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A comparative multi-fleet analysis of socio-economic indicators for fishery management in SE Brazil

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ABSTRACT

One of the problems in an ecosystem approach to fisheries management is the lack of economic analyses which clearly define the performance of different fishing fleets within the system. We describe a comparative multi-fleet analysis of socio-economic indicators applicable for inclusion into ecosystem modeling and management. Based on a survey of different industrial fishing fleets in São Paulo, Southeastern Brazil, an inter-fleet comparison of economic attributes such as investment, fixed costs, effort, labour, sailing-related costs and profits, as well as a set of performance indicators, was conducted. Costs varied between fleets with fuel being the largest component on average, representing almost 37% of total costs. Similarities between fleets were driven by fuel costs, gross incomes and profits. In general, the best economic performance was associated with indicators of profitability and economic efficiency. Bottom-longliners and both surface and bottom-gillnet fleets showed the best economic performance per fishing trip due to their low percentage of variable costs. Purse-seiners and pink-shrimp trawlers had the lowest average rate of return and economic efficiency because of their high variable costs and relatively low catch values, and were considered economically net losers. However, in terms of jobs generated, purse-seiners had the greatest value creating about 49% of total jobs by all fleets. The sea-bob-shrimp fleet had the lowest crew size per vessel but generated the second highest total number of direct jobs (23%), with high economic viability as a whole. The inter-fleet cost and socio-economic performance analysis revealed that additional attention should be given to the poor profitability and overcapacity of fleets, fishing impacts, and open-access related issues, while social indicators may also be considered. This study provides information useful for evaluating different fisheries management scenarios and fleet size optimization in the South Brazil Bight, for ecosystem modeling policy optimization routines, and for a pragmatic ecosystem approach to fisheries management.

1. Introduction

One of the aspects of fisheries science that is usually missing in integrative studies of the ocean is the human dimension of its uses and services, including key socio-economic indicators of fisheries (Sainsbury and Sumaila, 2001; Browman and Stergiou, 2005). For example, for some contemporary end-to-end fisheries ecosystem modeling applications, economic performance-related parameters such as the costs and profits of the different fishing fleets within a system are required as input values (i.e., Christensen and Walters, 2004; Christensen et al., 2009), but in practice these values are often unknown. In such cases, the model's parameterization will assume multi-fleet costs based on previous empirical approximations (Christensen et al., 2005; Araujo et al., 2008; World Bank, 2008). However, such distortion of real-world conditions and values may affect the predictions related to management trade-offs between ecological, economic, and social objectives, which would be undesirable.

In contrast, comparative economic performance indicators within a system, along with ecological analysis, are expected to be crucial to the success of an ecosystem approach to fisheries (EAF) (Garcia et al., 2003). These indicators can be useful for monitoring and assessing a sector's performance and the wider effects of fishing (Bonzon, 2000; Hundloe, 2000; Accadia and Spagnolo, 2006; Ceriola et al., 2008). In addition, research on the performance of industrial fisheries around the world has drawn attention to the issues of rent dissipation, overcapacity, and the need to reduce fleets to sustainable levels (FAO, 2007; World Bank, 2008; Sherman and Hempel, 2009; Sumaila et al., 2008; Worm et al., 2009). Thus, the lack of a comparative multi-fleet basic economic analysis appears to be a significant gap that should be addressed by local studies as part of regional EAF research.

A unified approach to evaluating the capital costs of different fisheries may allow the calculation of net profits, profitability of

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invested capital, and other economic indicators in order to assess the current state of a fishing fleet's operations within the marine system (Hundloe, 2000; Whitmarsh et al., 2000; IREPA, 2007). This approach can be considered analogous to an energy-budget approach applied to biological communities.

