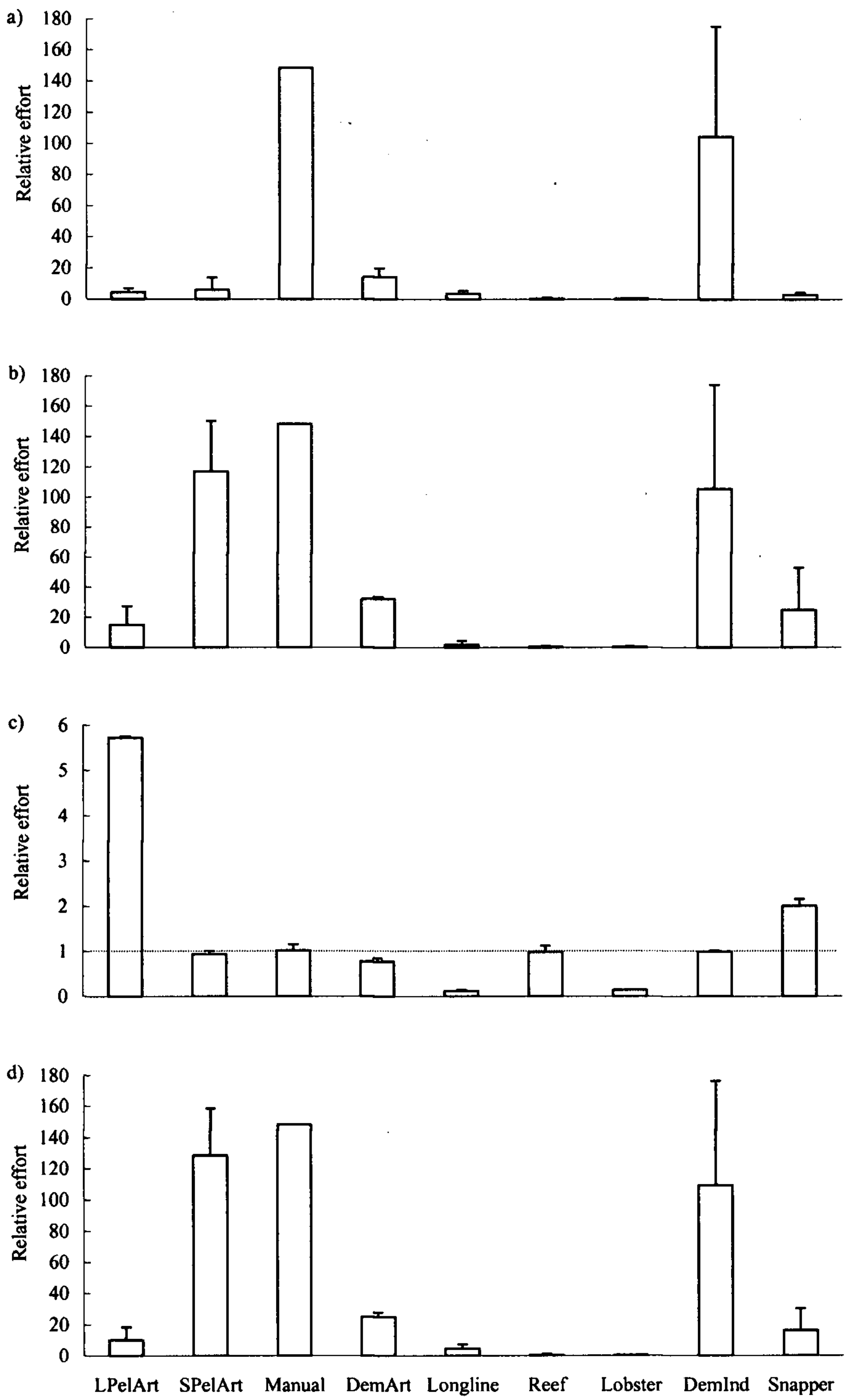

Figure 5.2: Relative changes in fishing effort (f_{2028}/f_{2000})for each fleet included in the 1978 model for northeastern Brazil after a simulation from 2000 to 2028 under four scenarios: a) economic, b) social, c) ecological, and d) compromise (n_{runs} = 10). Columns represent means and whiskers are means plus one standard deviation. Note the different scale used in the vertical axis for the ecological scenario (c). The horizontal dotted line in (c) indicates the 2000 effort level (not shown for the other scenarios).

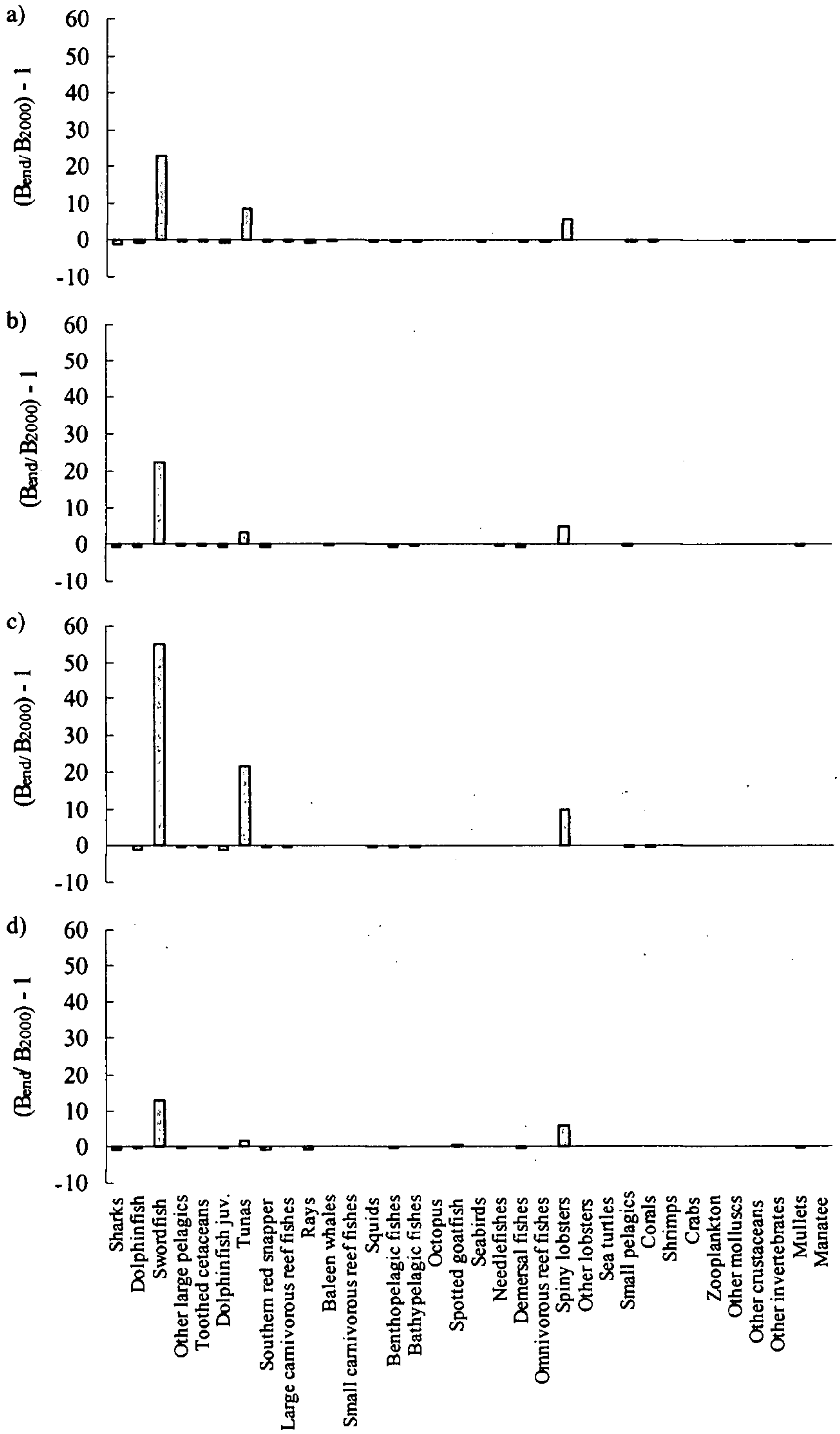

Figure 5.3: Mean relative change ($B_{end}/B_{2000} - 1$) in biomass for all functional groups (trophic level > 2; arranged in decreasing order) obtained by simulations for the period 2000-2028 under four optimization scenarios: a) economic, b) social, c) ecological, and d) compromise (n_{runs} = 10). Compromise indicates that an equal weight was given to the components a-c.

All scenarios discussed seem to be somewhat masked by the interaction between sharks and swordfish/tunas. In order to increase the biomass of tunas and swordfish (two groups with a high trophic level and high market value), sharks (which prey on tunas and swordfish) had to be fished out. As this is an unacceptable scenario due to Brazil's commitments towards the International Plan of Action for Sharks, a fifth scenario was run where a recovery of shark biomass was aimed for. The results of this scenario, which considers economic, social, and mandated rebuilding as equally important and attributes a higher weight in the multi-criterion function to the ecological component, are similar to the compromise scenario. However, fishing effort of large pelagic artisanal and longline fisheries should be decreased even further in order to protect sharks (Fig. 5.4). Lobster fisheries are expected to be turned off as well due to its low profitability. As in most of the other scenarios, manual collection effort could be increased in order to maximize profitability and number of jobs generated by this fishing sector.

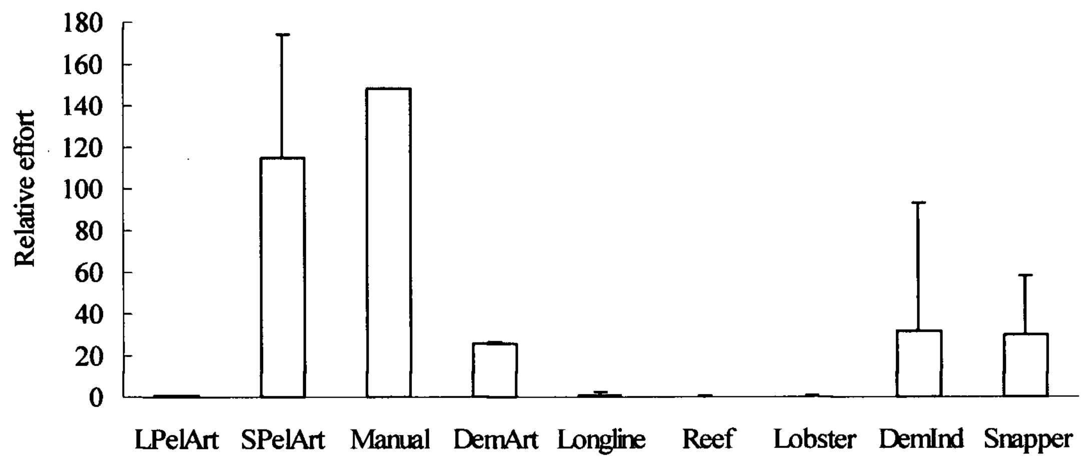

Figure 5.4: Relative changes in fishing effort (f_{2028}/f_{2000})in relation to 2000 for each fleet included in the 1978 model for northeastern Brazil after a simulation for 2001-2028 under the mandated rebuilding scenario aiming at the recovery of shark populations (n_{runs} = 10). Columns represent means and whiskers are means plus one standard deviation.

In terms of biomass, the mandated rebuilding scenario would lead to an increase of 21% in the biomass of sharks (Fig. 5.5). On the other hand, it would be expected a decrease of 52% in the biomass of tunas, 62% for southern red snapper, 38% for demersal fishes, 20% for small pelagics, and 29% for mullets. Swordfish would benefit from such a fleet configuration, probably due to a combination of the release from the competition imposed by tunas and from the fishing pressure by longliners. A strong increase in biomass of lobsters also resulted from this configuration due to the closure of non-profitable lobster fisheries.

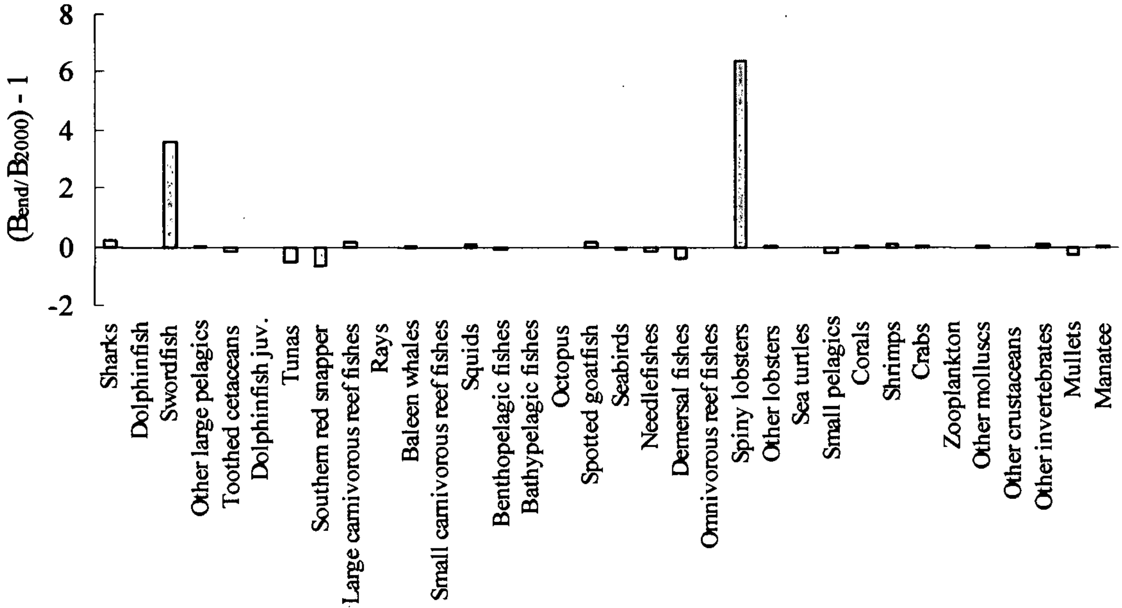

Figure 5.5: Mean relative change in biomass for all functional groups with trophic level (TL) equals or higher than 2 (arranged in decreasing order), obtained by the simulation for 2001-2028 under the mandated rebuilding scenario (n_{runs} = 10). This scenario aims to recover shark biomass to the 1978 level and considers an equal weight for the economic, social, and mandated rebuilding component (1). A weight of 5 was attributed to the ecological component.

