NATIONAL REPORT OF BRAZIL

by

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1. INTRODUCTION

The shrimp fishery in northern Brazil is one of the most important fishing activities in the country. A main fishing area is located between the mouth of Parnaíba River and the border of French Guiana, along the coast of the States of Maranhão, Pará and Amapá. Fisheries are conducted by artisanal, small scale and industrial vessels and the most important species caught are pink shrimp (*Penaeus subtilis*), white shrimp (*Penaeus schmitti*), and sea-bob shrimp (*Xiphopenaeus kroyeri*).

Belém, in the State of Pará, is the main landing port and the base of the fishing industry. Some industrial vessels operate from Macapá, in the State of Amapá and Fortaleza, in the State of Ceará, where there are also some processing plants. Off the eastern cost of the State of Maranhão there is an important white shrimp fishing ground and some small scale vessels operate from there. Artisanal landings occur in many communities along the coast and the catches are composed of the sea-bob shrimp, white shrimp and juveniles of pink shrimp.

This paper presents a summary of the current knowledge on the biology of the shrimp species and information on the fisheries. It consists of a revision and actualization of the National Report presented to the Third Workshop on the Biological and Economic Modeling of the Shrimp Resource on the Brazil-Guyana Shelf. Unfortunately, due to problems with the data collection system and the lack of sustained fishery research programmes, important progress in the status of knowledge of this fishery has not been observed in the last few years.

2. FISHING GROUNDS

As stated before, the shrimp fisheries in the North Region of Brazil take place mainly in the area between the mouth of Parnaíba River, at the border of the States of Piauí and Ceará, and the mouth of Oiapoque River, at the border of French Guiana. Three main fishing sub-areas may be identified within this Region whose limits and main characteristics are described by Studart-Gomes (1988), as follows:

(i) Maranhão coast: from the mouth of the Parnaíba River to Cape Gurupí. The fishing grounds are moderately deep (20-40m), consisting of hard sediments and clear waters. The fisheries are concentrated in the eastern coast of Maranhão, near the mouth of Parnaíba river, in the so called Tutóia area, with a high contribution of the white shrimp. The western part of this area is dominated by strong tidal currents, with irregular depth and thick layers of mud and rocks, where it is almost impossible to trawl.

(ii) Amazonas: from the mouth of the Pará River to the eastern coast of the State of Amapá. This area is under strong influence of the Amazon River. Fishing grounds are located at depths between 40m to 60m in muddy waters and the substratum varies between mud, sand and rocks.

(iii) Amapá coast: this area comprises the western coast of the State of Amapá up the mouth of Oiapoque River. The fishing grounds are deeper, between 60m and 100m, and the sea bottom is irregular and rocky, with the presence of canyons. There are strong currents that are difficult for trawling operations, requiring great skill from the captains of the vessels.

Along the coastline, there are many estuaries where artisanal fisheries catch sea bob shrimp (*X. kroyeri*), white shrimp (*P. schmitti*) and juveniles of pink shrimp (*P. subtilis*). The predominance of one species

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over the others depends on the area, the season and environmental conditions, especially the salinity. In Maranhão estuaries there is evidence of predominance of the sea-bob shrimp.

3. DESCRIPTION OF THE SHRIMP FISHERY - PRESENT SITUATION

3.1 Fishing Activities

3.1.1 Industrial fleet

Most of the industrial vessels operating in the shrimp fisheries in the north coast of Brazil are based in Belém/Macapá (159), in the States of Pará/Amapá. Some vessels are based in Fortaleza and Camocim, in the State of Ceará, and others in Parnaíba, State of Piauí. The number of Brazilian vessels in operation in each state since 1970 is shown in Table 1.

Besides this fleet, many foreign vessels had operated in Brazilian waters, under international fishing agreements that ended in 1978. Since then, only national vessels or Brazilian flag vessels under renting contracts, have operated in the area. In 1985, the Brazilian government began to stimulate the end of the renting contracts system. As consequence, some rented vessels were incorporated to the national fleet and the renting system was extinguished before the end of the 80's. Since then exclusively national vessels have made up the fleet.