In Brazil, analyses of the dynamics and economics of fishing fleets, together with collection of ecological data on fish stocks, has been attempted over past decades (Carvalho et al., 1997, 2000; Almeida et al., 2001; Gasalla et al., 2003; Tomás et al., 2003; Lucena and O'Brien, 2005), and the integration of ecological, technological, social, and economic parameters to support decision making has been recently recognized as essential (Isaac et al., 2009). However, detailed cost analysis of fishing fleets remains rare, limited, hard to conduct, and particularly unavailable for multi-fleet comparisons. Possible reasons for these obstacles include the lack of regulations requiring fisheries to provide this kind of information in Brazil and most of the world (i.e., bookkeeping). Furthermore, there is no reciprocal trust between the fishing industry and government institutions (Castro et al., 2001; Gasalla and Tutui, 2003). Indeed, in the face of the small number of local professionals in the areas of economics and social sciences who are specialized in marine fisheries, and the substantial gaps in systematic outlooks, ocean-based EAF research is presently filling key gaps in both ecosystem modeling and management.

A fisheries ecosystem's multi-fleet economic performance comparison can be particularly useful to address policy questions regarding fishery management in Brazil and elsewhere. For example, decisions and trade-offs aiming to promote an optimal size and composition of the fishing fleets, or those regarding the allocation of fuel subsidies would benefit from such assessment. In this context, the present study aims to provide a cost analysis of the different fleets of the multi-gear industrial fisheries of the South Brazil Bight area. We sought to establish an inter-fleet performance comparison as well as a concise financial multi-fleet rationale for future incorporation into ecosystem modeling and management.

1.1. Case study

The case study is focused on the assessment of socio-economic performance of the professional fishing fleets that frequently land their product on the coast of the Brazilian State of São Paulo. More precisely, we considered fleets that landed in the Santos region during the period of 2007–2009 that were locally classified as 'industrial'. Fig. 1 shows the locations of the Santos region's main ports (Guarujá and Santos) on the central coast of the Southeastern Brazil Bight, which is a crescent-shaped 'semi-enclosed' continental shelf of the Santos Basin (between 23°–28°S and 42°–48°W) that sustains important fishing grounds for the Brazilian sardine, penaeid shrimps and demersal fish. Presently, fishing landings in the whole South Brazil Bight are about 130,000 ton per year (in 2007), which can be considered a poor production if compared with past decades (IBAMA, 2007).

The state of São Paulo, which was formerly one of the top marine fishing states of Brazil, now is 7th out of 26 Brazilian States (IBAMA, 2007). Industrialization of the fisheries in São Paulo began in the 1950s and grew quickly with the financial subsidies in the late 1960s (Castro et al., 2005; Abdallah and Sumaila, 2007). Landing time-series collected by the Instituto de Pesca, Brazil, peaked in 1984 (131,000 tons) followed by a strong decrease between 1984 and 1999, stabilizing around 20,000–30,000 tons per year with 2005 being the poorest year (23,000 tons) since 1967. The main reason for the poor performance in 2005 was the decline of the Brazilian sardine (*Sardinella brasiliensis*) (Ávila-da-Silva et al., 2007), the most important local fishery resource. In 2006, fishery landings rose to 33,000 tons and produced an income of 80 million Brazilian Real (R$) (IBAMA, 2007).

In this case study, the definition of regional 'industrial' fishing may include what are considered as small-scale fisheries elsewhere (Berkes and Kislalioglu, 1989). Here, we adopted the definition of the Brazilian National Ocean's Independent Commission (CNIO, 1998), which is similar to the scale used by the Ministry of Environment (MMA, 2006). This includes motorized vessels that use diesel engines and wooden and steel boats bigger than the small-scale artisanal boats (<16 m length) (PROZEE, 2005). In 2007, the number of such fishing units in this area was estimated to be 629 vessels (Castro et al., 2005; Instituto de Pesca, 2008). For the purposes of this study, these were classified as 'Bottom-gillnetters', 'Bottom-longliners'; 'Surface-longliners', 'Octopus-pots', 'Pair-bottom trawlers', 'Pink-shrimp trawlers', 'Purse-seiners', 'Sea-bob-shrimp trawlers' and 'Surface-gillnetters' (Table 1).