A closer look at lobster fisheries indicates that a reduction of 50% in effort would avoid the looming collapse of the spiny lobsters' stocks and would lead to a slight increase in biomass (Fig. 5.6). These stocks would reach the same level of biomass as observed in 1978 only if the fishing effort were reduced to the 1978 level. A complete ban of lobster fisheries would result in a biomass 22% higher than the recovery scenario (Fig. 5.6 and Table 5.5). The more realistic recovery plan would lead to a very high gain in biomass (more than 9 times higher than the 2000 level) and to gains in catch (92%).

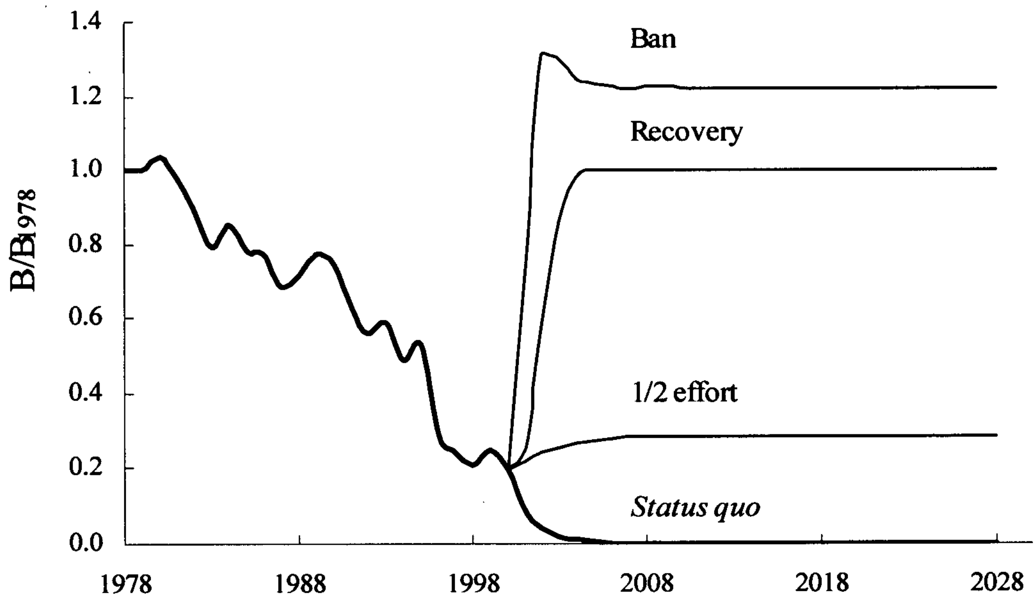

Figure 5.6: Changes is biomass of spiny lobsters in relation to the 1978 baseline after four policy strategies: maintenance of current fishing effort (*status quo*); reduction of effort to 50% of the 2000 effort level (1/2 effort); effort required to reach the 1978 biomass level (recovery); and banning of lobster fisheries (ban).

Table 5.5: Changes in biomass and catch for spiny lobsters caught by lobster fisheries in northeastern Brazil estimated in relation to 1978 and 2000 baselines ($Year_{start}$) resulting from changes in effort representing four scenarios (*status quo*, decreasing fishing pressure by 50% in relation to 2000 level, recovery of biomass to the 1978 level, and ban of lobster fisheries).

	$Year_{start}$	$Year_{end}$	Biomass	Catch	Effort
Observed	1978	2000	0.10	0.47	4.80
Status quo	1978	2028	0.00	0.00	4.80
< 50% effort	1978	2028	0.41	1.01	2.40
Recovery	1978	2028	1.00	0.96	0.96
Ban	1978	2028	1.22	0.00	0.00
Status quo	2000	2028	0.00	0.00	1.00
< 50% effort	2000	2028	3.99	2.01	0.50
Recovery	2000	2028	9.66	1.92	0.20
Ban	2000	2028	11.83	0.00	0.00

5.4. Discussion

The results of the simulations presented here indicate that the current levels of fishing pressure would lead to even further decline and eventual collapse of important local stocks such as lobsters and swordfish. As these stocks are mainly caught to supply international markets, these collapses would represent an important loss in terms of acquisition of foreign currency through exports. For other target groups such as sharks, and other large pelagics, biomass would continue declining slightly for the first years and would stabilize after that.

Avoiding the collapse of main fisheries requires that some decisions are made about the perceived 'value' of different components of an ecosystem and the benefits expected from its natural resources. As simulated here using a defined set of values (reflected in the weights used in the multi-criterion function), the ecological scenario resulted in a more diverse fleet configuration in relation to the other scenarios. Curiously, an increase in fishing effort of the artisanal large pelagic fishery is recommended in this scenario. This probably results from the high catches of sharks by this fishery in relation to the industrial sector (longliners). Sharks prey on groups that have a high B/P ratio, which served as a criterion to define the ecological structure of the system. Thus, the increasing effort for the artisanal pelagic fishery represents an attempt to decrease the biomass of sharks to obtain higher biomass of such groups. However, this scenario is not realistic as the low proportion of sharks recorded by longliners results from an artifact due to the non-inclusion of shark discards resulting from finning practices (Lessa *et al.*, 2004). Some effort should be put into determining the magnitude of these discards or hope for their complete ban after international initiatives such as the recent position of the International Commission for the Conservation of Atlantic Tuna (ICCAT) favorable to ban finning practices (Ocean Conservancy, 2004).

The compromise scenario suggested a fleet configuration equal to the social scenario and very close to the economic scenario. This reveals the importance of the way the multi-criterion function is defined and the weights attributed to each component included in the function. Zetina-Rejón *et al.* (2004) and others had already mentioned the similarity of the economic and social scenarios when fisheries that result in higher rent are the same that produce more jobs, in this case, manual collection fisheries targeting crabs and molluscs. Promoting manual collection does not seem plausible in terms of fishing policy, due to its essential subsistence feature, but these results indicate that there is potential for growth from a social and economic perspective. However, the biological limits of the target stocks have to be respected and are likely to be affected by pollution in coastal areas caused by urban and industry development and by destruction of mangrove areas (Leão and Dominguez, 2000; Marques *et al.*, 2004).

Additionally, the introduction of a new gear for collecting crabs ('redinha') has resulted in a three-fold increase in catchability, raising concern for the eventual overexploitation of these resources (Ivo and Vasconcelos, 2000).

One factor that affects the simulation of future economic gains of alternative fishing policies is the discount rate. A rate of 10% was used in the simulations run in this chapter, which reflects the high discount of future benefits in developing countries. The use of high values usually leads to the degradation of natural resources (Field and Olewiler, 2002). This opinion is shared by Costanza *et al.* (1997), who indicate that rates higher than 5% result in unsustainable practices. In fact, some simulations for the extraction of wild palmito in Brazil compiled by Orlande *et al.* (1996) indicated that rates in excess of 8% favored total extraction. All scenarios simulated here, but the ecological one, did suggest a very high increase in the most profitable fisheries. It is recommended that the effect of lower and higher discount rates be assessed in determining the trade-offs amongst different fishing sectors in northeastern Brazil.

All simulations presented here assumed no change to the ban of manatee, turtles, and whales fisheries, but did not explicitly consider the non-market value of these groups. This value was partially recognized through the use of the inverse of the P/B ratio in the definition of the desired ecosystem structure in the ecological and compromise scenarios. In the mandated rebuilding scenario, this value was set up even higher by the use of a weight of 5 for the ecological component (and 1 for all others). Ultimately, the decision on the relative weight of each component included in the multi-criterion function is to be reached through an agreement amongst all stakeholders involved in a direct or indirect way with the allocation of natural resources (Healey, 1984), within a framework of integrated coastal management that up to now has been considered deficient in northeastern Brazil and, in fact, in the whole country (Marques *et al.*, 2004).

The results generated by the simulations indicate that the biomass of several groups would be at lower levels by 2028 than in the 1970s, if current fishing pressure is maintained. Some of them would even collapse in a short time. The bulk of the increase in the fishing fleet proposed by the Brazilian government is directed towards increasing the fleet targeting tuna and tuna-like fishes. The model used as the basis for the simulations run in this chapter are not able to correctly duplicate the dynamics of these groups due to their highly migratory behavior. Thus, much of the response of the stock biomass to the fishing pressure within the East Brazil Large Marine Ecosystem (off northeastern Brazil) will depend on the fishing effort applied along the whole distribution area of the respective stocks. If the increase in the oceanic fleet size is coupled with negotiations of Brazil within ICCAT to increase its quotas, the scenario would be more positive as the total effort exerted over the stock is not expected to increase. If not, further decline of these stocks, beyond the documented by Myers and Worm (2003) and by ICCAT (2004b; 2004a; 2005), is expected.

For snappers and shrimps, the incompleteness of information evidenced through this simulation exercise indicates that increases in effort proposed by the 'Profrota Pesqueira' program have not been a result of a complete analysis of these fisheries. No cost-benefit analysis was found for snapper fisheries and the times series of catch and effort are not complete enough to allow for an analysis of CPUE trends (even with all its limitations). Additionally, the interchangeability between vessels targeting snappers and lobsters may pose additional fishing pressure on lobster stocks. The number of licenses allowed for shrimp trawlers in northern Brazil (for which catch and effort data are available) decreased from 250 to 185 in 1997 [Negreiros-Aragão and Silva, 2000]. The proposal to build new vessels for this fishery counteracts previous attempts to control fishing effort; old vessels may remain in this sector or be re-directed to other fisheries increasing the fishing pressure. Detailed information about the status of shrimp stocks in northeastern Brazil are lacking.

The lobster fishery is one of the most well studied fisheries in Brazil. In 2004, lobster exports yielded US$ 75 million, indicating the importance of this fishery for the local economy. The simulations indicated that this stock is expected to collapse within a few years if current fishing pressure is maintained. The biomass level of spiny lobsters would recover to the level observed in 1978 only if there were a significant decrease in fishing effort to the 1978 level. The resulting fishing effort is equivalent to the effort that would produce the maximum sustainable yield of 8,962 tonnes of spiny lobsters (Ivo and Pereira, 1996), a value well above the 6,500 tonnes officially recorded for 2000 (according to the database compiled in Chapter 3). Fishing effort in 2000 was 3.7 times higher than the 1978 level and 37.4 times higher than in 1965 when the first data were collected for lobster fisheries, indicating a strong decline in catch rates. This decline was the main reason that led to the rejection of the application of the lobster fishery in Prainha do Canto Verde (Ceará State) for certification by the Marine Stewardship Council (Chaffee, 2001; Schärer, 2001).

One factor not captured in these simulations was the dynamics of industrial and artisanal lobster fisheries due to the absence of effort data for each component. Castro e Silva *et al.* (2003) comment on the transference of boat ownership from large companies targeting lobsters to artisanal fishers, through special arrangements. Indeed the database presented in Chapter 3 was able to capture this transference through a change in the bulk of catches originating with industrial fisheries up to 1995 and with artisanal fisheries since then. It is also well known that effort was displaced to the coast of other States where the lobster fishery was not fully developed (IBAMA, 1994), and this could mask even more severe local depletions.

The analysis of the dynamics of lobster fisheries as presented here is also limited due to inclusion of one single fleet called 'lobster fisheries'. However, this sector is far from homogeneous as three basic gears are used in northeastern Brazil: traps, diving, and gillnets ('caçoeira'), each one with its own dynamics. Traps were introduced since the establishment of this fishery as an industrial activity in the late 1950s and the latter two were introduced in the 1970s after the decline in the CPUE obtained by lobster traps. Traps maintained legal status since its introduction, but gillnets and diving oscillated between the legal and illegal status in the last decade or so. Gillnets are responsible for the destruction of the substrate and in some cases led to the removal of up to 200 kg of substrate/net-day in Ceará State (Paiva *et al.* 1973, cited in Ivo and Pereira, 1996). Removal of substrate was also documented in Rio Grande do Norte State: 2.2 kg/100 m net-day (Vasconcelos and Lins-Oliveira, 1996). In relation to the size caught, Ivo and Ribeiro Neto (1996) did not find any statistical difference between the mean size of lobsters caught by gillnets and traps in Ceará State. In early 2005, a movement towards banning the use of gillnets had apparently succeeded after three years of negotiations. However, this regulation was withdrawn some days later due to the pressure of the industrial sector (www.ibama.gov.br; René Schärer, pers. comm., Instituto Terramar, Fortaleza, Brazil).

Diving is responsible for the capture of immature lobsters when practiced in waters shallower than 20 m (Lins-Oliveira *et al.*, 1997). In addition to the negative impact on the biological component of this fishery, there is a strong social component of this fishery that has to be considered: number of deaths and disability caused by physiologically inappropriate diving profiles. It is estimated that 90% of all lobster divers in Rio Grande do Norte State have suffered at least one diving accident (Procuradoria Regional do Trabalho - RN, 2005). Considering that lobsters have a market price about 3.3 higher than the second most valuable seafood resource, and as such are considered 'sea gold', the gains with diving activities are perceived as higher than the losses, and are worth the risk. This perception is emphasized by higher rents obtained by divers (and gillnets) in relation to trap fisheries (Carvalho *et al.*, 1996). The diving sector of lobster fisheries poses an additional challenge in terms of maximizing the objective function. Although this sector produces higher rent than the trap fisheries, and generates high number of jobs, there is a high risk associated with this activity that is not accounted for in the Ecosim simulations. A penalization system for such risky fisheries would allow simulations to become more realistic, as was done for the New England herring fishery (Healey, 1984).

