STOCK ASSESSMENT AND FISHERY MANAGEMENT OF THE PINK SHRIMP *Farfantepenaeus brasiliensis* LATREILLE, 1970 AND *F. paulensis* PÉREZ-FARFANTE, 1967 IN SOUTHEASTERN BRAZIL (23° TO 28° S)

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(With 5 figures)

ABSTRACT

Quantitative analyses of the pink shrimp (*Farfantepenaeus brasiliensis* and *Farfantepenaeus paulensis)* fisheries were carried out using data collected from July 1999 to July 2001 from the trawling operations of the fishing fleet based in Santos/Guarujá, SP. According to classical models, the fishery is at its maximum sustainable yield. Therefore, reduction of the fishing effort and adequate season and area closures seem to be the best management actions for the pink shrimp fishery.

Keywords: tropical commercial marine fisheries, pink shrimp, *Farfantepenaeus*, stock assessment, Brazil.

RESUMO

Avaliação de estoques e manejo pesqueiro do camarão-rosa *Farfantepenaeus brasiliensis* Latreille, 1970 e *F. paulensis* Pérez-Farfante, 1967 no Sudeste do Brasil (23°-28° S)

Análises quantitativas do camarão-rosa (*Farfantepenaeus brasiliensis* e *Farfantepenaeus paulensis)* foram realizadas com dados coletados de Julho/1999 a Julho/2001, da frota de arrasto sediada em Santos/Guarujá (SP). De acordo com os modelos clássicos de manejo, a pescaria atingiu seu rendimento máximo sustentável. Assim, uma redução no esforço pesqueiro, combinada com a adoção de defesos periódicos e o fechamento de algumas áreas à pesca, parecem ser as melhores medidas de manejo do estoque para o camarão-rosa.

Palavras-chave: pescarias industriais tropicais marinhas, camarão-rosa, *Farfantepenaeus*, avaliação de estoques, Brasil.

INTRODUCTION

Fishery history

Exploitation of shrimps of the family Penaeidae is a long-standing and widespread activity in many subtropical and tropical areas of the world, especially in coastal areas of several countries (Garcia & Le Reste, 1986).

From the 1950s on, shrimp exploitation increased dramatically due to the development of a specialized industrial fishery. This increase was first observed in the Gulf of Mexico and expanded rapidly throughout several countries in South America, Africa and Oceania. At the end of the 1970s, the international market became highly favorable to the commercialization of this resource, mostly because of high market prices and an increase in the demand by developed countries (*e.g.*, USA, Europe and Japan). Owing to this demand, the world production of shrimps from the

family Penaeidae reached 700 thousand tons in the early 1980s (Isaac *et al.*, 1992).

As a result of this increase, combined with a lack of basic biological information, most of the world's shrimp stocks are now highly or completely exploited, and many species can even be considered over-exploited. Owing to the paucity of basic knowledge about the population dynamics of the most exploited species, any effort towards a rational and well ordered exploitation of the stocks is a difficult task (Garcia & Le Reste, 1986; Isaac *et al.*, 1992).

The beginnings of small-scale shrimp fishery in Brazil's southeast and south is uncertain. The first available data on production rates date from 1945 for the state of Rio Grande do Sul. The small-scale fishery focuses basically on juvenile shrimps in coastal and estuarine areas, which are known to serve as nurseries for the species. The fishing gear utilized varies from one area to another. For example, fishery in southeastern Brazil involves the use of gear such as cast nets, trawl nets, and trawling by two rowing canoes, while in southern Brazil, besides the two aforementioned methods, "aviãzinho", "saco" and "coca" type nets are also commonly employed (Valentini *et al.*, 1991).

Industrial fishing in Brazil took off after World War II with the mechanization of the São Paulo and Rio de Janeiro fishing fleets. The most commonly used gear is the double otter trawl, using wooden or steel boats equipped with lateral masts called tangones, which allow for the simultaneous operation of two twin nets (Mexican method) and sometimes a third, smaller probe net to pre-evaluate the size of the catch (Iwai, 1973; Vendeville, 1990). Fishing is carried out at night, when the yield of the trawlers is higher due to the nocturnal habits of this species. During the day, individuals of this species bury themselves in the substratum. Nevertheless, occasionally catches also occur during the day, using "frighteners" to flush the shrimps out of hiding.

The trawling fleets basically operate on the adult stock in the open sea, ranging from Brazil's northern coast down to the state of Santa Catarina in the south. The history of Brazil's modern-day fishing industry has been marked by several eventful changes, including the replacement of cotton nets for synthetic nets in 1965, the introduction of double nets in the fishing fleets of Rio de Janeiro and São Paulo states, the beginning of industrial fishing in the state of Santa Catarina in 1968; exploitation of the shrimp stocks of the states of Espírito Santo and southern Bahia in 1970, and the experiments with twin net systems in Santa Catarina in 1986 (Valentini *et al.*, 1991).

Today the exploitation of pink shrimps in southern and southeastern Brazil is stable, with a fleet of almost 400 trawlers officially permitted by Brazil's Federal Environmental Agency (IBAMA) to exploit this resource. The fleet operates with wooden-hulled trawlers having an average total length of 18.5 m, average gross tonnage of 55 t and 246 HP engines. In southeastern Brazil, the São Paulo state fleet represents 59% of the country's fishing trawlers, followed by Santa Catarina (20%), Rio de Janeiro (18%), Espírito Santo (3%), and Rio Grande do Sul (0.4%) (IBAMA, 1997).

Worldwide, Brazil ranks 12th in terms of shrimp catches and 6th in the catch of the family Penaeidae (FAO, 1998). Between 1984 and 1985, shrimps represented about 6% of the weight and approximately 24% of the profits deriving from the total fishery production of southeastern and southern Brazil. In 1987, pink shrimp fishery alone represented 16% of the entire shrimp catch in the area (Valentini *et al.*, 1991).

Data garnered from 1965 to 1999 (D'Incao *et al.*, 2002) on Brazil's pink shrimp (*F. brasiliensis* and *F. paulensis*) fishery in the country's southeast and south indicates that the highest total stock catch (16,028 tons) occurred in 1972 and the lowest (2,008 tons) in 1998. These values coincide with the highest and lowest values (9,832 and 570 tons), respectively, achieved by small-scale fishery in the same years. The best results obtained by industrial fishing were recorded from 1969 (7,102 tons) to 1972 (6,797 tons), probably due to the federal government's policy of fiscal incentives for the fishing industry adopted at that time. This policy strongly favored shrimp fisheries because of its high economic value and the fast return on investments resulting from a rapid growth of the export market. The total production of pink shrimp in southeastern and southern Brazil expanded up to 1972, after which it showed a declining trend, albeit with peaks in 1979 (12,780 tons) and 1985 (12,511 tons), thereafter dropping to extremely low values in 1994, 1998 and 1999 (2,100, 2,008 and

2,207 tons, respectively) (Valentini *et al.*, 1991; D'Incao *et al.*, 2002).