In general, the shrimp trawlers are of the American type shrimp trawlers, made of steel, with total length varying between 19 and 25 m, powered with engines of 235 to 540 horsepower, and operating with a double-rig system. The vessels are equipped with freezing equipment and instruments for satellite navigation, echosounding and radio communication. Some of the vessels from Piauí, however, are smaller in size and a few of them operate with single trawls.

Based on data of the States of Pará and Ceará a mean of six trips per vessel per year was undertaken in 1994, with an average duration of 36 days. The crew is generally composed of 5 fishermen. A few larger vessels have 6 men on board.

The fleet based in Pará/Amapá operates mainly in the areas defined as II and III. The fishing season is from February to November, with a closed season from December to January. The best yields are obtained from February to June, when day and night fishing operations are carried out. After this period the operations are concentrated during night time and some vessels move to fish in the Maranhão area. In general, each haul takes about 6 (six) hours.

The fleet from Ceará operates along all the coast of the region. Most of these vessels belong to fishing companies established both in the States of Ceará and Pará, which gives them more flexibility in operations. On the other side, the vessels from Piauí concentrate their activities in the Maranhão area.

The shrimp by-catch is still an issue in the shrimp fishery in northern Brazil. According to Damasceno, F.G. (1988) about 7.2 kg of by-catch are caught per kilogram of shrimp of which 4.4 kg are useful for human consumption. More recent information is not available, but it is believed that the above rates have not changed significantly since then. Some vessels land small amounts of species of high commercial value, but most of this fish is caught by hook in directed fisheries.

3.1.2 Small scale and artisanal fleet

The small scale fishery is concentrated in Maranhão area, where small motorized trawlers, with length between 7 to 11 m, are commonly used to catch mainly sea-bob shrimp (*X. kroyeri*) and white shrimp (*P. schmitti*).

The artisanal fishery is conducted in estuaries and shallow waters, but detailed information on this fishery is not available. Most of the fishing operations are done with artisanal fixed gear or hand-operated trawl nets.

3.1.2.1 Fishery with fixed-frame trawls ("puça-de-arrasto" or "guizo")

The fishery is performed with a trawling net with a fixed rectangular mouth and a cone-shaped body. Two wooden stacks are used as towing bridles. The length varies between 4 to 6 meters, and the height is 1.5 meters, with a panel made of synthetic fiber and meshes of 10-20 mm in the body and less than 10 mm in the codend. Operated by two fishermen, one each side, the net is trawled in shallow waters, along the margins of the rivers and contributors ("igarapés"). It is used mainly in the State of Pará, during the night, in the period between the end of the low tide and the beginning of the high tide.

3.1.2.2 Fishery with cast nets ("tarrafa")

A cast net with the shape of a cone is used in this fishery. The panel is made of synthetic fiber with mesh size from 10 to 20 mm and the opening diameter varies from 1.6 to 2.8 meters. It is operated by one fisherman and set by hand. It is mainly used to catch large white shrimp during the second half of the year.

3.1.2.3 Fishery with "zangaria"

In this fishery a fixed trap is used with a structure made of stakes of wood covered with a synthetic fiber panel with meshes varying from 20 to 30 mm. It is set in semi-circular form, in open areas within bays. The total length of the trap varies normally from 500 to 900 meters but sometimes it can reach 2000 meters. This gear is used mainly in the coast of Maranhão, being forbidden in the State of Pará, due to the high catch of juvenile fish.

3.2 Processing activity

All the shrimp produced by the industrial fishery is processed as frozen products in the form of head-off and some as whole shrimp. In general, the de-heading process takes place on board. The tails are immersed in a solution of sodium metabisulphite and placed in polyethylene bags to be frozen. After landing, the catch is defrosted, classified by size according to international standards (number of tails/pound), packed in 5-pound boxes and frozen again.

The part of the catch that will be processed as whole shrimp is handled with special care on board. The individuals are carefully placed in plastic containers to be frozen. After landing the shrimp is classified by size, manually, packed in 5 pounds boxes, and frozen again.

The shrimp produced by the artisanal fishery is sold fresh or, sometimes, frozen in domestic freezers. A significant amount is cooked in saltwater and sun dried.