Thus, future developments of this model require the incorporation of the three gear types involved in lobster fisheries. This was not possible in this version of the model due to the lack of effort data for gillnet and diving sectors. Additionally, the recording system of Brazilian fisheries precluded the split of total lobsters catches amongst these three gear types. The incorporation of the dynamics of each lobster fishery will be a hard task due to the illegal nature of diving activities in northeastern Brazil since 1978 (Vasconcelos and Lins-Oliveira, 1996). The analysis of trade-offs for lobster fisheries in relation to another fisheries occurring in this region also requires a better understanding of relative importance of artisanal and industrial lobster fisheries. Finally, the spatial dynamics of the fleet should be incorporated, possibly through the use of Ecospace, a module available in EwE that allows for spatial simulation (Walters *et al.*, 1999).

All the simulations presented here inherited the high degree of uncertainty associated with the input data used in the Ecopath model built in the previous chapter. This uncertainty, associated with the lack of information on the social and economic aspects for most of the local fisheries, leads to a high degree of uncertainty in the results of the simulations. The scenarios simulated in this chapter did not consider differences in ex-vessel prices between artisanal and industrial fisheries, as national fisheries statistics only provide combined prices. Additionally, the results are valid only for a scenario of constant price for each fished group. Negreiros Aragão (2005) points out that the price for Brazilian spiny lobsters, e.g., has increased in the last years. This increase in price can precipitate the collapse of this stock due to the attraction of additional fishing effort.

The underestimation of catches, as discussed in the previous two chapters, also leads to somewhat unrealistic scenarios. For example, dolphinfish catches are much higher than officially recorded; a sampling program run in northeastern Brazil was able to sample much more dolphinfish than was recorded in statistical bulletins (Rosângela Lessa, pers. comm., Universidade Federal Rural de Pernambuco, Recife/Brazil). Shrimps are mainly exploited by artisanal fishers (84% on average, according to the database compiled in Chapter 3) and the statistics collection system may be failing to cover it all. The same problem is expected for crabs and other molluscs, which are mainly caught by artisanal fishers in remote areas. Finally, the non-inclusion of by-catch discards in this preliminary version of the model contributes to low exploitation rates. Discarding of by-catch is common practice in northeastern Brazil, but not usually quantified. Ivo (1996) points out that 47 fish and 9 crustacean species are caught as by-catch in lobster fisheries, and most of them (if not all) are discarded. In some States, the ratio of fish by-catch to shrimp catches in trawling fisheries reaches 5:1, with 50% of the by-catch being discarded (CEPENE, 2000b). In others States, discards from the industrial shrimp fleet include shrimp species caught by artisanal shrimp fisheries, a factor not considered by the model as presently defined.

The simulations presented here will also probably benefit from splitting tuna and swordfish groups into juveniles and adults, with predation by sharks heavily concentrated on juveniles. Fishing pressure on these groups would be somewhat shared by juveniles and adults: for swordfish, slightly higher proportion of juveniles is caught by longliners in this area (Lessa *et al.*, 2004); for yellowfin tuna the composition is reversed, with slightly higher proportion of adults in the catches (Lessa and Duarte-Neto, 2004); for the other two tuna species (bigeye and albacore), no local data was found. Another change recommended is to split the sharks group into two: coastal and pelagic. This would avoid the existence of a 'super shark' group that prey upon both the pelagic and demersal components of the system and thus has an impact on the system higher than expected. This task will be possible only if some effort is spent towards obtaining more detail in the identification of sharks' landings. Fisheries statistics in Brazil record 80-100% of sharks' landings (about 18,000 tonnes for 1978-2000, based on the database compiled in Chapter 3) as 'cação' or 'caçonete' (unidentified sharks).

Even though Ecosim has showed its usefulness for the exploration of fishing policies in other areas (Christensen and Walters, 2004), its application to areas such as northeastern Brazil will depend on more effort to improve the basic trophic model of the region and the collection of basic social and economic data for many of its fisheries. This is not a challenge for an ecosystem-based fisheries management approach only, but reveals the weakness of the current single-species based fisheries management and that many fishery-related decisions are rather based on guesses and on the belief that the large extension of the Brazilian marine waters would always support a production higher than what is biologically feasible.

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CHAPTER 6. Concluding remarks

The successive collapses of fisheries worldwide have led to a re-assessment of past and current practices of fisheries management and to a search for new directions. Collapses have been observed in areas where very detailed information is available, as well as in areas with limited data. These collapses have important ecological, economic, social, and cultural implications. Normally they imply a displacement of fishing effort from traditionally exploited species to previously unexploited resources and/or to new fishing grounds. However, with a continuous history of successive depletions and with few unfished places to go, managers are facing the hard task of deciding whether to continue with current exploitation levels, to preserve remaining stocks or, in some cases, to attempt to recover some of these stocks and ecosystem functions lost to intensive exploitation. Some developed countries have a social system in place that allows for provision of some benefits (e.g., unemployment insurance) to those depending on fisheries in case of resource collapse. Conversely, many (if not all) developing countries lack such a system and a more precautionary approach should be in place.

Brazil faced a severe decline of sardine stocks in the southeastern region in the early 1990s, and has also seen some of its main stocks in the northeastern region decline. This thesis aims to contribute to the management of marine fisheries resources off northeastern Brazil, a region that has been much less studied, and which is characterized by a large number of people depending on this activity to make a living through subsistence and artisanal fisheries: 47% of all fishers officially recorded in Brazil in 2004 (According to the Special Secretary of

Aquaculture and Fisheries: www.planalto.gov.br/seap/). The overall goal of this study was to evaluate the fishing impacts on the East Brazil Large Marine Ecosystem. In order to reach this goal, the following specific objectives were pursued: (a) identification of the richness of common names of Brazilian fishes and its effect on fishery statistics; (b) analysis of catches originating from Brazilian marine fisheries and assessment of their use as an indicator of ecosystem health; (c) description of the biomass and energy fluxes for the functional groups occurring in the East Brazil Large Marine Ecosystem, encompassing northeastern Brazil; and (d) assessment of the impact of current fishing policies and some alternatives.

Chapter 1 presented an overview of the state of world fisheries, of major fisheries in northeastern Brazil, and of the evolution of the Brazilian fisheries management system through time. This overview was essential to set the stage for all analyses presented in the following chapters. This chapter also showed how unstable the institutional framework has been since the onset of organized fishing in Brazil, leading to a poor system of collection of fisheries statistics and related undesirable consequences. A brief description of the ecosystem off northeastern Brazil was given, i.e., of a tropical environment with low productivity, but which is (unrealistically) expected to provide high catch levels.

Chapter 2 documented the high richness of common names of Brazilian fishes and was essential to the analyses presented in the following chapters. Each species present an average of six common names, but this ranged up to 37 names. Conversely, some common names may be used for up to 31 different species, creating a very intricate naming system. Not surprisingly, this system affects the quality of fishery statistics, as data are recorded by common names that may be associated with unrelated species. One of the analyses presented in this chapter indicated that higher diversity of names is associated with commercial species. There is also a difference between names used by the commercial and the recreational fishing sectors. With increasing interest in recreational fisheries in Brazil, and specifically in northeastern Brazil, managers should be able to combine catch data and related information from both sectors in order to make better decisions. A standardization of common names is proposed here, based on previous experience in North America. This standardization is not intended to eliminate cultural diversity, reflected in a wide variety of names, but to allow improvements in the collection system for catch statistics and to allow for better communication amongst members of the fishing sector.

Chapter 3 presented how fisheries statistics spread throughout documents were compiled through a database to be made widely available. This database was presented on a per State basis, which allows for addressing area-specific questions on the development of fisheries. More specifically, the compiled database allowed for the use of time series of catch statistics in the EwE model constructed for northeastern Brazil and the exploration of future fishing policy options. This was previously not possible, as the only comprehensive electronic database available to date was FAO's, which presents catch data at a national level. The results presented here indicated that fishery statistics presented in national databases are failing to capture the landings of tuna and tuna-like fishes originating with industrial fisheries. On the other hand, FAO statistics are using ICCAT catches to correct the database officially provided by Brazil. However, this approach will result in an underestimation of tuna and tuna-like fishes due to the omission of catches originating from artisanal fisheries. Additionally, FAO has also misallocated catches attributed to some species and overaggregated catches for others. Several additional sources of underestimation of total extractions from Brazilian waters were indicated, and will be later incorporated into the database presented here.

The preparation of this chapter faced the challenge of dealing with a high diversity of common names of fishes, as all national documents used in this compilation report landing data via common names. The task of combining all the information into a single database required a detailed analysis of common names, which was previously addressed. This chapter indicated that the 'fishing down the food web' trend observed in many other parts of the world is also occurring in Brazil. However, the trend is more visible when the analysis is performed at the level of States. This indicates that even low quality fisheries statistics can be useful to detect fishing impacts on the ecosystem, such as the gradual elimination of predators of higher trophic levels.

Chapter 4 described the trophic interactions of the marine ecosystem off northeastern Brazil and some of its main features. Forty-one groups were used to describe this system, including marine mammals, sea turtles, seabirds, fishes, cephalopods, crustaceans, corals, other invertebrates, zoo- and phytoplankton, and a complex of other primary producers (macroalgae, mangroves, and seagrasses), which created a set of subsystems with a total biomass of 222 $tonnes \cdot km^{-2}$ (excluding detritus). Catches were low, a result of several sources of underestimation discussed in the previous chapter, but mainly due to the low productivity in this region. System statistics indicated that detritus is an important component of this system. The degree of omnivory was low, as in other tropical shelves along the western Atlantic.

Chapter 5 indicated that in order to move towards ecosystem-based fisheries management and to be able to deal with trade-offs amongst fishery sectors in northeastern Brazil, much basic information is still missing. Preliminary results indicated that current fishing practices are unsustainable for lobsters and swordfish stocks, which are likely to collapse in a few years. Biomass of other groups, such as other large pelagics and sharks, will decline even further. Policies emphasizing ecosystem health would lead to a more diverse fleet configuration, but may require that longline and lobster fisheries are practically shut down. Economic, social, and compromise (equal weight for economic, social, and ecological components) scenarios indicated that fishing effort for manual collection and industrial demersal fisheries could be increased. All scenarios would lead to an increase in biomass of swordfish, tunas, and spiny lobsters. However, these results appear to be masked by the dynamics of sharks and tunas/swordfish. The biomass of spiny lobsters would reach 1978 levels if there were a massive decrease in fishing effort, down to a value equivalent to f_{MSY}. However, attention was called for the heterogeneity of lobster fisheries due to the existence of three sectors (traps, gillnets, and diving), each one with its own dynamics. Effort should be made towards collection of data for each of these sectors.

The general conclusion of the thesis is that fishing has negatively impacted the marine ecosystem off northeastern Brazil as evidenced by the 'fishing down the food web' phenomenon, with decreasing abundance of predators of higher trophic levels. This phenomenon is more visible, however, when the available data are analysed at the State level. Some stocks such as lobsters and swordfish had their biomass decreased to very low values in relation to the late 1970s, and will crash in a few years if rebuilding policies are not put in place.

A better analysis of the impact of fisheries on the local ecosystem is difficult due to the poor system of collection of fishery statistics that fails to keep continuous records, probably associated with the high instability of Brazilian management institutions. Besides, the system, which fails to record even basic information such as catches per fleet type, has not done much towards estimating by-catch discards, and has recorded catches using common names whose linkage to the scientific names are poorly defined. Biological, economic, and social information available for this area are still far from allowing for an ecosystem-based approach for fisheries management, considering trade-offs amongst multi-objectives. The attempt to quantify the impact of fishing in this ecosystem in the absence of basic data leads one to argue about the factual basis for the current program of the Brazilian government towards increasing and modernizing its fleet. If there are data supporting such decisions, its origin is not known. This makes for a lack of transparency in decision-making. Finally, the current situation of two institutions responsible for managing Brazilian fisheries (SEAP and IBAMA) is expected to make the state of fish resources in Brazilian waters even worse.

Study limitations and general recommendations:

The analyses presented in this thesis were based on catch statistics that are inherently weak, which may have affected the results obtained. The use of categories such as 'outros peixes', 'mistura' and 'caíco', all representing 'other' or 'miscellaneous' fishes, should be avoided in national fishery statistics or at least reduced to the minimum level possible. These categories may be including species that are major prey for some of the exploited fisheries resources and thus the analysis of the impact of fisheries on the ecosystem would be improved. Additionally, institutions reporting catch statistics would benefit from a standardized set of common names of exploited species, to be selected by all stakeholders involved in fishery-related activities. As this standardization is expected to be obtained through a long, elaborate process, these institutions should provide, for now, at least a list of species associated to each name per State and not for the whole of Brazil, as is currently the case. The impact of this richness of names was quantitatively assessed by equally splitting catches amongst all species of commercial interest linked to a given name. This analysis should be tested in the field, in at least some States. The database of common names should be continuously extended in order to improve the coverage of names on a per State basis and to include names commonly used before 1962. This extension is essential to deal with catch statistics from earlier periods (1950-1961).