The Permanent Shrimp Study Group (Grupo Permanente de Estudos de Camarões – GPE Camarão) has made several assessments of the shrimp stock of southeastern and southern Brazil. In 1984, the existing fishery data were divided into two periods: the first from 1965 to 1972 and the second starting in 1973. From 1992 to 1994, a group of specialists attending technical meetings promoted by IBAMA reorganized the historical shrimp production data, dividing them into three periods: a) 1965-1972, b) 1973-1986, and c) 1987-1994. The reason behind this reorganization was the discovery that the intensive exploitation of the stock had led to a break in the original stock balance, which settled to a lower level. An analysis of the historical data on industrial fishing yield from 1965 to 1994 shows a gradual increase up to 1969, with a production of 7,102 tons. This upward trend in yields was followed by a decline until 1973, when the catch was down to 2,283 tons. From 1974 to 1994, industrial fishing yields varied from 3,600 tons in 1984 to 1,476 tons in 1994 (Valentini *et al.*, 1991; IBAMA, 1997). This period was followed by a abrupt decline to the 948 tons recorded in 1999 (D'Incao *et al.*, 2002).

These figures clearly illustrate the sharp reduction in the abundance of industrial fishing yields, with pink shrimp fishery revealing three distinct periods, the first up to 1972, with an average CPUE (catch per unit effort) of 16.57 Kg.h^{-1}, the second from 1973 to 1986, with an average of 5.23 Kg.h^{-1}, and the third from 1987 to 1995, with an average of 3.81 Kg.h^{-1} (D'Incao *et al.*, 2002).

Fishery regulation and control

Pink shrimp fishing in southeastern and southern Brazil was officially regulated in the late 1960s. Since then, several additional measures have been adopted to limit the fleet (through the concession of special fishing permits), the size of individuals caught by small-scale fisheries, the fishing net mesh size and type of fishing gear, to delimit regulated fishing areas and, starting in 1983, introduction of the prohibition against year-round fishing and establishment of a legal fishing season starting the following year.

The current legislation for shrimp fishery in southeastern Brazil is based on two main objectives: stabilization of the fishing fleet and maintenance of a period when fishery is prohibited in order to protect the recruitment.

The ban period recommended by the GPE, which underpinned the old SUDEPE (Fishing Development Superintendence,) in the structuring of this action in 1983, was 120 days, beginning on February 1 and ending on May 31, when recruitment of the pink shrimp occurs. However, several actions by SUDEPE, which resulted in the relaxation of the prohibition in some years until its complete suppression in 1988, minimized the results achieved through the initial control. The ban for 2001 was established from March 1 to May 31 (Government Directive 074/2001 IBAMA/MMA).

In recent years, the species' productivity and abundance has been higher than during the years preceding the adoption of the ban. However, these improved conditions have led to the addition of new fishing boats, with and without permits, to the fleet, resulting in the increased exploitation of the resource. Thus, the interdiction has not led to a reduction in the fishing effort, as originally intended (SUDEPE/PDP, 1988; Isaac *et al.*, 1992; Valentini *et al.*, 1991; IBAMA, 1991; 1993; 1997).

Because of the economic importance of the pink shrimp fishery in southeastern and southern Brazil, and due to the steadily declining yield year after year despite the adoption of controlling actions, efforts are required to study the population dynamics of this resource, allowing for the evaluation and definition of the extent to which current management actions effectively preserve this resource.

Most of the studies carried out to date on the pink shrimp of southeastern and southern Brazil investigated the two species, *Farfantepenaeus brasiliensis* and *F. paulensis*, in tandem. This may lead to misleading conclusions about the stocks since, despite their similar habits, these species show subtle and important biological differences (Valentini *et al.*, 1991; IBAMA, 1991; 1993; 1997).

As mentioned earlier, actions aimed at managing the pink shrimp fishery are open to criticism. Although the results indicate that the ban produced reasonable results, the stocks are still over-exploited and far from a state of equilibrium; indeed, they are at serious risk of collapsing.

This study proposed to evaluate the stocks of both pink shrimp species and identify the level of maximum sustainable fishing effort, thereby preventing a collapse while allowing for the maximization of profits. Also proposed was an analysis of the current methods used in fishery control.

MATERIALS AND METHODS

From June 1999 through June 2001, except for the months of March and April 2000 and March through May 2001 – the ban period, length measurements and data on fishery statistics were garnered at the main fish depots in the municipality of Santos. This is a coastal city in the state of São Paulo, which concentrates the highest number of landings of industrial pink shrimp fishing in southern and southeastern Brazil. This concentration is due mostly to the fact that the São Paulo trawling fleet is the only one whose target species is the pink shrimp, whereas the fleets of other states have definitely opted for multispecific industrial fishing (Perez *et al.*, 2001).

The masters of 73 shrimpers were interviewed during 217 visits, representing an average of 11 boats per month, which resulted in the following information: the fishing area (location, depth and distance from the coast), dates at the beginning and end of the trips, as well as place of departure and landing, number of days at sea, amount and duration of the trawl, and the quantity of each catch, mollusks and shrimps, etc.

In 76 samplings collected during the period, a total of 6,861 pink shrimps of both species were individually handled in order to obtain data on the total length (Lt) and carapace length (Lc) in millimeters, the total weight (Wt) in grams, the sex, and the stage of female maturity of both species. The two species were differentiated by observing that *F. brasiliensis* has a rounded spot on the 3rd and 4th tergolateral plates on the abdomen (Pérez-Farfante, 1988). The total length, corresponding to the distance from the rostral extremity to the *telson* extremity, was measured with a special shrimp ruler graded in millimeters. Carapace length was measured with a precision caliper (0.01 mm) from the post-orbital angle to the dorsal posterior edge of the carapace (Isaac *et al.*, 1992; Ruffino, 1991). Weight was quantified with a precision balance

(0.01 g). The length measurements were grouped into classes and the monthly frequency per class was calculated. This was done per species per sex, separately or grouped. Sexual differentiation was determined by the macroscopic observation of the presence of *petasma* or *thelycum* in males and females, respectively.

Data analysis

Parameters associated with growth, mortality and the weight-length ratios used in stock evaluation models were taken from Leite Jr. & Petrere Jr. (submitted).

The data on the catch structure by age or length classes were analyzed based on the cohort analysis of Jones (1984) with the aid of the cohort analysis of Sparre & Venema (1997).

The pink shrimp stocks were assessed based on the following approaches: Schaefer and Fox's global production models, Beverton & Holt's model, the predictive cohort analysis based on the ength structure developed by Jones (1984), and Thompson & Bell's model (Sparre & Venema, 1997).