2. Methods

2.1. Data collection

A survey was conducted during 2007–2009 among the main landing points in the Santos/Guarujá zone (Fig. 1). Information was collected directly and via semi-structured personal interviews with key informants sampled from vessel owners, captains, skippers and fishery leaders. The interviews were carried out in these ports due to the significant numbers of vessels that landed in those sites and that are currently considered representative of the regional fisheries. Data on yields, financial details, and fishing effort were obtained from questionnaires (Table 2). These data included the values of the fishing vessels, gears and maintenance, and details on each vessel's most recent fishing trips (catch size, number of fishers, duration of the fishing trip, ex-vessel price of the catch and consumption of ice, food and fuel). Interviews conducted during the periods January–February 2007; September–October 2007, and February–March 2009 covered 60% of the total number of active vessels during the sampled fishing seasons, with a total of 81 questionnaires covering the nine fleet categories. The number of questionnaires per fishing fleet was: 2 from bottom-gillnetters, 10 from surface-gillnetters, 2 from bottom-longliners, 4 from surface-longliners, 8 from octopus-pots, 9 from pair-bottom trawlers, 18 from pink-shrimp trawlers, 18 from purse-seiners, and 10 from sea-bob-shrimp trawlers; for the two former fleets, the interviews covered 100% of the local fleet size. A compilation of already published material was also used to supplement the interviews (e.g., Table 1). Additional data, i.e., the estimate of the number of potentially active vessels in the area, were obtained from the Instituto de Pesca's fishery database (Instituto de Pesca, 2008; Castro et al., 2005).

2.2. Performance indicators and data analysis

Significant intra-fleet variability was found only for purse-seiners, mostly regarding the different number of fishing trips per month. Thus, average values were used to describe the characteristics and cost structure of each fleet, as well as net incomes per fishing trip and monthly revenues. In order to describe the main operational and technological characteristics, several indicators were calculated.

The average direct jobs per fleet (J) was estimated by multiplying the number of vessels (fleet size) and the crew size (CS). Fleet size corresponded to the data available for 2007 (Instituto de Pesca, 2008) and for 2003, in the case of bottom-gillnetters (Castro et al., 2005). The relative importance of jobs between fleets was calculated as a percentage (% of total direct jobs).

Catching efficiency (CE), which is usually expressed as the ratio of catch to fishing effort (Trinidad et al., 1993), was calculated

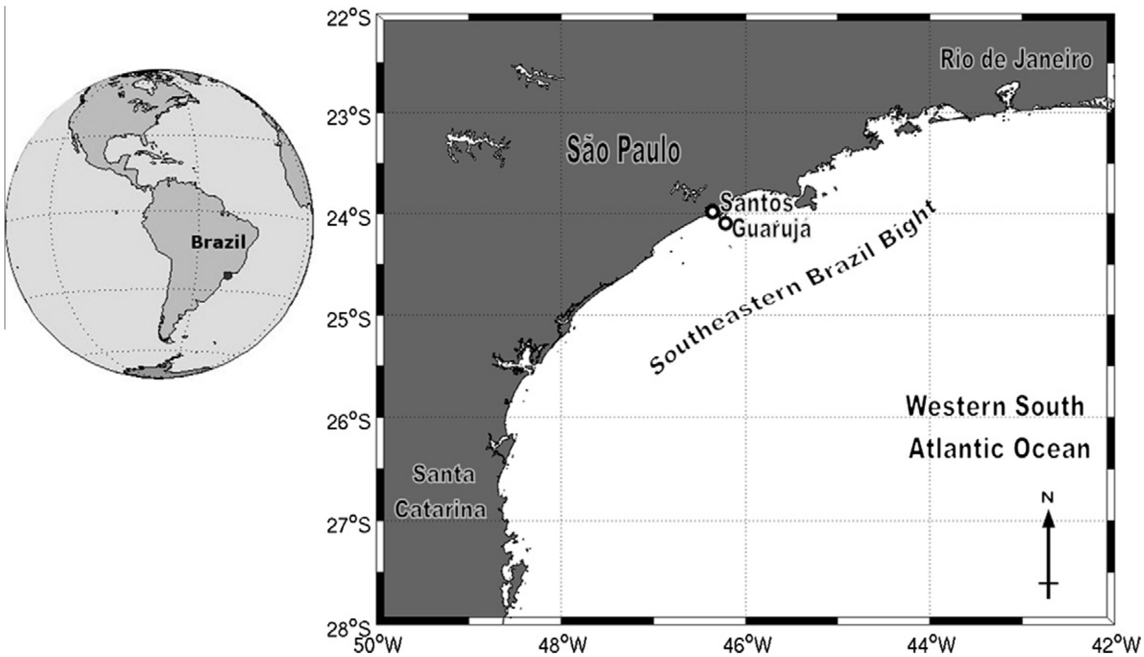

Fig. 1. Map of the Southeastern Brazil Bight showing the location of the fishery landing ports (Santos, Guaruja) in the Santos region, São Paulo.