The electronic database of landing data produced here will be incorporated into the database of the Sea Around Us Project (www.seaaroundus.org), which has been working on mapping global catches to assess the impact of fisheries on a larger scale. It also will be made available to the general public in Brazil through IBAMA, SEAP or a Brazilian Fisheries Society (still to be created). The database is expected to be extended backwards to 1950, as foreign fleets started to operate in this area by the mid 1950s. This will allow for better assessment of the impact of these fleets on local ecosystems. Quantification of discards and other sources of underestimation of catches would contribute to make this database more realistic. Particularly, data on finning activities, although recognizably difficult to obtain due to the illegal nature of this activity, are particularly crucial to assess the impact of current policies devoted to expanding tuna and swordfish fisheries.

After the catch database is extended to the 1950s, the spatial mapping of the catches by State would allow for a better understanding of the expansion of fishing grounds through time. One limitation of this analysis would be the fact that fishing boats of some States extend their operational area after a local depletion, but may still sell their catch in the port where they were originally registered. The only way to overcome this problem would be through explicit reporting of fishing grounds, which is currently done only by longliners.

Collection and analysis of catch data is very important, but not sufficient to draw inferences on the performance of fisheries and the health of ecosystems. The current system only records the number of boats legally registered in each State, but does not present information on fishing days, number of fishers, number of fishing traps, or number of hooks for most fleets. With the exception of data collected by study groups associated with the main resources in the area, there is no recognition that effort data should be provided together with catch data for better assessment of fisheries. In some cases, these study groups present effort by some specific gears used to catch a given resource, but fail to address the problem of other gears that may also impact the resource in question. Alternatively, the local government could move towards obtaining estimates of fishing mortality through tagging programs.

The trophic mass-balance model constructed here using Ecopath with Ecosim is very preliminary and has inherited several of its flaws from the original data sources. The absence of biomass surveys led to the use of data from other areas or to their estimation by the model. Mortality rates were, in many cases, also inferred from other systems or estimated based on length-frequency distributions. Local studies of diet composition mainly described diets in terms of frequency of occurrence or numerical frequency and data from other regions in Brazil or for the same species in other tropical areas were used as indicators of the impact of each group. It is recommended that local diet composition data be generated, at least for the main resource species, including *Lutjanus purpureus, Panulirus argus,* and *P. laevicauda*, as well as key species of crabs, shrimps, and molluscs. Data on predation on *Lutjanus purpureus* are also required, as no information was found on potential predators. This, together with an incomplete series of CPUE data, precluded explorations of policies specifically for snapper fisheries.

More functional groups (particularly tunas and swordfish) should be split into juveniles and adults, as was done for dolphinfish in the current version of the Ecopath with Ecosim model. This will allow for a better understanding of the impact of the development of longline fisheries. Recreational catch data were not incorporated in the model due to the lack of data on a per species basis. Considering the possible effect of recreational fisheries on juveniles of exploited fishes and/or on prey items of those fishes, the use of split groups for some of the other fish groups would allow for testing the effect of increasing effort by anglers.

The improvement of the basic model through the inclusion of additional local data or gathering the information available in the grey literature, theses, or reports not easily available is paramount to portrait more realistically local trophic interactions and the impact of fisheries in this region. A new version of the model will then be submitted to local experts for an in-depth evaluation. The improved version should be the result of an interdisciplinary team involving scientists with expertise on the different functional groups included in the model, as well as fisheries economists and social scientists.

Fishing policy exploration was limited by the manner in which catches were split amongst the fleets, by the absence of price data specific to the industrial and artisanal fleets, by the lack of data on costs for several fleets (or lack of consistency in the available data), and by the crudeness of the estimation of number of jobs generated by each fleet. This attempt to assemble all local information into a single framework to analyze the ecological structure of this system and fishing impacts showed several information gaps. It also demonstrated that if northeastern Brazil is going to move towards ecosystem-based fisheries management strategy, an extra effort should be made to collect the essential information required for improved trophic models to be used as the platform to explore future directions for local fisheries. Even if all of these information gaps are filled, the management of Brazilian fisheries would still be negatively affected by the unstable institutional structure. This is particularly worrisome if we consider the split of responsibility between two institutions working in a non-collaborative arrangement.

Appendix 1: Glossary of terms used throughout this thesis.

1. Artisanal fisheries: includes manual collection, paddling/sailing boats, and usually motorboats $<$ 12-15 m and $<$ 20 RGT (Registered Gross Tonnage), although limits may differ amongst States;
2. Bathydemersal – near the bottom below 200 m;
3. Bathypelagic – from 200 m to the bottom, thus including the mesopelagic, bathypelagic, and abyssopelagic zones;
4. Benthopelagic – in zones about 100 m off the bottom at all depths below the edge of the continental shelf;
5. Commercial fisheries: include both artisanal and industrial fisheries, but excludes subsistence and recreational fisheries;
6. Demersal – on or near the bottom and feeding on benthic organisms;
7. Industrial fisheries: originated from boats usually $\geq$ 12-15 m and $\geq$ 20 RGT, although limits may differ amongst States;
8. Landing data: refers to live weight in tonnes of the taxa caught (molluscs, crustaceans, fishes, turtles, mammals), without discards or other unreported catches;
9. Pelagic – at the sea surface or mid water, from 0 to 200 m depth;
10. Reef-associated – on or near coral reefs.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil.

Functional group	Species	Sources	Comments
1. West Indian manatee	*Trichechus manatus*	(Albuquerque and Marcovaldi, 1982) (Paludo and Langguth, 2002)	Occurs from Amapá to Sergipe States and disappeared from the south of its distribution range (Espírito Santo and Bahia States). Currently *T. manatus* is considered endangered.
2. Baleen whales	minke (*Balaenoptera acutorostrata*), sei (*B. borealis*), blue (B. *musculus*), Bryde's (*B. edeni*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), southern right (*Eubalaena australis*), and southern minke (*B. bonaerensis*).	(Singarajah, 1997)	With the exception of the last two species, all were commercially exploited until early 1980s.
3. Toothed cetaceans	*Globicephala macrorhynchus, Hyperoodon planifrons, Kogia breviceps, K. simus, Orcinus orca, Peponocephala electra, Physeter macrocephalus, Pseudorca crassidens, Sotalia fluviatilis, Stenella attenuata, S. clymene, S. coeruleoalba, S. frontalis, S. longirostris, Steno bredanensis, Tursiops truncatus*, and *Ziphius cavirostris*.	(Singarajah, 1997)	Seventeen out of the 30 species of toothed cetaceans reported in Brazil are found in the northeastern region; only the sperm whale (*Physeter macrocephalus*) was commercially exploited.
4. Seabirds	*Aramides mangle, Arenaria interpres, Buteogallus aequinoctialis, Butorides striatus, Charadrius collaris, Fregata magnificens, Nyctanassa violacea, Phalacrocorax olivaceus, Puffinus gravis*, and *Rallus longirostris*.	Vooren and Brusque (1999)	Ninety-three out of the 148 seabird species recorded for Brazil are found in northeastern region; the most important in terms of distribution range and common occurrence are listed here.
5. Sea turtles	*Chelonia mydas, Caretta caretta, Dermochelys coriacea, Eretmochelys imbricata*, and *Lepidochelys olivacea*.	(Marcovaldi and Marcovaldi, 1999)	All these species were commercially exploited until 1986.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
6. Tunas	*Thunnus alalunga, T. albacares*, and *T. obesus.*	www.fishbase.org	Only includes large tunas.
7. Other large pelagics	*Acanthocybium solandri, Auxis rochei, A. thazard, Euthynnus alletteratus, Istiophorus albicans, Katsuwonus pelamis, Makaira nigricans, Mola mola, Ranzania laevis, Sarda sarda, Scomber colias, S. japonicus, Scomberomorus cavala, S. regalis, S. serra, Sphyraena barracuda, S. guachancho, Tetrapturus albidus*, and *T. pfluegeri.*	www.fishbase.org	—
8. Dolphinfish	*Coryphaena hippurus*	www.fishbase.org	—
9. Dolphinfish juveniles	*Coryphaena hippurus*	www.fishbase.org	—
10. Swordfish	*Xiphias gladius*	www.fishbase.org	—
11. Sharks	*Alopias vulpinus, Carcharhinus acronotus, C. falciformis, C. galapagensis, C. leucas, C. limbatus, C. longimanus, C. obscurus, C. perezi, C. plumbeus, C. porosus, C. signatus, Carcharias taurus, Euprotomicrus bispinatus, Galeocerdo cuvier, Isogomphodon oxyrhynchus, Isurus oxyrinchus, Mustelus canis, M. higmani, Negaprion brevirostris, Prionace glauca, Rhizoprionodon lalandii, R. porosus, Scyliorhinus haeckelii, Sphyrna lewini, S. media, S. mokarran, S. tiburo, S. tudes*, and *S. zygaena.*	www.fishbase.org	Incomplete list.
12. Rays	*Aetobatus narinari, Atlantoraja castelnaui,*	www.fishbase.org	Incomplete list.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
	Dasyatis americana, D. centroura, D. guttata, D. marianae, D. say, Gymnura altavela, G. micrura, Manta birostris, Narcine brasiliensis, Pteroplatytrygon violacea, Rhinobatos percellens, Rhinoptera bonasus, Torpedo nobiliana, and *Zapteryx brevirostris.*		
13. Small pelagics	*Anchoa cubana, A. filifera, A. hepsetus, A. januaria, A. lyolepis, A. pectoralis, A. spinifer, A. tricolor, Anchoviella brevirostris, A. cayennensis, A. lepidentostole, Cetengraulis edentulus, Cheilopogon cyanopterus, Chloroscombrus chrysurus, Exocoetus volitans, Hirundichthys affinis, H. speculiger, Lycengraulis grossidens,* and *Sardinella aurita.*	www.fishbase.org	—
14. Needlefishes	*Hemiramphus balao, H. brasiliensis, Hyporhamphus unifasciatus, H. robertii,* and *Oxyporhamphus micropterus similis.*	www.fishbase.org	—
15. Southern red snapper	*Lutjanus purpureus*	(Fonteles-Filho and Ferreira, 1987)	
16. Large carnivorous reef fishes	*Epinephelus flavolimbatus, E. guttatus, E. itajara, E. niveatus, E. striatus, Gymnothorax moringa, Lutjanus buccanella, L. griseus, L. jocu, L. vivanus, Mycteroperca bonaci,* and *Rachycentrum canadum.*	www.fishbase.org	Incomplete list.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
17. Small carnivorous reef fishes	*Aulostomus maculatus, Bodianus rufus, Dactylopterus volitans, Fistularia petimba, F. tabacaria, Halichoeres bivittatus, Holocentrus adscensionis, H. rufus, Hippocampus erectus, Lutjanus apodus, Myripristis jacobus,* and *Selar crumenophthalmus.*	www.fishbase.org	Incomplete list.
18. Herbivorous reef fishes	*Acanthurus bahianus, A. chirurgus, A. coeruleus, Cantherhines pullus, Halichoeres bivittatus, H. cyanocephalus, H. maculipinna, H. poeyi, Kiphosus incisor, Scarus guacamaia, S. trispinosus, S. zelindae, Sparisoma amplum, S. atomarium, S. axillare, S. frondosum,* and *S. radians.*	www.fishbase.org	Incomplete list.
19. Omnivorous reef fishes	*Acanthostracion quadricornis, Albula vulpes, Archosargus rhomboidalis, Balistes vetula, Cantherhines macrocerus, C. pullus, Chilomycterus schoepfii, Diodon hystrix, Epinephelus morio, Eucinostomus argenteus, E. gula, Haemulon plumieri, Lutjanus analis, L. synagris, Monacanthus ciliatus,* and *Ocyurus chrysurus.*	www.fishbase.org	Incomplete list.
20. Demersal fishes	*Amphichthys rubigenis, Antigonia capros, Bairdiella ronchus, Bothus ocellatus, B. robinsi, Centropomus parallelus, Conodon nobilis, Corniger spinosus, Cynoscion acoupa, C. jamaicensis, C. leiarchus, C. virescens, Diapterus auratus, D. rhombeus, Diplectrum radiali, Eucinostomus havana, E. jonesii, E. melanopterus, Eugerres*	www.fishbase.org	At least 186 species are included in this group. Some of them are listed here.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
	brasilianus, E. plumieri, Isopisthus parvipinnis, Larimus brevipes, Macrodon ancylodon, Menticirrhus littoralis, Micropogonias furnieri, Ophioscion punctatissimus, Orthopristis rubber, Paralonchurus brasiliensis, Prionotus punctatus, P. roseus, Stellifer rastrifer, and *Umbrina coroides*		
21. Mullets	*Mugil curema, M. curvidens, M. gyrans, M. hospes, M. incilis, M. liza, M. platanus,* and *M. trichodon.*	www.fishbase.org	—
22. Spotted goatfish	*Pseudupeneus maculatus*	(Campos and Oliveira, 2001)	—
23. Benthopelagic fishes	*Acanthistius brasilianus, Bryx dunckeri, Caelorinchus marinii, Caranx lugubris, Centropomus ensiferus, C. pectinatus, Etmopterus gracilispinis, Lobotes surinamensis, Neobythites gilli, N. ocellatus, Nezumia aequalis, Oligoplites palometa, O. saliens, Peprilus alepidotus, P. paru, Promethichthys prometheus, Ribeiroclinus eigenmanni, Rivulus marmoratus, Ruvettus pretiosus, Scombrolabrax heterolepis, Selene setapinnis, Seriola fasciata, S. zonata, Serranus auriga, Stromateus brasiliensis, Thyrsitops lepidopoides, Trachinotus carolinus, T. marginatus, Trichiurus lepturus,* and *Zenopsis conchifera.*	www.fishbase.org	47 species are included in this group. Some are listed here.
24. Bathypelagic fishes	Some of these species are: *Alepisaurus*	www.fishbase.org	A total of 113 species are recorded for