RESULTS

Length structure cohort analysis

A cohort analysis was carried out separately for the two species studied here. For the input values, the growth parameters used were obtained by ELEFAN-1, the estimates of natural mortality were calculated by Pauly's method (1980), and the terminal E (exploitation rate) used was 0.5.

Tables 1 and 2 list the results of the cohort analysis for the period of Jun 1999 to Dec 2000 (19 months). Columns 1 and 2 represent the length classes, column 3 shows the relative age in years for each length class, column 4 indicates the permanence time of each individual in each length class, column 5 indicates natural mortality (M), columns 6 and 14 represent, respectively, the catches by number of individuals and by weight (Kg) during the study period, column 7 shows the number of individuals that reached each class at the beginning of the period, columns 8, 9 and 10 show, respectively, exploitation rates (E), fishing mortality (F) and total mortality (Z), column 11 represents the average weight (Kg) of each length class,

TABLE 1

Cohort Analyses for the Pink shrimp *Farfantepenaeus brasiliensis* in Brazil's southeastern/southern region from June 1999 to December 2000.

Growth Parameters			Natural Mortality and Exploitation Rate			Total Weight (Wt)/Total length (Lt) relationship							
L_∞ = 29.00 (cm) K = 1.96 (19 months) t_0 = 0.00			M = 2.82 (19 months) E term. 0.50			a = 0.01 b = 3.03 W_∞ = 224 (g)							
1	2	3	4	5	6	7	8	9	10	11	12	13	14
L1 (cm)	L2 (cm)	t (years)	Δt (years)	H	C (N°)	N	E	F	Z	W (Kg)	N Δt (N°)	B Δt (N°)	C (Kg)
9	10	0.19	0.03	1.04	17481	13309560	0.0	0.1	2.9	0.01	335003	2539	132
10	11	0.22	0.03	1.04	43663	12347928	0.0	0.1	3.0	0.01	326593	3353	448
11	12	0.24	0.03	1.04	133430	11383818	0.1	0.4	3.2	0.01	316281	4280	1805
12	13	0.27	0.03	1.04	152631	10359002	0.2	0.5	3.3	0.02	304040	5298	2660
13	14	0.30	0.03	1.05	216971	9349484	0.2	0.7	3.6	0.02	290044	6383	4775
14	15	0.34	0.04	1.05	374779	8315072	0.3	1.4	4.2	0.03	271769	7429	10244
15	16	0.37	0.04	1.05	592002	7174356	0.5	2.4	5.2	0.03	246016	8232	19810
16	17	0.41	0.04	1.06	747229	5889000	0.6	3.5	6.3	0.04	212005	8576	30226
17	18	0.45	0.04	1.06	541395	4544270	0.5	3.0	5.9	0.05	177694	8592	26179
18	19	0.49	0.05	1.07	450090	3502073	0.5	3.0	5.9	0.06	148332	8490	25760
19	20	0.54	0.05	1.08	541973	2633934	0.6	4.6	7.4	0.07	117172	7867	36390
20	21	0.60	0.06	1.09	615878	1761732	0.7	7.7	10.6	0.08	79523	6214	48126
21	22	0.66	0.07	1.10	324189	921733	0.7	7.0	9.8	0.09	46535	4202	29271
22	23	0.72	0.08	1.12	207497	466393	0.7	8.3	11.1	0.10	25139	2605	21505
23	24	0.80	0.09	1.14	91067	188046	0.7	8.0	10.8	0.12	11401	1348	10769
24	25	0.90	0.11	1.17	37975	64847	0.8	8.8	11.6	0.13	4312	579	5096
25	26	1.01	0.15	1.23	7710	14719	0.7	6.1	9.0	0.15	1256	190	1168
26	∞	1.16			1734	3467	0.5	2.8	5.6	0.18	615	109	306
					Total	Total	Mean	Mean	Mean	Mean	Total	Total	Total
					5097696	92229433	0.5	3.8	6.6	0.07	2913731	86286	274672

TABLE 2

Cohort Analyses for Pink shrimp *Farfantepenaeus paulensis* in Brazil's southeastern/southern region from June 1999 to December 2000.

	Growth Parameters $L_\infty = 27.50$ (cm) $K = 2.12$ (19 months) $t_0 = 0.00$			Natural Mortality and Exploitation Rate $M = 2.99$ (19 months) E term. 0.50					Total Weight (Wt)/Total length (Lt) relationship $a = 0.01$ $b = 3.04$ $W_\infty = 183$ (g)				
1	2	3	4	5	6	7	8	9	10	11	12	13	14
L1 (cm)	L2 (cm)	t (years)	Δt (years)	H	C (N°)	N	E	F	Z	W (Kg)	N Δt (N°)	B Δt (N°)	C (Kg)
9	10	0.19	0.03	1.04	2380	13422392	0.0	0.01	3.0	0.01	338099	2436	17
10	11	0.21	0.03	1.04	6936	12408250	0.0	0.02	3.0	0.01	330133	3226	68
11	12	0.24	0.03	1.05	41223	11413391	0.0	0.1	3.1	0.01	321328	4142	531
12	13	0.27	0.03	1.05	144193	10410593	0.1	0.5	3.5	0.02	310108	5152	2396
13	14	0.30	0.03	1.05	265608	9338402	0.2	0.9	3.9	0.02	294830	6192	5578
14	15	0.34	0.04	1.06	682676	8190516	0.5	2.5	5.5	0.03	269493	7035	17821
15	16	0.37	0.04	1.06	971843	6701382	0.6	4.2	7.2	0.03	229922	7353	31081
16	17	0.41	0.04	1.07	411637	5041498	0.4	2.1	5.1	0.04	194325	7518	15925
17	18	0.45	0.05	1.07	463664	4048343	0.5	2.8	5.8	0.05	167543	7753	21457
18	19	0.50	0.05	1.08	806360	3083305	0.7	6.2	9.2	0.05	129269	7085	44195
19	20	0.55	0.06	1.09	862743	1890108	0.8	11.1	14.1	0.06	77858	5009	55505
20	21	0.61	0.07	1.11	418817	794374	0.8	11.9	14.9	0.07	35083	2628	31376
21	22	0.68	0.08	1.13	154489	270572	0.8	11.7	14.7	0.09	13243	1147	13380
22	23	0.76	0.09	1.15	39575	76454	0.7	8.7	11.7	0.10	4553	453	3936
23	∞	0.85			11627	23255	0.5	3.0	6.0	0.13	3885	486	1454
					Total	Total	Mean	Mean	Mean	Mean	Total	Total	Total
					5283772	87112837	0.4	4.4	7.4	0.05	2719673	67614	244721

and columns 12 and 13 represent, respectively, the instantaneous stock biomass in number of individuals and in weight (Kg) during the period. The mean biomass in the period (19 months) was 86 tons (2,913,731 individuals) of *F. brasiliensis* and 68 tons (2,719,673 individuals) of *F. paulensis.*

In addition, the cohort analysis gives estimates of Z and F per length class for the period. For *F. brasiliensis*, the estimates of Z, converted to annual values, increased with length and varied from 1.8 year^{-1} to 7.3 year^{-1}, with an average of 4.2 year^{-1}. For *F. paulensis*, the Z estimates varied from 1.9 to 9.4 year^{-1}, with an average of 4.7 year^{-1}. The F values also increased with length for *F. brasiliensis*, varying from 0.06 year^{-1} to 5.5 year^{-1}, with an average of 2.4 year^{-1}. For *F. paulensis*, the F values varied from 0.006 year^{-1} to 7.5 year^{-1}, with an average of 2.8 year^{-1}.