3.3 Commercialization

Most of the northern Brazilian shrimp production is exported as frozen tails to the United States of America and Japan. Some whole shrimp is marketed mainly to Japan, as a high quality product.

According to the Syndicate of the Fishing Industry of Pará/Amapá (SINPESCA), the average FOB price per kilogram of frozen shrimp tails, exported from Belém, in the period 1991/94, varied between US$ 7.0 / kg and US$ 24.8 / kg, in the Japan market, and between US$ 6.16 / kg, to US$ 17.05 / kg, in the US market. The average income in this period was about US$ 47,338,489.63.

The market prices vary among companies depending on the final market, quality of the product and average size. The price offered by the Japanese market has been historically higher than the one offered by the US market, but requires high quality.

The small scale and artisanal fishery production is commercialized as fresh, frozen and salted and dried shrimp. Besides the local market, shrimp produced by the artisanal fishery is exported to other states in Brazil.

4. CATCH AND EFFORT

After a period of relative stabilization, the industrial shrimp fishery in northern Brazil has suffered crises in the last years, due to the low catch rates and high costs of operation. Tables 2, 3, 4 and 5 show the performance of the fleet by state of origin, with figures of landings, fishing effort and catch (landing) rates, for the period of 1970 to 1996. For the State of Pará, data are available until 1996 (Table 3) but for other states are not available for the more recent years (Table 4 and 5).

From 1984, when the fleet reached the maximum number of boats allowed, to 1994, it can be observed that the total landings of shrimp, in all the area, oscillated from 3888.4 to 5493.5 tonnes of tails, with the exception of the years of 1987 and 1988, that were atypical, showing record landings of 6435.4 and 6356.5 tonnes of tails, respectively (Table 2). These years were followed by a period of more stabilized landings, varying around the mean of 4300 ton, until 1994. The fishing effort varied from an estimated 30860 days at sea, in 1992, to 49677 days at sea, in 1985 (Table 2).

Considering the data only for the fleet of Pará/Amapá, that are more complete, catch rates for the same period were lowest in 1986, with 99 kg of tails/day at sea. In the following years the fishery recovered and yields oscillated around the mean of 130 kg of tails/day at sea, between 1987 and 1994. The maximum was observed in 1988, with 164 kg of tails/day at sea (Table 3 and Figure 2).

In the last two years of the series, 1995 and 1996, however, the yields of the fishery suffered a sharp decline, reaching the lowest levels for the whole period. The total landings in the area were only 2159.8 and 2264.9 tonnes, with the lowest levels of fishing effort estimated at 22267 and 30608 days at sea, respectively (Table 2). The catch rates of the Pará/Amapá fleet were only 97 and 74 kg of tails/day at sea (Table 3).

5. POPULATION DYNAMICS

Shrimp population dynamics studies in the north of Brazil are conducted by researchers that integrate the Permanent Working Group on Shrimp (GPE), belonging to various institutions. Results of these efforts are published by the National Institute for Environment and Natural Renewable Resources – IBAMA. Isaac et al (1992), also published by IBAMA, provided estimations of the main population parameters and an evaluation of the status of exploitation of the stock. The main results available were presented in the Brazilian Report to the Third Workshop on the Biological and Economic Modeling of the Shrimp Resource on the Brazil-Guiana Shelf and are briefly summarized below.

5.1 Reproduction

The data available suggest the existence of two intensive spawning periods, the first from March to July, and the second from September to October. The average length at which 50% of the females begin to mature for the first time is 110mm. However, spawning usually occurs at lengths of $L_{50\%}$ = 140mm.

5.2 Recruitment

Although the entry of postlarvae into the rivers occurs all year round, the conclusion for the data obtained in 1986 is that there are two peaks of greater recruitment intensity, between February and April, and between July and September. However, the authors recommended to compare these results with others to be obtained from the historical data available.

Recruitment to the open sea also seems to occur in two peaks a year, the first between December and May and the other between July and August. The first is more significant and is evident from higher catch rates during those months. The time between the arrival and departure of the shrimp in the nursery grounds is around two or three months.