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
	ferox, Allocyttus verrucosus, Antimora rostrata, Ceratoscopelus warmingii, Chauliodus sloani, Diaphus fragilis, D. metopoclampus, D. perspicillatus, D. taaningi, Gempylus serpens, Howella brodiei, Lampanyctus nobilis, Lampris guttatus, Lepidocybium flavobrunneum, Lobianchia dofleini, Malacosteus niger, Melanonus zugmayeri, Melanostomias bartonbeani, Myctophum nitidulum, Nessorhamphus ingolfianus, Notolychnus valdiviae, Photonectes braueri, Sternoptyx diaphana, S. pseudobscura, Stomias affinis, and *Yarrella blackfordi.*		this area. Some are listed here.
25. Spiny lobsters	*Panulirus argus, P. laevicauda,* and *P. echinatus.*	(Lins-Oliveira *et al.*, 1993)	All of these lobster species are commercially important. *P. argus* is associated with the highest catches.
26. Other lobsters	*Parribacus antarticus, Scyllarides brasiliensis,* and Nephropidae.		—
27. Shrimps	*Farfantepenaeus brasiliensis, F. subtilis, Litopenaeus schmitti,* and *Xiphopenaeus kroyeri.*	(IBAMA, 1994)	All are commercially exploited.
28. Crabs	*Aratus pisonii, Arenaeus cribarius, Callinectes bocourti, C. danae, C. exasperatus, C. larvatus, C. ornatus, C. sapidus, Cardisoma guanhumi, Goniopsis cruentata, Ocypode quadrata, Uca leptodactyla, U. maracoani, U. rapax, U. yhayeri,* and *Ucides cordatus.*	(Amaral *et al.*, 2000) (Castro, 2000)	At least 170 species of crabs are included in this group. Some are listed here.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
29. Squids	*Bathyteuthis abyssicola, Histioteuthis bonnellii, Loligo plei, Lolliguncula brevis, Ommastrephes bartramii, Onychoteuthis banksii, Ornithoteuthis antillarum, Sthenoteuthis pteropus,* and *Thysanoteuthis rhombus.*	www.cephbase.org	—
30. Octopus	*Benthoctopus januarii, Eledone massyae, Octopus defilippi, O. filosus, O. macropus, O. vulgaris, Ocythoe tuberculata, Pteroctopus tetracirrhus,* and *Scaeurgus unicirrhus.*	www.cephbase.org	—
31. Other molluscs	*Anomalocardia brasiliana, Crassostrea rhizophorae, Lucina pectinata, Mytella charruana, M. falcata, Tagelus plebeius,* and *Tivela mactroides.*	(Amaral *et al.*, 2000) (Castro, 2000)	According to these authors, there are 155 species for sand beaches and reef areas around Abrolhos, respectively, but no comprehensive list of molluscs was found for northeastern Brazil; this group is here mainly represented by species of commercial interest.
32. Other crustaceans	*Albunea paretii, Blepharipoda doelloi, Calianassa grandimana, C. guassutinga, C. jamaicense, Callichirus major, Cloridopsis dubia, Dulichiella spinosa, Emerita portoricensis, Ericthonius brasiliensis, Excirolana braziliensis, Gammaropsis atlantica, Hippa testudinaria, Lepidopa distincta, L. richmondi, L. venusta, Leucothoe dissimilis, L. spinicarpa, Maera hirondelei, M. quadrimana, Orchestia gammarella, O. montagui,* and *O. platensis.*	(Amaral *et al.*, 2000)	This group encompasses all crustacean species not cited above, which belong to the following groups: Benthic Copepoda, Gammaridae, Isopoda, Ostracoda, Stomatopoda, Tanaidacea and Thalassinidea. Some of the species are listed here.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
33. Other invertebrates	*Astropecten riensis, Astrophyton muricatum, Callispongia pergamentacea, Capitella capitata, Chiridota rotifera, Cucumaria pulcherrima, Diamphiodia riisei, Diopatra tridentate, Dysidea janiae, Echinaster echinophorus, Echinometra lucunter, Encope emarginata, Eurithoe complanata, Holothuria grisea, Hyatella cavernosa, Laeonereis acuta, Lumbrineris limicola, Lytechinus variegates, Mellita quinquiosperforata, Micropholis atra, Naineris laevigata, Narcissia trigonaria, Nereis indica, Ophidiaster guildingii, Ophionereis squamulosa, Spongia bresiliana, Stylocidaris affinis, Thyone brasiliensis, Tripneustes ventricosus,* and *Tropiometra carinata.*	(Amaral *et al.*, 2000) (Castro, 2000)	This group includes ascidians, chitons, non-annelid worms, polychaets, sea cucumbers, sea stars/brittle stars, sea urchins, and sponges; a comprehensive list of invertebrates was not found for this region, except for the partial lists provided by these authors for reef and sandy substrates; some species are listed here.
34. Zooplankton	Coelenterata (Siphonophorae, Hydromedusae, Scyphomedusa), Ctenophora, Turbellaria, Rotifera, Pteropoda, Copepoda (Calanoidea, Cyclopoidea, Harpacticoida, Poecilostomatoida), Cladocera, Mysidaceae, Amphipoda Hyperidea, Euphausiacea, Chaetognatha, Appendicularia, and Thaliacea.	(Yoneda, 2000)	See source for species occurrence.
35. Corals	*Agaricia agaricites, A. fragilis, Astrangia brasiliensis, A. rathburi, Favia gravida, F. leptophylla, Madracis decactis, Meandrina braziliensis, Montastrea cavernosa,*	(Maida and Ferreira, 1997) (Leão *et al.*, 2003)	Low diversity and high degree of endemism.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
	Mussismilia braziliensis, M. harti, M. hispida, Phylangia americana, Porites astreoides, P. branneri, Scolymia wellsi, Siderastrea stellata, and *Stephanocoenia michelini* (scleractinian), *Millepora alcicornis, M. brasiliensis, M. nitida,* and *Stylaster roseus* (hydrocorals), and *Neopongodes atlantica* (soft corals).		
36. Microfauna	Foraminifera, pelagic and benthic bacteria, and ciliates.	(Telles, 1998)	—
37. Phytoplankton	Chlorophyta, Cryptophyceae, Chrysophyceae, Diatomophyceae, Dictyochophyceae, Dinophyceae, Euglenophyceae, Prasinophyceae, Prymnesiophyceae, Raphidophyceae, and Xantophyceae.	(Yoneda, 2000)	See source for species occurrence.
38. Macroalgae	*Bryopsis pennata, Bryothamnion triquetrum, Caulerpa cupressoides, C. mexicana, C. prolifera, C. racemosa, C. sertularioides, Centroceras clavulatum, Chamaedoris peniculum, Cladophora vagabunda, Cladophoropsis membranacea, Codium isthmocladum, Dictyopteris justii, D. plagiogramma, Dictyota menstrualis, Digenea simplex, Enteromorpha lingulata, Gelidiella acerosa, Gelidium americanum, G. coarctatum, G. crinale, Hypnea musciformis, H. spinella, Laurencia papillosa, Lobophora variegate, Neomeris annulata, Pterocladiella bartlettii, P.*	(Oliveira *et al.*, 2000)	A total of 404 species (including Chlorophyta, Phaeophyta, and Rhodophyta) are listed for this region; species with broader distribution area are listed here.

Appendix 2: List of species included in each functional group representing the marine ecosystem off northeastern Brazil (continued).

Functional group	Species	Sources	Comments
	caerulescens, Stypopodium zonale, Ulva fasciata, U. lactuca, Valonia aegagropila, and *Ventricaria ventricosa.*		
39. Mangroves	*Avicennia germinans, A. schaueriana, Conocarpus erecta, Laguncularia racemosa,* and *Rhizophora mangle.*	(Schaeffer-Novelli *et al.*, 1990)	—
40. Seagrasses	*Ruppia maritime, Halodule emarginata, H. wrightii, Halophila baillonii,* and *H. decipiens.*	(Oliveira Filho, 1983) (Green and Short, 2003)	—
41. Detritus	—	—	—

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil.

Group	Species	B ($t \cdot km^{-2}$)	Source/Area	P/B ($year^{-1}$)	Source/Area	Q/B ($year^{-1}$)	Source/Area
1. Manatee	*Trichechus manatus*	0.00015	(Medeiros *et al.*, 2000) Northeastern Brazil	0.065	(Langtimm *et al.*, 1998) Florida	27.375	(Edwards, 2000) Global
2. Baleen whales	*Balaenoptera acutorostrata*	—	—	0.035	(Blanchard *et al.*, 2002) Barents Sea	5.950	(Kaschner *et al.*, 2001) Global
	Balaenoptera borealis	—	—	—	—	5.070	(Kaschner *et al.*, 2001) Global
	Balaenoptera edeni	—	—	—	—	5.060	(Kaschner *et al.*, 2001) Global
	Balaenoptera physalus	—	—	0.020	(Blanchard *et al.*, 2002) Barents Sea	3.850	(Kaschner *et al.*, 2001) Global
	Balaenoptera musculus	—	—	—	—	3.430	(Kaschner *et al.*, 2001) Global
	Megaptera novaeangliae	—	—	0.020	(Blanchard *et al.*, 2002) Barents Sea	4.380	(Kaschner *et al.*, 2001) Global
	Various species	0.02510	(Kaschner *et al.*, 2001) Global Kaschner (pers. com.) LME 16	—	—	—	—
3. Toothed cetaceans	*Globicephala macrorhynchus*	—	—	—	—	12.154	(Kaschner *et al.*, 2001) Global
	Kogia breviceps	—	—	—	—	12.970	(Kaschner *et al.*, 2001) Global
	Kogia simus	—	—	—	—	14.508	(Kaschner *et al.*, 2001) Global
	Orcinus orca	—	—	0.050	(Okey, 2002) Alaska	8.600	(Kaschner *et al.*, 2001) Global
	Physeter macrocephalus	—	—	—	—	6.902	(Kaschner *et al.*, 2001) Global
	Pseudorca crassidens	—	—	—	—	11.810	(Kaschner *et al.*, 2001) Global
	Stenella attenuata	—	—	0.078	(Kasuya, 1976) Pacific Ocean	—	—

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
	Stenella coeruleoalba	—	—	0.126	(Kasuya, 1976) Pacific Ocean	—	—
	Tursiops truncatus	—	—	0.080	(Hersh *et al.*, 1990) Florida, US	—	—
	Ziphius cavirostris	—	—	—	—	8.600	(Kaschner *et al.*, 2001) Global
	Various species	0.00520	(Kaschner *et al.*, 2001) Global Kaschner (pers. com.) LME 16	—	—	—	—
4. Seabirds	Unidentified species	0.01500	(Opitz, 1996) Caribbean	5.400	(Opitz, 1996) Caribbean	80.000	(Opitz, 1996) Caribbean
5. Sea turtles	Unidentified species	0.16300	(Telles, 1998) Northeastern Brazil	0.150	(Telles, 1998) Northeastern Brazil	22.000	(Telles, 1998) Northeastern Brazil
6. Tunas	*Thunnus alalunga*	0.01830	(ICCAT, 2004b) Southern Atlantic	0.660	(ICCAT, 2004b) Atlantic Ocean	9.600	(Vasconcellos, 2002) South Atlantic
	Thunnus albacares	0.00710	(ICCAT, 2004b) Atlantic Ocean	0.969	(ICCAT, 2004a) Atlantic Ocean	15.530	(Vasconcellos, 2002) South Atlantic
	Thunnus obesus	0.00960	(ICCAT, 2003b) Atlantic Ocean	0.680	(ICCAT, 2005) Southern/Southeastern Brazil	17.160	(Vasconcellos, 2002) South Atlantic
7. Other large pelagics	*Istiophorus albicans*	0.00314	(ICCAT, 2001a) Western Atlantic	0.271	(ICCAT, 2001a) Western Atlantic	5.000	(Cox *et al.*, 2002) Central Pacific
	Makaira nigricans	0.00147	(ICCAT, 2001b) Atlantic Ocean	0.139	(ICCAT, 2001b) Atlantic Ocean	4.000	(Cox *et al.*, 2002) Central Pacific
	Scomberomorus cavala	0.55000	(Arreguín-Sánchez *et al.*, 1993)/Gulf of Mexico	0.640	(Fonteles-Filho, 1988) Northeastern Brazil	8.900	(Arreguín-Sánchez *et al.*, 1993) Gulf of Mexico
	Scomberomorus serra	0.67000	(Arreguín-Sánchez *et al.*, 1993)/Gulf of Mexico	0.882	(Fonteles-Filho, 1988) Northeastern Brazil	10.200	(Arreguín-Sánchez *et al.*, 1993) Gulf of Mexico
	Tetrapturus albidus	0.00168	(ICCAT, 2004b) (ICCAT, 2003c)	0.152	(ICCAT, 2004b) (ICCAT, 2003c)	5.000	(Cox *et al.*, 2002)