Schaefer and Fox global production models

The data of the total catch of the industrial fleet (1995 to 2000) and the pink shrimp fishery alone (1996 to 1999) were analyzed (Fig. 1). The 1995 and 2000 data on the pink shrimp catch were excluded from the analysis because they did not fit the regression model. Table 3 presents the results of the Maximum Sustainable Yield (MSY) and Maximum Effort (f$_{MSY}$).

Beverton & Holt model

The growth parameters used as inputs for the model were obtained through the ELEFAN-1 (electronic length frequency analysis) method. Figs 2 and 3 depict the yield per recruit curves, expressed as the percentage of maximum biomass obtained for different values of F and Lc (length at first capture) for the species.

Cohort analysis based on length structure

The results obtained from this procedure were based on a cohort analysis of the Jun 1999 to Dec 2000 period. The model was elaborated based on hypothetical changes in the fishing effort, with situations ranging from no effort to 100% increase in effort. Fig. 4 illustrates the catch and economic yield curves obtained from the different effort values. The points in the curve represent the maximum points for catches and yield. The maximum catch of both species occurred when the actual effort was increased by 20%. The economic yield curves indicate that the current fleet already operates at its maximal yield.

The monetary values of the catch (price per Kg of shrimp) used in both projection models were R$ 11,00 for individuals of up to 15 cm, R$ 22,50 for individuals of up to 17 cm and R$ 23,50 for individuals longer than 17 cm. These average prices were obtained from the fleet owners and represent the average prices paid to the boat masters for the three size categories (small, medium and big shrimps). The limit lengths were obtained from samplings done after the shrimps were separated at the fisheries' facilities.

Thompson & Bell model

The input data for this model were also based in the cohort analysis, but with the modifications proposed by Sparre & Venema (1997).

Again we worked with hypothetical changes in the fishing effort, from zero effort to a 100% increase in the effort. Fig. 5 shows the catch curves, economic yield and biomass of the stock obtained with the values modified from the current effort. The points in the curve represent the maximum points for catches and yield. The results obtained

TABLE 3
Schaefer and Fox Yield Model results for Pink Shrimp data from Brazil's southeastern/southern regions.

Data	Method	MSY (Kg)	f$_{MSY}$ (h)	Y/f$_{MSY}$ (Kg/h)
Pink-Shrimp (1996-1999)	Schaefer (1984)	366331	249120	1.47
Pink-Shrimp (1996-1999)	Fox (1970)	355699	266667	1.33
Total Catch (1995-2000)	Schaefer (1984)	1465180	169716	8.63
Total Catch (1995-2000)	Fox (1970)	1452784	141176	10.29

Schaefer yield model (Pink-shrimp)

$$Y/E = - 0.0034E + 70.584$$
$$r^2 = 0.8368$$

Schaefer yield model (Total Catch)

$$Y/E = - 0.0293E + 414.39$$
$$r^2 = 0.6887$$

(a)   (b)

Fox yield model (Pink-shrimp)

$$CPUE = - 0.00009f + 4.46614$$
$$r^2 = 0.83740$$

Fox yield model (Total Catch)

$$Y/E = - 0.00017E + 6.50928$$
$$r^2 = 0.64408$$

(c)   (d)

Yield models (Pink-shrimp)

—— Schaefer (1984)   - - - - Fox (1970)

Yield models (Total Catch)

—— Schaefer (1984)   - - - - Fox (1970)

(e)   (f)
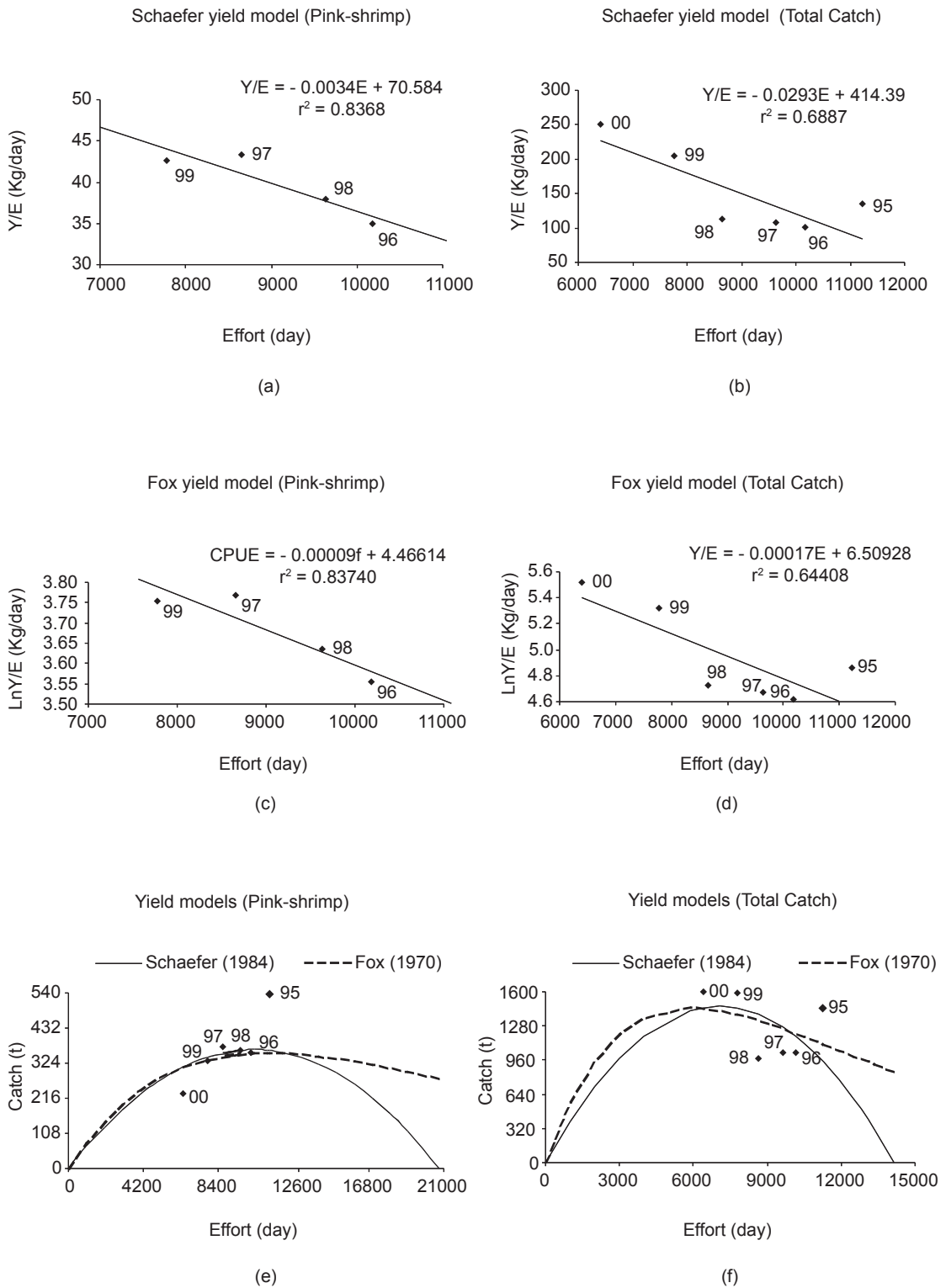
Fig. 1 — Schaefer and Fox Yield Models for Pink Shrimp data in Brazil's southeastern/southern region.