5.3 Population Parameters and Stock Assessment

Population parameters, including some biometrics relationships, and the results of the stock assessment are presented in the Table 6.

6. ECONOMIC ASPECTS

An economic analysis of this fishery can not be carried out due to the lack of reliable data on the cost of fishing operations. A total income curve was estimated using Schaefer's production model and Fox's production model. The results showed that the maximum income varied between 46 and 50 million dollars, obtained with an effort between 56 and 79 thousands days at sea (Table 7). The comparison of these results with the estimated income for the northern Brazilian coastal fishery in the last few years indicates that the fishery has reached the level of the maximum economic yield.

7. SECONDARY RESOURCES

Between December 1987 and May 1989, a research project called "Multidisciplinary Study on the Utilization of By-Catch of the Industrial Shrimp Fishery in the Northern Brazil Coast", was carried out and the results were already presented in the previous report. No further research has been implemented in the last few years.

8. MANAGEMENT

The number of vessels established to operate in the fishery is limited to 250. A special license, renewable on an annual basis, is granted to the vessels that are obliged to present logbooks with information on catch and effort. Since 1986 a closed season has been established from December to January. A coastal zone of 10 miles is protected from all forms of trawling in Pará and Amapá State, and 3 miles in Maranhão and Piauí State. There are no specific regulations for nursery grounds, except the prohibition of any type of motorized trawl in these areas.

9. RESEARCH PROGRAMME

From 1977 to 1988, a research programme for shrimp was carried out in the State of Pará, consisting of biological sampling and collection of data on catch and effort. The programme covered both industrial and artisanal fisheries and intended to obtain subsidies to understand the whole life cycle of the species, from its juvenile phase, in the estuaries, to the adult phase, at sea.

From 1989 to 1994, only the collection of catch and effort data has been maintained. In December 1993, a fishery research center, CEPNOR, was created in Belém and initiated a sampling programme for shrimp in factories, nursery areas and at sea. The project aimed to continue the studies on biological and ecological aspects of the shrimp and provide support for the management of the fisheries.

10. REFERENCES

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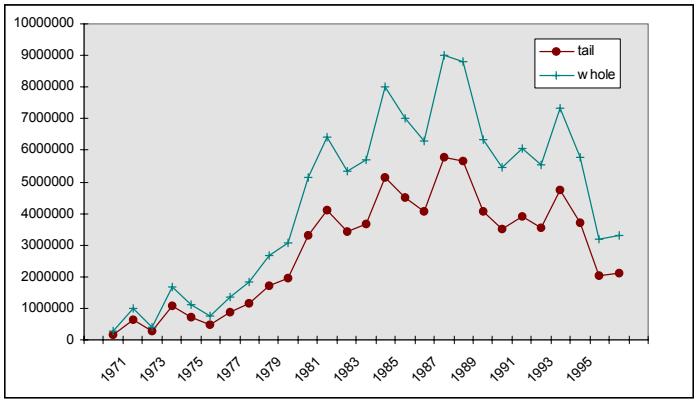