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
			Atlantic Ocean		Atlantic Ocean		
	Tetrapturus pfluegeri	0.00081	(Cox *et al.*, 2002) Central Pacific	0.440	(Cox *et al.*, 2002) Central Pacific	5.000	(Cox *et al.*, 2002)
8. Dolphinfish	*Coryphaena hippurus*	0.00500	(Mohammed, 2003) Caribbean	4.362	(Lessa *et al.*, 2004) Northeastern Brazil	8.470	(Mohammed, 2003) Caribbean
9. Dolphinfish juveniles	*Coryphaena hippurus*	0.00170	Ecopath with Ecosim software	13.085	3x adult mortality	24.406	Ecopath with Ecosim software
10. Swordfish	*Xiphias gladius*	—	—	0.220	(ICCAT, 2003a) Southern Atlantic	4.000	(Vasconcellos, 2002) South Atlantic
11. Sharks	*Carcharhinus acronotus*	—	—	—	—	6.410	(Opitz, 1996) Caribbean
	Carcharhinus falciformis	—	—	0.329	(Beerkircher *et al.*, 2003) Southeastern US	4.870	(Opitz, 1996) Caribbean
	Carcharhinus leucas	—	—	—	—	4.225	(Opitz, 1996) Caribbean
	Carcharhinus limbatus	—	—	—	—	6.090	(Opitz, 1996) Caribbean
	Carcharhinus longimanus	—	—	0.460	(Lessa *et al.*, 2004) Northeastern Brazil	4.870	(Opitz, 1996) Caribbean
	Carcharhinus perezi	—	—	—	—	6.280	(Opitz, 1996) Caribbean
	Carcharhinus plumbeus	—	—	0.300	(Brewster-Geisz and Miller, 2000) United States	3.100	(Stillwell and Kohler, 1993) Eastern United States
	Carcharhinus porosus	—	—	0.219	Based on Lessa and Santana (1998) Northeastern Brazil	—	—
	Carcharhinus signatus	—	—	0.370	(Lessa *et al.*, 2004) Northeastern Brazil	—	—
	Galeocerdo cuvier	—	—	—	—	4.270	(Opitz, 1996) Caribbean

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
	Isurus oxyrhynchus	—	—	—	—	10.000	(Stillwell and Kohler, 1982) Northwest Atlantic
	Negaprion brevirostris	—	—	—	—	4.500	(Opitz, 1996) Caribbean
	Prionace glauca	—	—	0.650	(Lessa *et al.*, 2004) Northeastern Brazil	2.750	(Cox *et al.*, 2002) Pacific
	Rhizoprionodon porosus	—	—	—	—	11.480	(Opitz, 1996) Caribbean
	Sphyrna lewini	—	—	—	—	4.740	(Opitz, 1996) Caribbean
	Sphyrna tiburo	—	—	0.534	(Cortés and Parsons, 1996) Florida	6.520	(Opitz, 1996) Caribbean
12. Rays	Unidentified species	—	—	0.500	(Manickchand-Heileman *et al.*,2004)/Venezuela-Trinidad	4.900	(Manickchand-Heileman *et al.*, 2004)/Venezuela-Trinidad
13. Small pelagics	*Anchoa spinifer*	—	—	—	—	16.000	(Isaac and Moura, 1998) Northern Brazil
	Anchoviella lepidentostole	—	—	4.135	(Camara *et al.*, 2001) Southeastern Brazil	—	—
	Chloroscombrus chrysurus	—	—	—	—	14.100	(García and Duarte, 2002) Colombia
	Hirundichthys affinis	—	—	13.030	(Lessa *et al.*, 2004) Northeastern Brazil	—	—
	Opisthonema oglinum	—	—	6.640	(Lessa *et al.*, 2004) Northeastern Brazil	13.700	(Vega-Cendejas *et al.*, 1993) Eastern Mexico
	Sardinella aurita	—	—	2.410	(Mendoza, 1993) Venezuela	—	—
14. Needlefishes	*Hemirhamphus brasiliensis*	—	—	3.170	(Lessa *et al.*, 2004) Northeastern Brazil	37.900	(García and Duarte, 2002) Colombia
	Hyporhamphus unifasciatus	—	—	13.100	(Lessa *et al.*, 2004) Northeastern Brazil	—	—
15. Southern red snapper	*Lutjanus purpureus*	0.50000	(Ivo and Hanson, 1982) Northeastern Brazil	0.904	(Ivo and Sousa, 1988) Northeastern Brazil	5.300	Based on Palomares and Pauly (1998) Global

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
16. Large carnivorous reef fishes	*Epinephelus flavolimbatus*	—	—	0.307	(Manickchand-Heileman and Phillip, 2000) Trinidad and Tobago	—	—
	Epinephelus guttatus	—	—	—	—	4.800	(Opitz, 1996) Caribbean
	Epinephelus itajara	—	—	0.850	(Sadovy and Eklund, 1999) Western Atlantic	6.400	(García and Duarte, 2002) Colombia
	Epinephelus niveatus	—	—	0.418	(Wyanski *et al.*, 2000) North & South Carolina, US	8.800	(García and Duarte, 2002) Colombia
	Epinephelus striatus	—	—	0.550	(Sadovy and Eklund, 1999) Cuba	3.900	(Opitz, 1996) Caribbean
	Lutjanus buccanella	—	—	1.190	(Tabash and Sierra, 1996) Western Costa Rica	12.600	(García and Duarte, 2002) Colombia
	Lutjanus griseus	—	—	0.640	(Burton, 2001) Eastern Florida	—	—
	Lutjanus jocu	—	—	0.134	(Rezende and Ferreira, 2004) Northeastern Brazil	4.500	(García and Duarte, 2002) Colombia
	Lutjanus vivanus	—	—	1.260	(Tabash and Sierra, 1996) Western Costa Rica	7.100	(García and Duarte, 2002) Colombia
	Mycteroperca bonaci	—	—	—	—	2.600	(Opitz, 1996) Caribbean
17. Small carnivorous reef fishes	*Aulostomus maculatus*	—	—	—	—	8.100	(Opitz, 1996) Caribbean
	Bodianus rufus	—	—	—	—	5.900	(Opitz, 1996) Caribbean
	Halichoeres bivittatus	—	—	—	—	8.900	(Opitz, 1996) Caribbean
	Halichoeres maculipinna	—	—	—	—	13.800	(Opitz, 1996) Caribbean

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
	Halichoeres poeyi	—	—	—	—	9.400	(Opitz, 1996) Caribbean
18. Herbivorous reef fishes	*Acanthurus bahianus*	—	—	—	—	34.500	(Opitz, 1996) Caribbean
	Acanthurus chirurgus	—	—	—	—	24.800	(Opitz, 1996) Caribbean
	Acanthurus coeruleus	—	—	—	—	24.500	(Opitz, 1996) Caribbean
	Scarus coelestinus	—	—	—	—	13.600	(Opitz, 1996) Caribbean
	Scarus coeruleus	—	—	—	—	19.300	(Opitz, 1996) Caribbean
	Scarus guacamaia	—	—	—	—	12.000	(Opitz, 1996) Caribbean
	Scarus taeniopterus	—	—	—	—	20.900	(Opitz, 1996) Caribbean
	Sparisoma aurofrenatum	—	—	—	—	29.600	(Opitz, 1996) Caribbean
	Sparisoma chrysopterum	—	—	—	—	22.900	(Opitz, 1996) Caribbean
	Sparisoma radians	—	—	—	—	34.000	(Opitz, 1996) Caribbean
	Sparisoma rubripinne	—	—	—	—	20.800	(Opitz, 1996) Caribbean
19. Omnivorous reef fishes	*Archosargus rhomboidalis*	—	—	—	—	25.500	(Opitz, 1996) Caribbean
	Balistes vetula	—	—	0.763	Based on Menezes (1985) Northeastern Brazil	7.700	(García and Duarte, 2002) Colombia
	Epinephelus morio	—	—	—	—	5.100	(Opitz, 1996) Caribbean
	Haemulon aurolineatum	—	—	1.150	(Lessa *et al.*, 2004) Northeastern Brazil	12.950	(Opitz, 1996) Caribbean

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
	Haemulon plumieri	—	—	—	—	10.600	(García and Duarte, 2002) Colombia
	Lutjanus analis	—	—	0.763	(Lessa *et al.*, 2004) Northeastern Brazil	4.500	(García and Duarte, 2002) Colombia
	Lutjanus synagris	—	—	0.270	(Lessa *et al.*, 2004) Northeastern Brazil	6.700	(García and Duarte, 2002) Caribbean
	Monacanthus ciliatus	—	—	—	—	11.800	(Opitz, 1996) Caribbean
	Ocyurus chrysurus	—	—	0.470	(Lessa *et al.*, 2004) Northeastern Brazil	7.900	(Opitz, 1996) Caribbean
20. Demersal fishes	*Aspredinichthys filamentosus*	—	—	2.810	(Silva Júnior, 2004) Northern Brazil	—	—
	Aspredo aspredo	—	—	1.450	(Silva Júnior, 2004) Northern Brazil	—	—
	Bagre bagre	—	—	0.895	(Silva Júnior, 2004) Northern Brazil	—	—
	Bothus ocellatus	—	—	—	—	10.200	(Opitz, 1996) Caribbean
	Cathorops spixii	—	—	—	—	12.000	(Isaac and Moura, 1998) Northern Brazil
	Conodon nobilis	—	—	—	—	6.100	(García and Duarte, 2002) Colombia
	Cynoscion jamaicensis	—	—	2.002	(Magro *et al.*, 2000) Southeastern Brazil	7.700	(García and Duarte, 2002) Colombia
	Cynoscion microlepidotus	—	—	3.640	(Silva Júnior, 2004) Northern Brazil	—	—
	Diapterus auratus	—	—	—	—	11.800	(García and Duarte, 2002) Colombia
	Diapterus rhombeus	—	—	—	—	11.400	(García and Duarte, 2002) Colombia
	Eugerres plumieri	—	—	—	—	10.200	(García and Duarte, 2002) Colombia

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B ($t \cdot km^{-2}$)	Source/Area	P/B ($year^{-1}$)	Source/Area	Q/B ($year^{-1}$)	Source/Area
	Isopisthus parvipinnis	—	—	1.070	(Soares, 2003) Southeastern Brazil	30.650	(Soares, 2003) Southern Brazil
	Larimus brevipes	—	—	—	—	10.840	(Soares, 2003) Southern Brazil
	Macrodon ancylodon	—	—	1.808	(Magro *et al.*, 2000) Southeastern Brazil	—	—
	Menticirrhus americanus	—	—	—	—	9.100	(García and Duarte, 2002) Colombia
	Menticirrhus littoralis	—	—	—	—	6.700	(García and Duarte, 2002) Colombia
	Micropogonias furnieri	—	—	1.100	(Soares, 2003) Southeastern Brazil	11.100	(Soares, 2003) Southern Brazil
	Orthopristis ruber	—	—	2.460	(Vianna and Verani, 2002) Southeastern Brazil	11.600	(Opitz, 1996) Caribbean
	Paralonchurus brasiliensis	—	—	1.100	(Soares, 2003) Southeastern Brazil	8.320	(Soares, 2003) Southern Brazil
	Prionotus punctatus	—	—	1.244	(Magro *et al.*, 2000) Southeastern Brazil	17.000	(Soares *et al.*, 1998) Southern Brazil
	Stellifer rastrifer	—	—	3.590	(Gianninni and Paiva Filho, 1990) / Southeastern Brazil	12.500	(Isaac and Moura, 1998) Northern Brazil
	Umbrina coroides	—	—	—	—	7.800	(García and Duarte, 2002) Colombia
21. Mullets	*Mugil cephalus*	—	—	1.054	(Marquez, 1975) Tamiahua Lagoon, Mexico	—	—
	Mugil curema	—	—	1.000	(Abarca-Arenas and Valero-Pacheco, 1993) Tamiahua Lagoon, Mexico	22.600	(García and Duarte, 2002) Colombia
22. Spotted goatfish	*Pseudupeneus maculatus*	0.50500	(Opitz, 1996) Caribbean	0.819	(Lessa *et al.*, 2004) Northeastern Brazil	10.800	(Opitz, 1996) Caribbean
23. Benthopelagic fishes	*Caranx lugubris*	—	—	—	—	9.600	(Opitz, 1996) Caribbean
	Centropomus ensiferus	—	—	0.930	(Zetina-Rejon *et al.*, 2003) Pacific coast of Mexico	—	—

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B ($t \cdot km^{-2}$)	Source/Area	P/B ($year^{-1}$)	Source/Area	Q/B ($year^{-1}$)	Source/Area
	Promethichthys prometheus	—	—	0.490	(Lorenzo and Pajuelo, 1999) Canary Islands	—	—
	Selene setapinnis	—	—	—	—	13.400	(García and Duarte, 2002) Colombia
	Syacium micrurum	—	—	—	—	7.800	(García and Duarte, 2002) Colombia
	Trachinotus carolinus	—	—	—	—	7.700	(García and Duarte, 2002) Colombia
	Trichiurus lepturus	—	—	0.928	Based on REVIZEE, unpublished data	9.200	(García and Duarte, 2002) Colombia
24. Bathypelagic fishes	*Alepisaurus ferox*	—	—	0.300	(Kitchell *et al.*, 2002) Central Pacific	2.900	(Kitchell *et al.*, 2002) Central Pacific
	Allocyttus verrucosus	—	—	0.466	(Mel'nikov, 1981) South Africa	—	—
	Antimora rostrata	—	—	0.228	(Magnusson, 2001) (Kulka *et al.*, 2003) North Atlantic	—	—
	Arctozenus risso	—	—	0.650	(Ainsworth *et al.*, 2001) Bay of Biscay	7.128	(Ainsworth *et al.*, 2001) Bay of Biscay, France
	Chauliodus sloani	—	—	—	—	6.297	(Ainsworth *et al.*, 2001) Bay of Biscay, France
	Ceratoscopelus warmingii	—	—	4.700	(Tsarin, 1994) Equatorial Indian Ocean	—	—
	Unidentified species	2.29192	(Vasconcellos, 2002) South Atlantic	—	—	—	—
25. Spiny lobsters	*Panulirus argus*	—	—	1.230	(Ivo and Pereira, 1996) Northeastern Brazil	0.740	(Opitz, 1996) Caribbean
	Panulirus laevicauda	—	—	1.770	(Ivo and Pereira, 1996) Northeastern Brazil	0.740	(Opitz, 1996) Caribbean
26. Other lobsters	Unidentified species	—	—	0.350	Based on the natural mortality for spiny lobsters	0.740	(Opitz, 1996) Caribbean
27. Shrimps	*Farfantepenaeus*	—	—	3.261	(Villela *et al.*, 1997)	—	—