with this model corroborate the results obtained through the predictive cohort analysis.

DISCUSSION

Stock assessment

The Jones cohort analysis

The VPA (virtual population analysis) method allows for a retroactive calculation of how many individuals were expected to be in the sea for a given catch, taking into account natural and fishing mortalities. The method assumes the existence of a stable age structure in the population, *i.e.*, the growth parameters remain constant along the years, and differences in the individuals lengths can only be explained by age differences. To circumvent this assumption, it is advisable to use production data from several years, thus simulating a balanced situation and compensating for the differences among years in the recruitment and abundance of each class (Isaac *et al.*, 1992; Jones, 1984).

Although we had access to the data on the fleet's total catch from 1995 to 2000, we were only able to use the data from 2 years. Thus, in this 6-year period, the sampling period for the length distribution frequency was only 19 months (Jun 1999 to Dec 2000). The data obtained in the studies of cohort analysis were used as guidelines for the projection models.

Schaefer and Fox production models

The results of the production models indicated that pink shrimp catches have been declining steadily since 1995, when the catch was 535 tons, to 228 tons recorded for 2000. The fleet's total catches were 1450 tons in 1995, 978 tons in 1997 and 1599 tons in 2000. This reduction was a response to the decline of the target resource, which led the fleet to exploit other resources such as demersal fishes, mollusks and other crustaceans. The effort levels also diminished along the years, from 11,235 days at sea (269,640 h) in 1995 to 6,399 days (153,576 h) in 2000 (Fig.1).

Based on industrial pink shrimp fishery data for the southeastern and southern regions covering three different periods of fishing activity, D'Incao *et al.* (2002) obtained MSY values of 7165 tons and f_{MSY} of 577,035 fishing hours from 1965 to 1972, 3049 tons and 731,964 fishing hours from

1973 to 1986, and 1963 tons and 623,522 fishing hours from 1987 to 1995. Although the results of this study are underestimated since they involve only catch data from the fleet that lands fish in the Santos/Guarujá-SP area, we found that the tendency for decreasing catches has remained constant along the years, indicating that this resource is seriously depleted.

The values of MSY and f_{MSY} obtained through the models exceed the optimum level for the pink shrimp fishery. However, taking into account the total catch, the MSY is obviously below the current catch values, with effort values close to f_{MSY}, suggesting that the fleet is operating at levels close to the maximum yield. This finding is a matter of concern, since it is advisable for fisheries to remain at levels below the maximum estimated effort, which Garcia & Le Reste (1986) consider a precautionary strategy.

Beverton & Holt model

The Y/R X F curves do not present a clearly domed shape (albeit always in this case with a maximum), which is a pattern common to short-lived species (Isaac *et al.*, 1992). Based on the catch curve (Pauly, 1983), the fleet's calculated Lc value was around 19 cm for *F. brasiliensis* and 18 cm for *F. paulensis*, while the values of F were 4.7 year^{-1} and 6.8 year^{-1} for *F. brasiliensis* and *F. paulensis*, respectively. These values indicate that the Lc of both species is close to the MSY and that an increase in the mesh size would not lead to a substantial increase in the catches for any level of effort in the case of *F. brasiliensis* and only a slight increase in the catches of *F. paulensis*, with an increase of 3 cm in the size of first catch for levels of F above 5.6 year^{-1}.

Predictive cohort analysis based on length structure and the Thompson & Bell model