Figure 1: Landings of shrimp in Northern Brazil

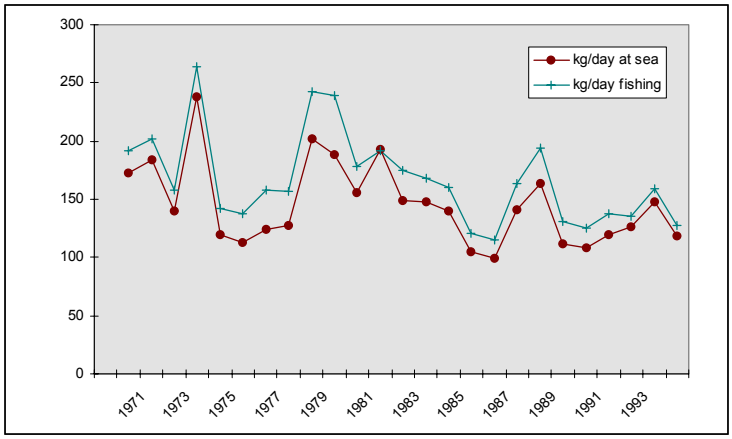

Figure 2: Catch rates of shrimp fisheries in Northern Brazil

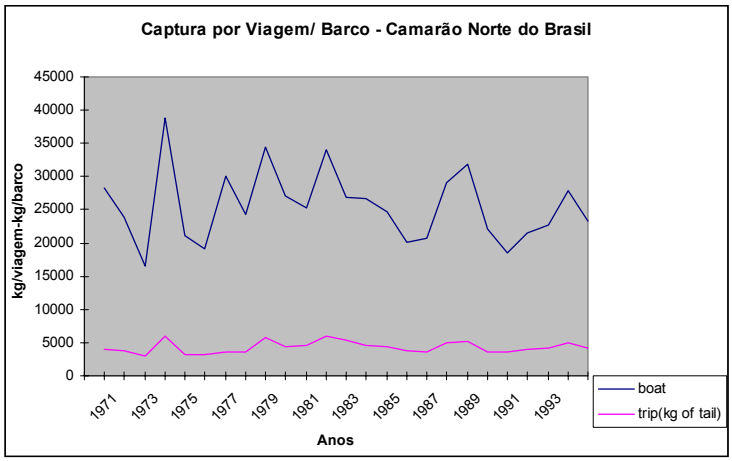

Figure 3: Capture by trip/boat – Shrimp in Northern Brazil

Table 1: Licensed Vessels Operating in the Shrimp Fishery in Northern Brazil

Years	Pará/Amapá	Ceará	Piauí (*)	Total
1970	6			6
1971	27			27
1972	16			16
1973	28			28
1974	34			34
1975	26			26
1976	39			39
1977	48			48
1978	50			50
1979	73	2	11	86
1980	131	8	19	158
1981	121	6	23	150
1982	127	10	18	155
1983	137	24	18	179
1984	208	27	19	254
1985	224	41	22	287
1986	196	40	20	256
1987	198	36	12	246
1988	177	36	15	228
1989	183	42	17	242
1990	189	48	19	256
1991	180	47	16	243
1992	156	43	(**)	
1993	170	20	(**)	
1994	159	25	(**)	
1995	155	(**)	(**)	
1996	158	(**)	(**)	

(*) most vessels are below 18 m
(**) number of boats not available
Source: IBAMA

Table 2: Landing, fishing effort and landing per unit of effort in the industrial shrimp fisheries in northern Brazil

Year	Landing		No. of boats	No. of trips	Days at sea	Landing per boat (kg tails)	Landing per trip (kg tails)	LPUE kg/day at sea
	tail	whole						
1970	169,789	264,871	6	42	987	28,298.2	4,043	172.03
1971	646,485	1,008,517	27	169	3,518	23,943.9	3,825	183.76
1972	264,864	413,188	16	88	1,896	16,554.0	3,010	139.70
1973	1,084,594	1,691,970	28	182	4,550	38,735.5	5,959	238.37
1974	716,625	1,117,935	34	221	5,967	21,077.2	3,243	120.10
1975	495,418	773,632	26	153	4,394	19,054.5	3,238	112.75
1976	871,955	1,360,250	29	248	7,018	30,067.4	3,516	124.25
1977	1,162,124	1,812,913	48	330	9,133	24,210.9	3,522	127.24
1978	1,718,407	2,680,715	50	299	8,502	34,368.1	5,747	202.12
1979	2,063,529	3,219,105	86	493	11,256	23,994.5	4,186	183.33
1980	3,571,165	5,570,908	158	912	23,913	22,602.3	3,916	149.34
1981	4,476,648	6,983,571	150	913	24,684	29,844.3	4,903	181.36
1982	3,770,477	5,881,944	155	807	25,702	24,325.7	4,672	146.70
1983	3,899,217	6,082,779	179	892	27,273	21,783.3	4,371	142.97
1984	5,493,466	8,569,807	254	1,339	40,355	21,627.8	4,103	136.13
1985	5,131,828	8,005,655	287	1,450	49,677	17,880.9	3,539	103.30
1986	4,574,966	7,136,257	256	1,341	46,510	17,871.0	3,412	98.37
1987	6,435,427	10,039,266	246	1,362	46,852	26,160.3	4,725	137.36
1988	6,356,622	9,916,332	228	1,247	39,593	27,879.9	5,098	160.55
1989	4,489,849	7,004,166	242	1,227	39,650	18,553.1	3,659	113.24
1990	3,918,749	6,111,529	256	1,136	36,226	15,307.6	3,450	108.18
1991	4,328,753	6,752,378	243	1,117	36,379	17,813.8	3,875	118.99
1992 (*)	3,888,439	6,065,965			30,860			126.00
1993 (*)	5,256,404	8,199,990			35,758			147.00
1994 (*)	4,071,313	6,351,249			34,213			119.00
1995 (*)	2,159,857	3,369,377			22,267			97.00
1996 (*)	2,264,964	3,533,344			30,608			74.00