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
	brasiliensis				Southeastern Brazil		
	Farfantepenaeus subtilis	—	—	1.913	(Ehrhardt, 2001) (Isaac *et al.*, 1992) Northern/Northeastern Brazil	—	—
	Xiphopenaeus kroyeri	—	—	3.024	(CEPENE, 2000) Northeastern Brazil	—	—
	Unidentified species	—	—	—	—	26.900	(Opitz, 1996) Caribbean
28. Crabs	*Aratus pisonii*	—	—	—	—	13.110	(Wiedemeyer, 1997) Northeastern Brazil
	Callinectes danae	—	—	—	—	12.300	(Wiedemeyer, 1997) Northeastern Brazil
	Callinectes sapidus	—	—	9.450	(Villasmil *et al.*, 1997) Venezuela	22.000	(Wolff *et al.*, 2000) Northern Brazil
	Eurytium limosum	—	—	1.650	(Koch and Wolff, 2002) Northern Brazil	22.000	(Wolff *et al.*, 2000) Northern Brazil
	Goniopsis cruentata	—	—	—	—	9.590	(Wiedemeyer, 1997) Northeastern Brazil
	Pachygrapsus gracilis	—	—	4.660	(Koch and Wolff, 2002) Northern Brazil	—	—
	Uca cumulanta	—	—	9.990	(Koch and Wolff, 2002) Northern Brazil	95.000	(Wolff *et al.*, 2000) Northern Brazil
	Uca maracoani	—	—	4.941	(Koch and Wolff, 2002) Northern Brazil	32.160	(Wiedemeyer, 1997) Northeastern Brazil
	Uca rapax	—	—	4.530	(Koch and Wolff, 2002) Northern Brazil	95.000	(Wolff *et al.*, 2000) Northern Brazil
	Uca thayeri	—	—	—	—	78.270	(Wiedemeyer, 1997) Northeastern Brazil
	Uca vocator	—	—	6.480	(Koch and Wolff, 2002) Northern Brazil	95.000	(Wolff *et al.*, 2000) Northern Brazil
	Ucides cordatus	—	—	0.160	(Koch and Wolff, 2002) Northern Brazil	14.000	(Wolff *et al.*, 2000) Northern Brazil

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
29. Squids	Unidentified species	0.42068	(Vasconcellos, 2002) South Atlantic	4.600	(Vasconcellos, 2002) South Atlantic	36.500	(Vasconcellos, 2002) South Atlantic
30. Octopus	Unidentified species	—	—	1.900	(Opitz, 1996) Caribbean	6.760	(Opitz, 1996) Caribbean
31. Other molluscs	*Crassostrea rhizophorae*	—	—	5.160	(Mancera and Mendo, 1996) Colombia	—	—
	Macoma bathica	—	—	1.500	Burke and Mann (1974, in Tata and Prieto, 1991) Canada	—	—
	Mytella falcata	—	—	2.768	(Pereira-Barros and Santos, 1971)/Northeastern Brazil	—	—
	Tagelus plebeius	30.80000	(Viegas, 1982) Northeastern Brazil	1.227	(Viegas, 1982) Northeastern Brazil	—	—
	Tivela mactroides	96.70000	(Tata and Prieto, 1991) Venezuela	2.200	(Tata and Prieto, 1991) Venezuela	—	—
	Unidentified species	—	—	—	—	18.871	(Opitz, 1996) Caribbean
32. Other crustaceans	Benthic Copepoda	1.75000	(Arias-González *et al.*, 1997)/French Polynesia	32.545	(Arias-González *et al.*, 1997) French Polynesia	203.070	(Arias-González *et al.*, 1997) French Polynesia
	Emerita brasiliensis	14.00000	(Petracco *et al.*, 2003) Southeastern Brazil	7.500	(Petracco *et al.*, 2003) Southeastern Brazil	—	—
	Isopoda	0.17500	(Rocha *et al.*, 2003) Southeastern Brazil	13.750	(Rocha *et al.*, 2003) Southeastern Brazil	219.920	(Arias-González *et al.*, 1997) French Polynesia
	Ostracoda	0.02500	(Rocha *et al.*, 2003) Southeastern Brazil	—	—	—	—
	Stomatopoda	0.01500	(Rocha *et al.*, 2003) Southeastern Brazil	23.680	(Arias-González *et al.*, 1997) French Polynesia	85.270	(Arias-González *et al.*, 1997) French Polynesia
	Tanaidacea	0.07500	(Rocha *et al.*, 2003) Southeastern Brazil	20.430	(Arias-González *et al.*, 1997) French Polynesia	100.930	(Arias-González *et al.*, 1997) French Polynesia
33. Other invertebrates	Ascidians	35.00000	Caribbean (Opitz, 1996)	2.300	(Opitz, 1996) Caribbean	29.000	(Opitz, 1996) Caribbean

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B ($t \cdot km^{-2}$)	Source/Area	P/B ($year^{-1}$)	Source/Area	Q/B ($year^{-1}$)	Source/Area
	Asteroidea	0.02000	(Rocha *et al.*, 2003) Southeastern Brazil	0.550	(Rocha *et al.*, 2003) Southeastern Brazil	3.240	(Opitz, 1996) Caribbean
	Chitons	18.00000	(Opitz, 1996) Caribbean	0.260	(Opitz, 1996) Caribbean	7.200	(Opitz, 1996) Caribbean
	Crinoidea	0.50500	(Rocha *et al.*, 2003) Southeastern Brazil	0.450	(Rocha *et al.*, 2003) Southeastern Brazil	—	—
	Echinoidea	0.03000	(Rocha *et al.*, 2003) Southeastern Brazil	0.600	(Rocha *et al.*, 2003) Southeastern Brazil	14.154	(Rocha *et al.*, 2003) Southeastern Brazil
	Holothuroidea	0.00500	(Rocha *et al.*, 2003) Southeastern Brazil	6.250	(Rocha *et al.*, 2003) Southeastern Brazil	3.360	(Opitz, 1996) Caribbean
	Ophiuroidea	15.08500	(Rocha *et al.*, 2003) Southeastern Brazil	1.350	(Rocha *et al.*, 2003) Southeastern Brazil	—	—
	Polychaeta (detritivorous)	9.52500	(Rocha *et al.*, 2003) Southeastern Brazil	6.335	(Rocha *et al.*, 2003) Southeastern Brazil	33.361	(Rocha *et al.*, 2003) Southeastern Brazil
	Polychaeta	6.99000	(Rocha *et al.*, 2003) Southeastern Brazil	3.600	(Rocha *et al.*, 2003) Southeastern Brazil	—	—
	Sponges	30.50000	Caribbean (Opitz, 1996)	1.700	(Opitz, 1996) Caribbean	4.020	(Opitz, 1996) Caribbean
34. Zooplankton	Unidentified species	12.40000	(Schwamborn, 1997) Northeastern Brazil	26.044	(Hirst and Lampitt, 1998) (Harris *et al.*, 2000) R. Schwamborn, pers. comm.	165.000	(Opitz, 1996) Caribbean
35. Corals	Unidentified species	51.85600	(Telles, 1998) Northeastern Brazil	1.090	(Telles, 1998) Northeastern Brazil	8.460	(Telles, 1998) Northeastern Brazil
36. Microfauna	Unidentified species	5.98900	(Telles, 1998) Northeastern Brazil	280.000	(Telles, 1998) Northeastern Brazil	1786.00	(Telles, 1998) Northeastern Brazil
37. Phytoplankton	Unidentified species	3.67000	(Medeiros *et al.*, 1999) Northeastern Brazil	496.630	(Ekau and Knoppers, 1999) Northeastern Brazil	NA	NA
38. Macroalgae	Unidentified species	1930.807	(Paula *et al.*, 2003) (Mansilla-Muñoz and Pereira, 1997) (Guedes and Moura, 1996) Northeastern Brazil	13.250	(Opitz, 1996) Caribbean	NA	NA

Appendix 3: Input parameters for the functional groups included in the Ecopath model of northeastern Brazil (continued).

Group	Species	B (t·km^{-2})	Source/Area	P/B (year^{-1})	Source/Area	Q/B (year^{-1})	Source/Area
39. Mangroves	*Avicennia* sp.	47107.50	(Wiedemeyer, 1997) Northeastern Brazil	68.000	(Wiedemeyer, 1997) Northeastern Brazil	NA	NA
	Conocarpus erecta	4054.10	(Wiedemeyer, 1997) Northeastern Brazil	49.296	(Wiedemeyer, 1997) Northeastern Brazil	NA	NA
	Laguncularia racemosa	16045.10	(Wiedemeyer, 1997) Northeastern Brazil	39.502	(Wiedemeyer, 1997) Northeastern Brazil	NA	NA
	Rhizophora mangle	80910.70	(Wiedemeyer, 1997) Northeastern Brazil	71.771	(Wiedemeyer, 1997) Northeastern Brazil	NA	NA
40. Seagrasses	*Halodule wrightii*	57.10 119.38 366.28	(Wiedemeyer, 1997) (Paula *et al.*, 2003) (Magalhães *et al.*, 1997) Northeastern Brazil	31.561	(Wiedemeyer, 1997) Northeastern Brazil	NA	NA
41. Detritus	—	201.91	(Pauly *et al.*, 1993) (Medeiros *et al.*, 1999) Northeastern Brazil	—	—	NA	NA

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil*.

GROUP	SPECIES	SOURCE	AREA
1. Manatee	*Trichechus manatus*	(Mignucci-Giannoni and Beck, 1998)	Puerto Rico
2. Baleen whales	*Balaenoptera acutorostrata*	(Pauly *et al.*, 1998)	Global
	Balaenoptera borealis	(Pauly *et al.*, 1998)	Global
	Balaenoptera edeni	(Pauly *et al.*, 1998)	Global
	Balaenoptera musculus	(Pauly *et al.*, 1998)	Global
	Balaenoptera physalus	(Pauly *et al.*, 1998)	Global
	Megaptera novaeangliae	(Pauly *et al.*, 1998)	Global
3. Toothed cetaceans	*Globicephala macrorhynchus*	(Pauly *et al.*, 1998)	Global
	Kogia breviceps	(Pauly *et al.*, 1998)	Global
	Kogia simus	(Pauly *et al.*, 1998)	Global
	Orcinus orca	(Pauly *et al.*, 1998) (Ford *et al.*, 1998)	Global British Columbia
	Peponocephala electra	(Pauly *et al.*, 1998)	Global
	Physeter catodon	(Pauly *et al.*, 1998)	Global
	Sotalia fluviatilis	(Pauly *et al.*, 1998) (Santos *et al.*, 2002)	Global Southeastern Brazil
	Stenella attenuata	(Pauly *et al.*, 1998)	Global
	Stenella clymene	(Pauly *et al.*, 1998)	Global
	Stenella coeruleoalba	(Pauly *et al.*, 1998) (Rosas *et al.*, 2002)	Global Southeastern Brazil
	Stenella frontalis	(Pauly *et al.*, 1998)	Global
	Stenella longirostris	(Pauly *et al.*, 1998)	Global

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Steno bredanensis	(Pauly *et al.*, 1998)	Global
	Tursiops truncatus	(Pauly *et al.*, 1998) (Santos *et al.*, 2002)	Global Southeastern Brazil
	Ziphius cavirostris	(Pauly *et al.*, 1998)	Global
4. Seabirds	*Anous stolidus*	(Morris and Chardine, 1992)	Puerto Rico
	Arenaria interpres	(Tsipoura and Burger, 1999)	Eastern United States
	Calidris alba	(Tsipoura and Burger, 1999)	Eastern United States
	Calidris canutus	(Tsipoura and Burger, 1999)	Eastern United States
	Calidris pusilla	(Tsipoura and Burger, 1999)	Eastern United States
	Charadrius semipalmatus	(Tsipoura and Burger, 1999)	Eastern United States
	Diomedea melanophrys	(Prince and Morgan, 1987) (Prince, 1980)	South Georgia
	Eudocimus ruber	(Martinez, 2004)	Northern/Northeastern Brazil
	Fregata magnificens	(Calixto-Albarrán and Osorno, 2000)	Western Mexico
	Nyctanassa violacea	(Martinez, 2004)	Northern/Northeastern Brazil
	Pachyptila desolata	(Prince and Morgan, 1987)	South Georgia
	Rallus longirostris	(Zembal and Fancher, 1988)	Western United States
	Sterna hirundo	(Bugoni and Vooren, 2004)	Southern Brazil
5. Sea turtles	*Caretta caretta*	(Plotkin *et al.*, 1993)	Gulf of Mexico
	Chelonia mydas	(Ferreira, 1968)	Northeastern Brazil