In the projection models used in this study, we worked only with a hypothetical increase or decrease in the fishing effort. As discussed above, an increase in the mesh size used by the fleet would not only reduce the yield but would also have little effect on the structure of the catch length. It is worth mentioning that the fishing operation consists of trawling the bottom for an average time of 4.5 hours. With this protocol, larger organisms were also caught (fishes, mollusks, etc.) but the
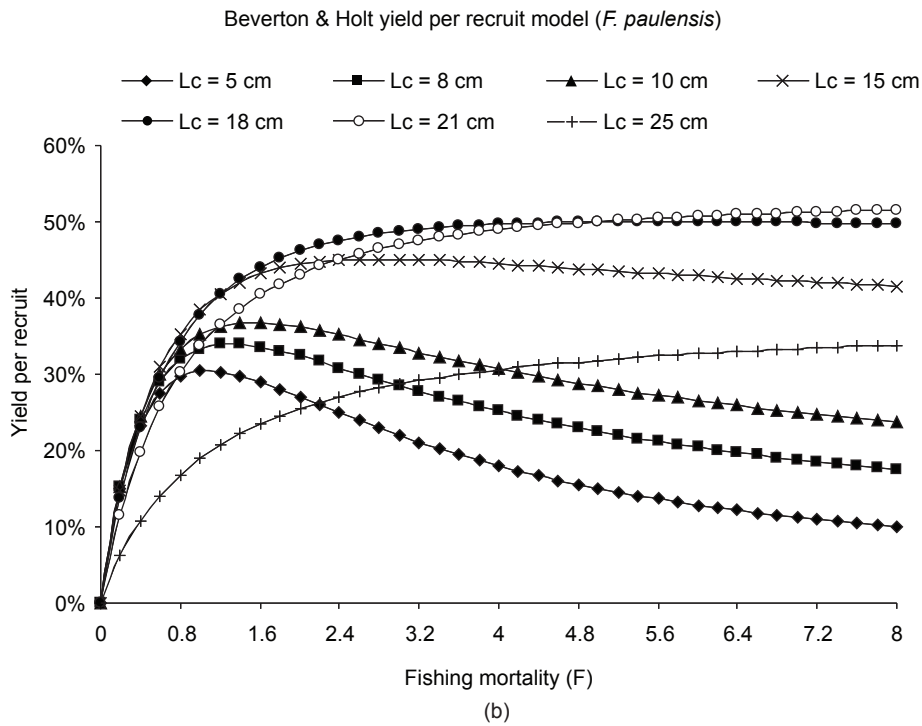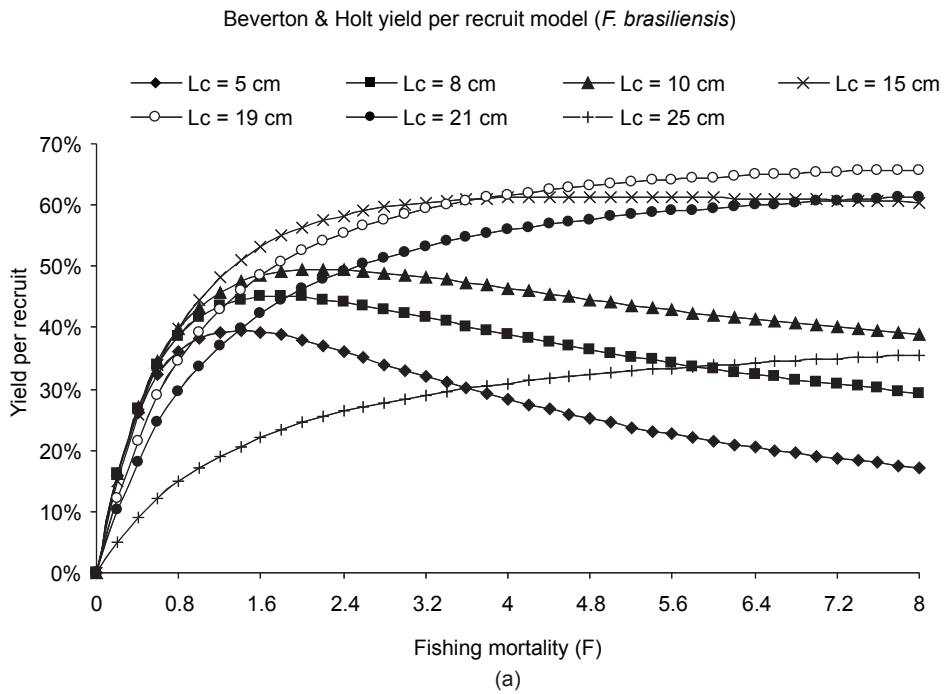
Beverton & Holt yield per recruit model (*F. brasiliensis*)

(a)

Beverton & Holt yield per recruit model (*F. paulensis*)

(b)

Figure 2 — Beverton & Holt Yield per Recruit model with 7 values of first catch length, Lc, for Pink Shrimp *Farfantepenaeus brasiliensis* and *F. paulensis*.
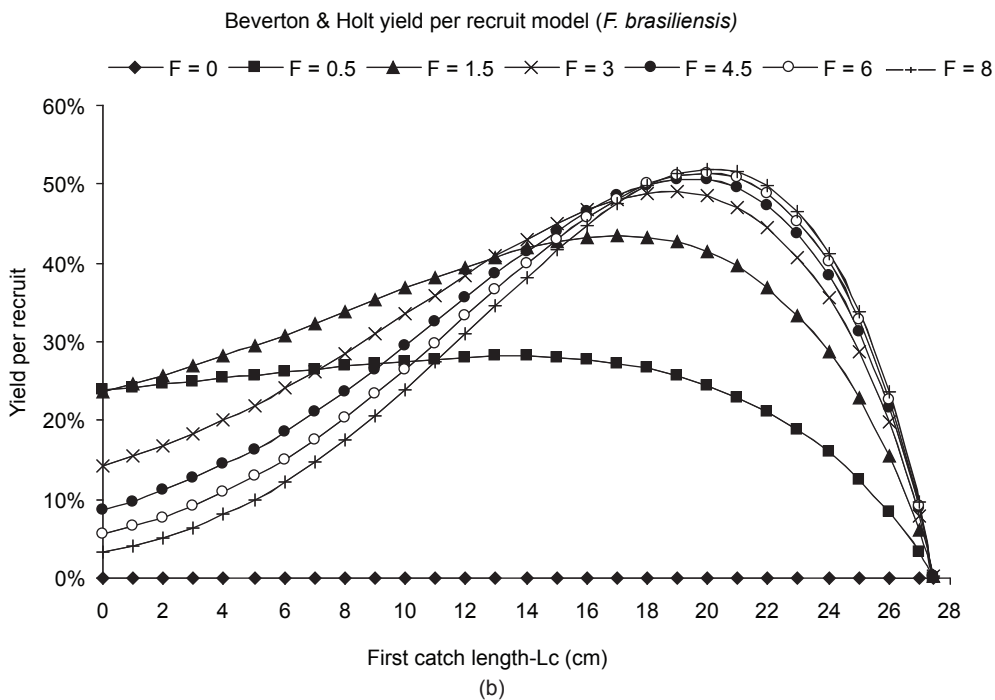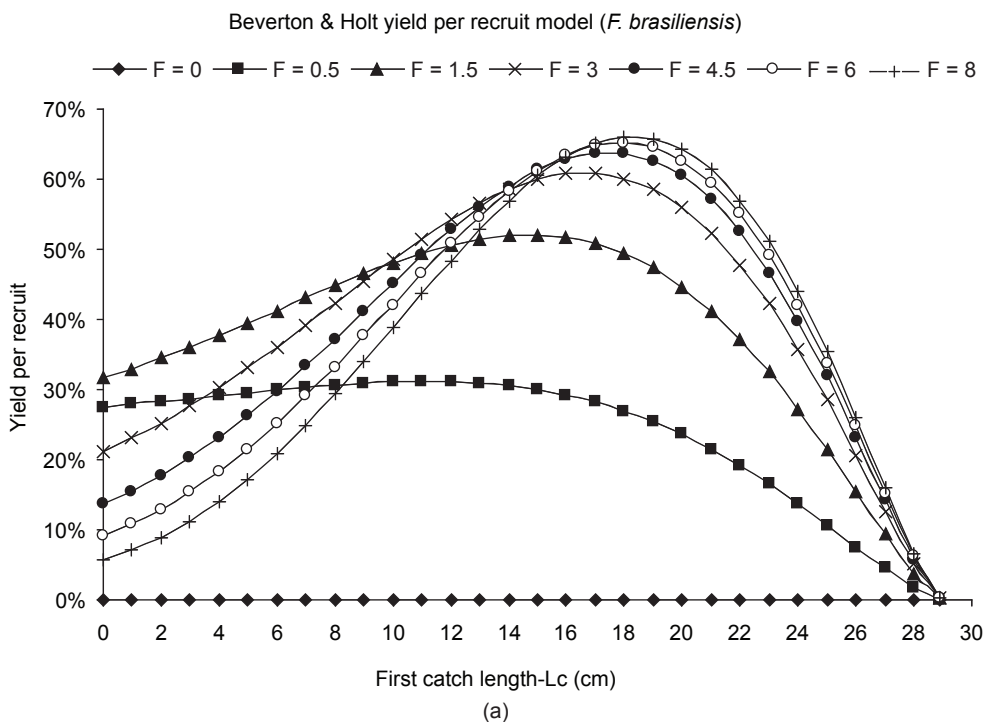
Beverton & Holt yield per recruit model (*F. brasiliensis*)