(*) Estimates based on data of State of Pará
Source: IBAMA

Table 3: Landing, Fishing Effort and Landing per Unit of Effort in the Industrial Shrimp Fisheries in the State of Pará

Year	Landings		Number of boats	Number of trips	Days at sea	Number of fishing days	Landing per boat (kg of tail)	Landing per trip (kg of tail)	LPUE kg/day at sea	LPUE kg/day fishing
	Tail	Whole								
1970	169,789	264,871	6	42	987	886	28,298	4,043	172	192
1971	646,485	1,008,517	27	169	3,518	3,209	23,944	3,825	184	201
1972	264,864	413,188	16	88	1,896	1,681	16,544	3,010	140	158
1973	1,084,594	1,691,970	28	182	4,550	4,113	38,736	5,959	238	264
1974	716,625	1,117,935	34	221	5,967	5,041	21,077	3,243	120	142
1975	495,418	773,632	26	153	4,394	3,614	19,055	3,238	113	137
1976	871,955	1,360,250	29	248	7,018	5,530	30,067	3,516	124	158
1977	1,162.124	1,812,913	48	330	9,133	7,408	24,211	3,522	127	157
1978	1,718,407	2,680,715	50	299	8,502	7,086	34,368	5,747	202	243
1979	1,971,890	3,076,148	73	446	10,478	8,244	27,012	4,421	188	239
1980	3,301,682	5,150,624	131	733	21,271	18,470	25,204	4,504	155	179
1981	4,111,060	6,413,254	121	679	21,261	21,430	33,976	6,055	193	192
1982	3,426,179	5,344,839	127	639	22.942	19,586	26,978	5,362	149	175
1983	3,663,696	5,715,366	137	783	24,780	21,826	26,742	4,679	148	168
1984	5,126,993	7,998,109	208	1,187	36,695	32,006	24,649	4,319	140	160
1985	4,482,562	6,994,357	224	1,195	42,729	37,061	20,016	3,752	105	121
1986	4,045,966	6,311,707	196	1,120	40,747	35,083	20,643	3,612	99	115
1987	5,772,427	9,004,986	198	1,161	40,941	35,198	29,154	4,972	141	164
1988	5,647,296	8,809,782	177	1.079	34,461	29,180	31,906	4,234	164	194
1989	4,051,157	6,319,805	183	1,120	36,433	30,937	22,137	3,617	111	131
1990	3,510,918	5,477,032	189	1,006	32,279	28,017	18,576	3,490	109	125
1991	3,886,249	6,062,548	180	979	32,632	28,229	21,590	3,970	119	138
1992	3,542,279	5,525,955	156	831	28,092	26,192	22,707	4,263	126	135
1993	4,736,427	7,338,826	170	934	32,148	29,723	27,861	5,071	147	159
1994	3,701,917	5,774,992	159	872	31,151	29,120	23,.262	4,245	119	125
1995	2,033,335	3,172,033	155	609	20,997	19,360	13,118	3,339	97	105
1996	2,125,087	3,315,127	158	656	28,548	26,240	13,450	3,239	74	81

Source: IBAMA/SUPES-Pa

Table 4: Landing, Fishing Effort and Landing per Unit of Effort in the Industrial Shrimp Fisheries in State of Ceará