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Dermochelys coriacea	(Bjorndal, 1997)	Global
	Eretmochelys imbricata	(Meylan, 1988)	Caribbean
	Lepidochelys olivacea	(Montenegro Silva *et al.*, 1986) (Bjorndal, 1997)	Western Mexico Global
6. Tunas	*Thunnus alalunga*	(Vaske-Júnior, 2000)	Northeastern Brazil
	Thunnus albacares	(Vaske-Júnior, 2000)	Northeastern Brazil
	Thunnus obesus	(Vaske-Júnior, 2000)	Northeastern Brazil
7. Other large pelagics	*Acanthocybium solandri*	(Vaske-Júnior, 2000)	Northeastern Brazil
	Istiophorus albicans	(Vaske-Júnior, 2000)	Northeastern Brazil
	Makaira nigricans	(Vaske-Júnior, 2000)	Northeastern Brazil
	Sphyraena barracuda	(Vaske-Júnior, 2000)	Northeastern Brazil
	Tetrapturus albidus	(Vaske-Júnior, 2000)	Northeastern Brazil
	Tetrapturus pfluegeri	(Vaske-Júnior, 2000)	Northeastern Brazil
8. Dolphinfish	*Coryphaena hippurus*	(Vaske-Júnior, 2000)	Northeastern Brazil
9. Dolphinfish juveniles	*Coryphaena hippurus*	(Vaske-Júnior, 2000) (Oxenford and Hunte, 1999)	Northeastern Brazil Eastern Caribbean
10. Swordfish	*Xiphias gladius*	(Vaske-Júnior, 2000)	Northeastern Brazil
11. Sharks	*Carcharhinus falciformis*	(Vaske-Júnior, 2000)	Northeastern Brazil
	Carcharhinus longimanus	(Vaske-Júnior, 2000)	Northeastern Brazil
	Carcharhinus signatus	(Vaske-Júnior, 2000)	Northeastern Brazil
	Prionace glauca	(Vaske-Júnior, 2000)	Northeastern Brazil

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Rhizoprionodon porosus	(Silva and Almeida, 2001)	Northeastern Brazil
	Sphyrna lewini	(Vaske-Júnior, 2000)	Northeastern Brazil
12. Rays	*Dasyatis americana*	(Gilliam and Sullivan, 1993)	Bahamas
	Dasyatis centroura	(Bowman *et al.*, 2000)	Northeastern US
	Dasyatis say	(Bowman *et al.*, 2000)	Northeastern US
	Myliobatis freminvillii	(Bowman *et al.*, 2000)	Northeastern US
	Pteroplatytrygon violacea	(Vaske-Júnior, 2000)	Northeastern Brazil
	Rhinoptera bonasus	(Bowman *et al.*, 2000)	Northeastern US
	Rioraja agassizii	(Muto *et al.*, 2001)	Southeastern Brazil
	Torpedo nobiliana	(Bowman *et al.*, 2000)	Northeastern US
13. Small pelagics	*Anchoa hepsetus*	(DeLancey, 1989)	South Carolina, US
	Anchoa januaria	(Sergipense *et al.*, 1999)	Southeastern Brazil
	Cetengraulis edentulus	(Sergipense *et al.*, 1999)	Southeastern Brazil
	Chloroscombrus chrysurus	(Chaves and Umbria, 2003) (Vega-Cendejas *et al.*, 1994)	Southeastern Brazil Yucatan Peninsula, Mexico
	Opisthonema oglinum	(Furtado-Ogawa, 1970) (Vasconcelos Filho, 1979)	Northeastern Brazil Northeastern Brazil
14. Needlefishes	*Hemiramphus balao*	(Berkeley and Houde, 1978)	Southeast Florida
	Hemiramphus brasiliensis	(Berkeley and Houde, 1978)	Southeast Florida
	Strongylura marina	(Arceo-Carranza *et al.*, 2004)	Eastern Mexico
15. Southern red snapper	*Lutjanus purpureus*	(Monteiro and Barroso, 1963)	Northeastern Brazil

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
16. Large carnivorous reef fishes	*Epinephelus guttatus*	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Epinephelus itajara	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Gymnothorax moringa	(Young and Winn, 2003)	Belize
	Lutjanus griseus	(Harrigan *et al.*, 1989)	Florida, US
	Lutjanus jocu	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Mycteroperca bonaci	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Rachycentron canadum	(Arendt *et al.*, 2001)	Chesapeake Bay, US
17. Small carnivorous reef fishes	*Aulostomus maculatus*	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Bodianus rufus	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Halichoeres bivittatus maculipinna	(Sierra *et al.*, 1994)/FishBase	Cuba
	Lutjanus apodus	(Morinière *et al.*, 2003)	Netherlands Antilles
	Selar crumenophthalmus	(Roux and Conand, 2000)	Southwestern Indian Ocean
18. Herbivorous reef fishes	*Acanthurus chirurgus*	(Dias *et al.*, 2001)	Northeastern Brazil
	Acanthurus bahianus	(Dias *et al.*, 2001)	Northeastern Brazil
	Acanthurus coeruleus	(Dias *et al.*, 2001)	Northeastern Brazil
	Kiphosus incisor	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Scarus guacamaia	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands
	Sparisoma radians	(Randall, 1967)/FishBase	Puerto Rico/US Virgin Islands

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
19. Omnivorous reef fishes	*Acanthostracion quadricornis*	(Vega-Cendejas *et al.*, 1994)	Yucatan Peninsula, Mexico
	Albula vulpes	(Crabtree *et al.*, 1998)	South Florida, US
	Archosargus rhomboidalis	(Vega-Cendejas *et al.*, 1994)	Yucatan Peninsula, Mexico
	Balistes vetula	(Schiller and Garcia, 2000)	Colombian Caribbean
	Chilomycterus schoepfii	(Motta *et al.*, 1995)	Florida, US
	Diodon holocanthus	(Huizar and Carrara, 2000)	Western Mexico
	Diodon hystrix	(Huizar and Carrara, 2000)	Western Mexico
	Eucinostomus argenteus	(Vega-Cendejas *et al.*, 1994)	Yucatan Peninsula, Mexico
	Eucinostomus gula	(Vega-Cendejas *et al.*, 1994)	Yucatan Peninsula, Mexico
	Haemulon plumieri	(Vega-Cendejas *et al.*, 1994)	Yucatan Peninsula, Mexico
	Lutjanus analis	(Duarte and Garcia, 1999b)	Colombian Caribbean
	Lutjanus synagris	(Duarte and Garcia, 1999a) (Rodrigues, 1974)	Colombian Caribbean Northeastern Brazil
20. Demersal fishes	*Bairdella ronchus*	(Vendel and Chaves, 1998)	Southern Brazil
	Citharichthys spilopterus	(Castillo-Rivera *et al.*, 2000)	Gulf of Mexico
	Dormitator maculatus	(Teixeira, 1994)	Northeastern Brazil
	Eleotris pisonis	(Teixeira, 1994)	Northeastern Brazil
	Etropus crossotus	(Chaves and Serenato, 1998)	Southern Brazil
	Eucinostomus melanopterus	(Chaves and Robert, 2001)	Southern Brazil
	Isopisthus parvipinnis	(Soares and Vazzoler, 2001b)	Southeastern Brazil

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Larimus breviceps	(Soares and Vazzoler, 2001b)	Southeastern Brazil
	Menticirrhus littoralis	(DeLancey, 1989)	South Carolina
	Micropogonias furnieri	(Soares and Vazzoler, 2001b)	Southeastern Brazil
	Ophioscion punctatissimus	(Zahorcsak *et al.*, 2000)	Southeastern Brazil
	Orthopristis ruber	(Zahorcsak *et al.*, 2000)	Southeastern Brazil
	Paralonchurus brasiliensis	(Soares and Vazzoler, 2001a)	Southeastern Brazil
	Prionotus punctatus	(Braga and Braga, 1987) (Teixeira and Haimovici, 1989)	Southeastern Brazil Southern Brazil
	Stellifer rastrifer	(Chaves and Vendel, 1998)	Southern Brazil
	Symphurus tessellatus	(Chaves and Serenato, 1998)	Southern Brazil
	Umbrina coroides	(Zahorcsak *et al.*, 2000)	Southeastern Brazil
21. Mullets	*Mugil curema*	(Dualiby, 1988)	Colombian Caribbean
	Mugil curvidens	(González-Sansón and Alvarez-Lajonchere, 1978)/FishBase	Cuba
	Mugil incilis	(Dualiby, 1988)	Colombian Caribbean
	Mugil liza	(Dualiby, 1988)	Colombian Caribbean
	Mugil trichodon	(González-Sansón and Alvarez-Lajonchere, 1978)/FishBase	Cuba
22. Goatfish	*Pseudupeneus maculatus*	(Randall, 1967)/FishBase	West Indies
23. Benthopelagic fishes	*Centropomus ensiferus*	(Sierra *et al.*, 1994)	Cuba
	Hymenocephalus italicus	(Macpherson, 1979)	Western Mediterranean Sea
	Neobythites gilli	(Nielsen, 1999)	Atlantic

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Nezumia aequalis	(Macpherson, 1979)	Western Mediterranean Sea
	Oligoplites palometa	(Duque-Nivia *et al.*, 1996) (Azevedo-Araújo and Vasconcelos Filho, 1979)	Colombian Caribbean Northeastern Brazil
	Trachinotus carolinus	(DeLancey, 1989)	South Carolina, US
	Trichiurus lepturus	(Bowman *et al.*, 2000) (Portsev, 1980)	Northwestern Atlantic Western India
24. Bathypelagic fishes	*Alepisaurus ferox*	(Vaske-Júnior, 2000)	Northeastern Brazil
	Argyropelecus aculeatus	(Hopkins and Baird, 1985)	Gulf of Mexico
	Argyropelecus affinis	(Kinzer and Schulz, 1988)	Central Equatorial Atlantic
	Argyropelecus sladeni	(Kinzer and Schulz, 1988)	Central Equatorial Atlantic
	Ceratoscopelus warmingii	(Kinzer and Schulz, 1985) (Duka, 1986)	Central Equatorial Atlantic Tropical Atlantic
	Diaphus dumerilii	(Kinzer and Schulz, 1985)	Central Equatorial Atlantic
	Diaphus taaningi	(Baird *et al.*, 1975)	Venezuela
	Gempylus serpens	(Vaske-Júnior, 2000)	Northeastern Brazil
	Notolychnus valdiviae	(Kinzer and Schulz, 1985)	Central Equatorial Atlantic
	Sternoptyx diaphana	(Hopkins and Baird, 1985) (Hopkins and Baird, 1973)	Gulf of Mexico Atlantic and Pacific oceans
	Sternoptyx pseudobscura	(Hopkins and Baird, 1985)	Gulf of Mexico
25. Spiny lobsters	*Panulirus argus*	(Colinas-Sanchez and Briones-Fourzán, 1990) (Fernandes, 1971)	Quintana Roo, Mexico Northeastern Brazil
26. Other lobsters	*Parribacus antarticus*	(Lau, 1988)	Indo-Pacific

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
27. Shrimps	*Farfantepenaeus brasiliensis*	(Albertoni *et al.*, 2003)	Southeastern Brazil
	Farfantepenaeus subtilis	(Stoner and Zimmerman, 1998)	Western Puerto Rico
	Litopenaeus schmitti	(Tararam *et al.*, 1993)	Southeastern Brazil
	Xiphopenaeus kroyeri	(Branco and Moritz Júnior, 2001)	Southern Brazil
28. Crabs	*Aratus pisonii*	(Brogim and Lana, 1997)	Southern Brazil
	Callinectes danae	(Branco and Verani, 1997)	Southern Brazil
	Callinectes ornatus	(Branco *et al.*, 2002) (Mantelatto and Christofoletti, 2001) (Mantelatto *et al.*, 2002)	Southern Brazil Southeastern Brazil Southeastern Brazil
	Callinectes salpidus	(Laughlin, 1982)	Florida, US
	Ocypode quadrata	(Wolcott, 1978)	North Carolina, US
	Pachygrapsus transversus	(Furtado-Ogawa, 1977)	Northeastern Brazil
	Ucides cordatus	(Wolff *et al.*, 2000, based on Rademaker, 1998)	Northern Brazil
29. Squids	*Loligo plei*	(Arocha and Urosa, 1991)	Venezuela
	Lollingula brevis	(Dragovich and Kelly Jr., 1964)	Florida, US
	Ommastrephes bartramii	(Lipinski and Linkowski, 1988)	Argentina and Uruguay
	Ornithoteuthis antillarum	(Arkhipkin *et al.*, 1998)	Central-east Atlantic
	Sthenoteuthis pteropus	(Nigmatullin and Toporova, 1982)	Atlantic
30. Octopus	*Octopus vulgaris*	(Smith, 2003)	South Africa

Appendix 4: Sources used to estimate the diet composition for all species included in the functional groups used in the trophic model of the marine ecosystem off northeastern Brazil* (continued).

GROUP	SPECIES	SOURCE	AREA
	Eledone massyae	(Perez and Haimovici, 1995)	Southern Brazil
	Scaeurgus unicirrhus	(Aluigi and Spedicato, 1994)	Mediterranean Sea
31. Other molluscs	*Crassostrea rhizophorae*	(Gomes Azevêdo, 1980)	Northeastern Brazil
	Macoma constricta	(Arruda *et al.*, 2003)	Southeastern Brazil
	Mytella falcata	(Eskinazi-Leça, 1969)	Northeastern Brazil
	Olivella minuta	(Arruda *et al.*, 2003)	Southeastern Brazil
	Tagelus pleibeus	(Arruda *et al.*, 2003)	Southeastern Brazil
32. Other crustaceans	Amphipoda/Isopoda/Tanaidacea	(Opitz, 1996)	Caribbean
33. Other invertebrates	Echinodermata	(Telles, 1998) (Tararam *et al.*, 1993)	Northeastern Brazil Southeastern Brazil
	Porifera	(Telles, 1998)	Northeastern Brazil
	Polychaeta/Ascidia/Briozoa/ Sipunculida	(Telles, 1998)	Northeastern Brazil
34. Zooplankton	Various	(Telles, 1998) (Vasconcellos, 2002) (Mohammed, 2003)	Northeastern Brazil South Atlantic Southern Caribbean
35. Corals	Various	(Telles, 1998)	Northeastern Brazil
36. Microfauna	Various	(Mohammed, 2003)	Southern Caribbean

* Groups 37 to 40 are not included as they are primary producers and group 41 is a detritus group.