(a)

Beverton & Holt yield per recruit model (*F. brasiliensis)*

(b)

Fig. 3 — Beverton & Holt Yield per Recruit model with 7 values of fishing mortality for Pink Shrimp *Farfantepenaeus brasiliensis* and *F. paulensis*.
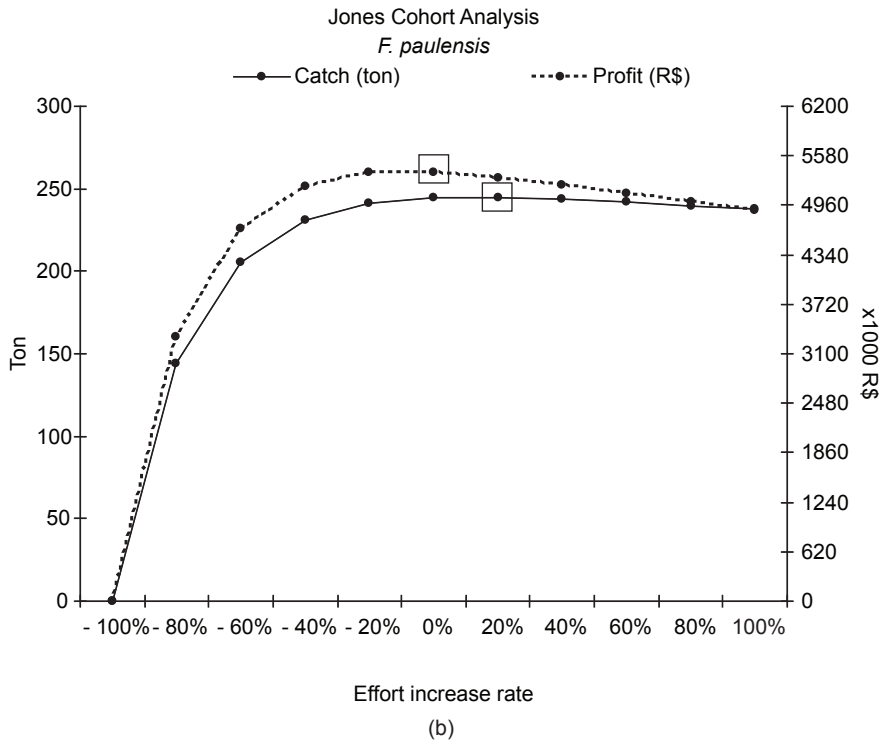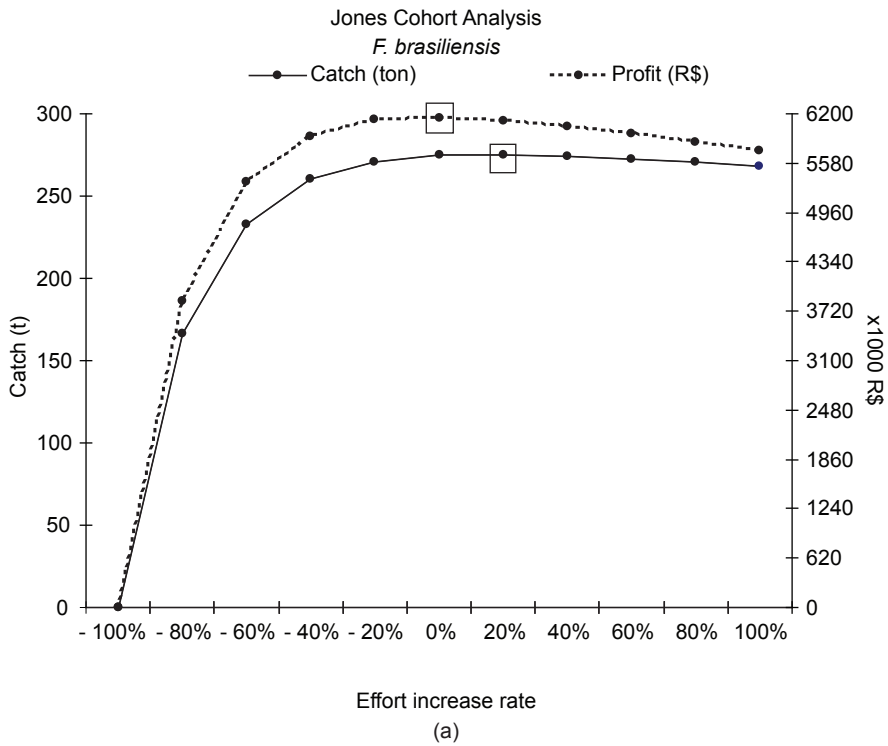
Jones Cohort Analysis
F. brasiliensis

— ●— Catch (ton)   ----●---- Profit (R$)

Effort increase rate

(a)

Jones Cohort Analysis
F. paulensis

— ●— Catch (ton)   ----●---- Profit (R$)

Effort increase rate

(b)