Year	Landing		Number of boats	Number of trips	Days at sea	Landings per boat kg tails	Landings per trip (kg of tails)	LPUE kg/day at sea
	Tail	Whole						
1979	21,845	34,078	2	3	107	10,922.5	7,281.67	204.16
1980	76,188	118,744	8	11	368	9,523.5	6,926.18	207.03
1981	54,838	85,547	6	12	376	9,139.7	4,569.83	145.85
1982	80,831	126,096	10	19	657	8,083.1	4,254.26	123.03
1983	134,603	209,981	24	34	1,368	5,608.5	3,958.91	98.39
1984	259,622	405,010	27	64	2,118	9,615.6	4,056.59	122.58
1985	447,536	698,159	41	126	4,300	10,915.5	3,551.87	104.08
1986	401,000	625,550	40	136	4,406	10,025.0	2,948.53	91.01
1987	522,000	814,320	36	147	4,770	14,500.0	3,551.02	109.43
1988	553,173	862,950	36	109	3,878	15,365.9	5,074.98	142.64
1989	230,904	360,211	42	51	2,019	5,497.7	4,527.53	114.37
1990	291,151	452,476	48	69	2,795	6,065.6	4,219.58	104.17
1991	286,992	447,230	47	57	2,532	6,106.2	5,034.95	113.35
1992	503,552	785,541	43	125	5,514	11,710.5	4,028.42	91.32
1993	240,175	374,673	20	40	1,928	12,008.8	6,004.38	124.57
1994	372,708	596,333	25	70	3,051	14,908.3	5,324.40	122.16
1995 (*)								
1996 (*)								

(*) No data available - Source: IBAMA / SUPES-Ce

Table 5: Landing, Fishing Effort and Landing per Unit of Effort in the Industrial Shrimp Fisheries in the State of Piauí

Year	Landings		Number of boats	Number of trips	Days at sea	Landing per boat (kg tail)	Landing per trip (kg tail)	LPUE kg/day at sea
	tail	whole						
1979	69,794	108,879	11	44	671	6,345	1,586	104
1980	193,295	301,540	19	168	2,274	10,173	1,151	85
1981	310,750	484,770	23	222	3,047	13,511	1,400	102
1982	263,467	411,009	18	149	2,103	14,637	1,768	125
1983	100,918	157,432	18	75	1,125	5,607	1,346	90
1984	106,851	166,688	19	88	1,542	5,624	1,214	69
1985	200,730	313,139	22	129	2,648	9,124	1,556	76
1986	128,000	199,000	20	85	1,357	6,400	1,506	94
1987	141,000	219,960	12	54	1,141	11,750	2,611	124
1988	156,153	243,600	15	59	1,254	10,410	2,647	125
1989	207,788	324,150	17	56	1,198	12,223	3,711	173
1990	116,680	182,021	19	61	1,152	6,141	1,913	101
1991	155,512	242,600	16	81	1,215	9,720	1,920	128
1992 (*)								
1993 (*)								
1994 (*)								
1995 (*)								
1996 (*)								

(*) No data available
Source: IBAMA / SUPES-P

Table 6: Growth Parameters, L_∞, K and t_0

Data/Method		**L_∞ (mm)**	**K year**	**t_0 years**
Frequency Distribution				
Elefan I	grouped	220	1.08	
	males	187	1.08	
	females	225	1.00	
Wetherall	grouped	213		
	males	178		
	females	208		
Modal Progression Analysis	females	208		
Bhattacharya/Allen	males	171	1.23	-0.528
Bhattacharya/EIAL	males	172	1.2	-0.537
Bhattacharya/Allen	female	218	1.07	-0.441
Bhattacharya/EIAL	female	216	1.12	-0.441
AVERAGE				
General		201	1.11	
Males		177	1.17	
Females		217	1.06	

Adaptated from Isaac *et al.*, 1992

Table 7: Results of the Application of Schaefer and Fox Production Models in the Shrimp Fishery off Northern Brazil

Method	Production			Income	
	MSY	fMSY	r	MSE	fMSE
	(ton)	(days at sea)		(US$x1,000)	(days at sea)
Schaefer	8,490	52,336	0.88	46,602	56,421
Fox	9,090	72,087	0.87	50,138	78,819

Adapted from Isaac *et al.,* 1992