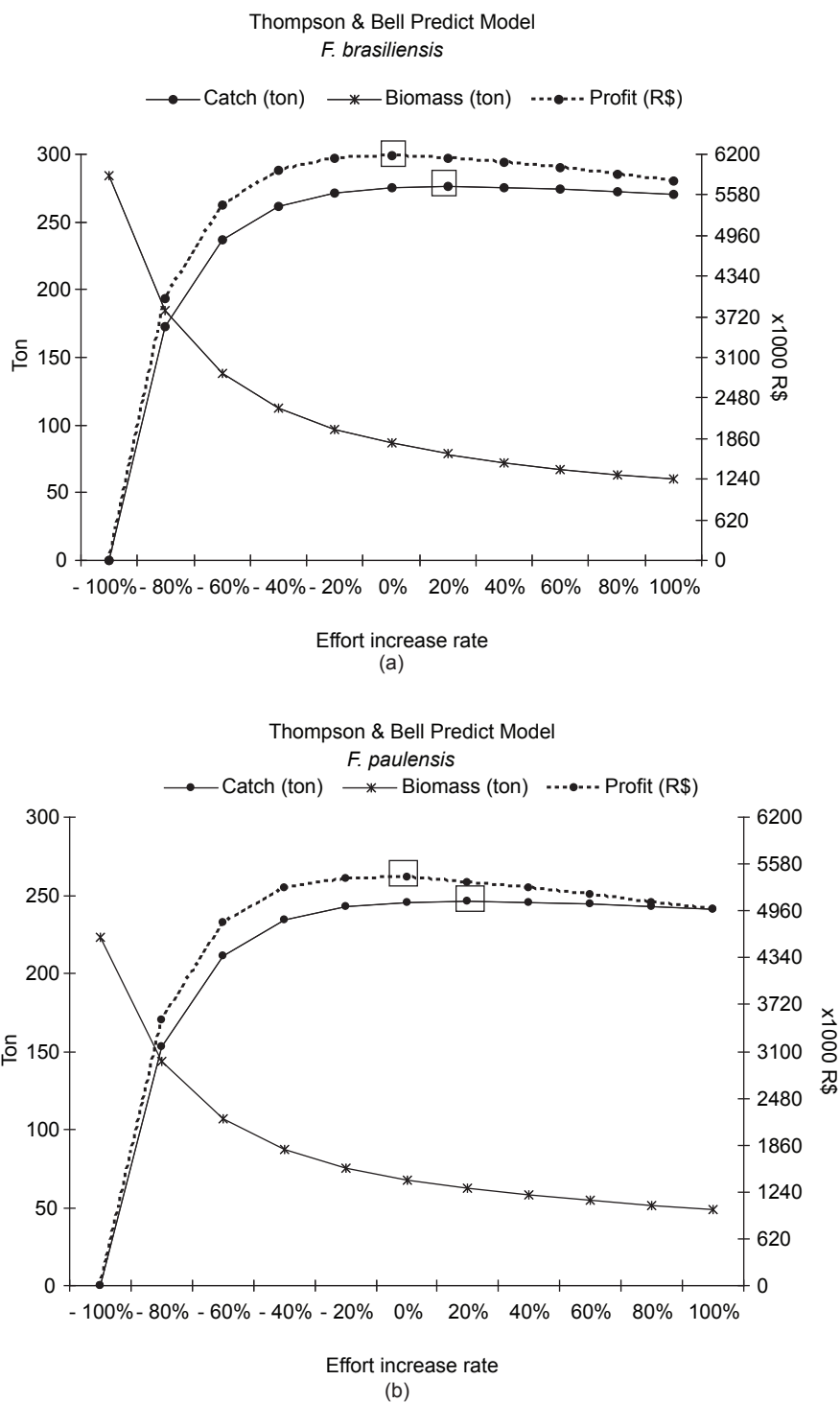**Fig. 4 —** Cohort analysis for *Farfantepenaeus brasiliensis* and *F. paulensis*, from June 1999 to December 2000.

Thompson & Bell Predict Model
F. brasiliensis

— ● — Catch (ton) — ✳ — Biomass (ton) ---●--- Profit (R$)

Effort increase rate
(a)

Thompson & Bell Predict Model
F. paulensis

— ● — Catch (ton) — ✳ — Biomass (ton) ---●--- Profit (R$)

Effort increase rate
(b)

Fig. 5 — Thompson & Bell Model for the Pink shrimp *Farfantepenaeus brasiliensis* and *F. paulensis*, from June 1999 to December 2000. Average exchange rate during the period: US$ 1 = R$ 1.924.

concomitant accumulation of debris soon clogged the nets.

When variations in the fishing effort were applied from zero up to a 100% increase (doubling the current effort), the models indicated that an increase in the effort caused the fish mortality and hence, the catches, to increase for the smaller length classes of both species, while decreasing the catches in the larger length classes (*i.e.*, those of greater economic value). These results demonstrate that pink shrimp fishing has reached its peak in terms of economic yield, and that any increase in the fishing effort would lead to an increase in the proportion of smaller individuals in the catches and hence, to financial losses for the fisheries.

FINAL CONSIDERATIONS

It should be noted that this study considered only catch data relating to the industrial open sea fishery of the fleet that lands its catches in the Santos/Guarujá-SP area. Moreover, since we were unable to use the small-scale fishery data, our stock estimates are probably underestimated. Nevertheless, these estimates at least constitute good indices of stock abundance, because the São Paulo fleet represents 2/3 of southeastern and southern Brazil's total active fleets (Valentini *et al.*, 1991). All the stock evaluation models employed here indicate that the stock is at its MSY, and that urgent actions are imperative to reduce the current pink shrimp fishing effort.

Fishery management

The topics discussed here in were based mostly on data reported by Garcia & Le Reste (1986), Isaac *et al.* (1992) and IBAMA (2001 – unpublished report).

Peneid shrimps are one of the world's most profitable natural resources and, as such, should be treated as a common asset of society. Moreover, because they occur in public habitats and are thus subject to free access, peneid shrimps are vulnerable to several external factors such as excessive fishing effort and environmental degradation. Since they constitute a renewable natural resource, it should be possible to exploit them widely without jeopardizing the replacement of the stock. Therefore, regulating this type of fishery right from the animals' initial phases is crucial for the

optimal and profitable development of industrial pink shrimp fishing. The management of peneid shrimps involves various constraining factors, such as their high market value, short life cycle, high mortality rates, and the fact that juveniles and adults occupy different habitats. The latter factor enables different social groups (small-scale and industrial fisheries) to employ dissimilar and specialized fishing strategies for individuals of different ages. Lastly, the progressive degradation that estuarine environments (nurseries) currently face must also be considered.

The success of a fishery management policy begins with a clear definition of its objectives and the existence of an appropriate structure within which to carry out the necessary actions. According to Garcia & Le Reste (1986), the shrimp fishery management objectives are long-term conservation of the resource, maximization of total production, catches, income and profit, reduction of production costs, improvement of the economic and social conditions of workers, with better job opportunities and redistribution of benefits, better use of the by-catch, and greater profitability for the trawlers in order to reduce juvenile fish mortality. Once these management policies have been outlined, the methods required for their implementation should be defined.

CONCLUSIONS

- Pink shrimp catches have been declining steadily since 1995, while the total catch per fleet has increased. This decline in the catch of the target resource has prompted the fleet to exploit other resources such as demersal fishes, mollusks and other crustaceans. The levels of effort have also declined along the years, from 11235 days in 1995 to 6399 days in 2000;

- From the standpoint of the industrial fleet catch, the MSY is below the current catch values, showing effort values close to F_{MSY}, which suggests that the fleet is operating at maximum production levels. It should be noted that these calculations do not include small-scale coastal fishery landings;

- The production model indicates pink shrimp fishery is at its MSY, and that any modification

in fishing net mesh sizes would fail to result in higher catches;

- The predictive models also indicate that the pink shrimp fishery is at its MSY. An increase in effort of up to 20% would lead to an increase in the catch. However, such an increase would lead to financial losses for the industry; and
- Since the fishery is at its maximum production level, administrative procedures must be implemented to preserve the stock. The best steps for regulating the industry are the immediate reduction of the fishing effort through a reduction of the fleet, along with the establishment of a fishing period ban and the closing of some fishing areas to ensure the recruitment of the species.

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