using the total fishers/day indicator, by multiplying the crew size (CS) by the number of days per fishing trip: $\frac{\text{Catch}(t)}{\text{CS} \times \text{days}}$. The crude measure of effort fitted the available data for multiple fleet purposes, and was adopted considering that capital use is not intensive for the fisheries under consideration.

Beyond the technological characterization, we also calculated costs, income and profits for each fleet and carried out some standard economic analyses.

Total cost (TC) corresponded to the sum of the *fixed* (FC) and *variable costs* (VC). Fixed costs included repairs to the vessel, social insurance and fees (i.e., unions). Variable costs included fuel, ice, food, bait, gear and others such as sodium sulfite used for on-board conservation. Costs per month were based on the costs per trip multiplied by the average number of trips per month plus monthly fees and social insurance.

Average capital investment (CI) in fishing vessels was estimated, including the initial cost of acquiring a fishing vessel and all the equipment necessary to carry out the activity.

Labour cost (LC) corresponded to the crew's payment. *Gross income* (GI) was the total catch value (ex-vessel price of the total catch) (Almeida et al., 2001; Sumaila and Marsden, 2007). *Profit*, defined as the amount of money remaining after all costs have been met (Oliveira, 2006) was calculated as: $\text{Pr} = \text{GI} - \text{TC} - \text{LC}$, where Pr is the profit, GI is the gross income, TC is the total cost and LC is the labour cost.

The relative importance of each type of cost within a fleet, as well as an inter-fleet comparison, was calculated from total values. As an indicator of profitability, the *average rate of return* (RR) (Bonzon, 2000; Garza-Gil and Amigo-Dobano, 2008) was calculated, which is based on the quotient between the Profit (Pr) and an estimation of the value of the initial capital investment (CI) made in the fishing vessel, $RR = \frac{Pr}{CI}$.

Depreciation was assumed equal to zero, as suggested by Castro et al. (2001a,b), since most of the actual capital lifespan is due and assumed to be sunk. However, in order to consider a situation where new vessels would be built, the return foregone on other uses of that capital were taken into account as opportunity costs (i.e., interest rate). Thus, the following economic indicators were estimated for multi-fleet comparison purposes:

Economic efficiency (EE) (adapted from Grafton et al., 2000; Almeida et al., 2001) was estimated by dividing the value of the gross income (total catch value) by the total costs, $\text{EE} = \frac{\text{GI} \times (1+i)}{\text{TC} \times (1+i)}$, where i is the interest rate.

Net Present Value (NPV) (Whitmarsh et al., 2003; Sumaila, 2004) is an indicator of how much value an investment or project adds to the firm. $NPV = \sum_{t=0}^{T} \frac{GI_t - TC_t}{(1+i)^t}$, where GI_t is the gross income, TC_t is the total cost of the project at time t, and the opportunity cost of capital is represented by the interest rate (i). If $\text{NPV} > 0$, the investment would add value, but when $\text{NPV} < 0$ the investment would subtract value and the project should be rejected. For this economic viability estimate of running the project as a whole (NPV), we considered a 4-year exploitation scenario with the investment in vessel plus gears integrally applied in year zero. An interest rate of 4% was adopted for the analyses (MPA, 2009).

Investment payback period (PP) (Garza-Gil and Varela-Lafuente, 2005) was calculated as the ratio between the initial investment (CI) minus the profit (Pr) and the profit (Pr) per month, $PP = \frac{CI - Pr}{Pr}$.

Note that all costs and values are in Brazilian currency (Real, R$; conversion rate of 1US$ = 1.73 R$, in October 20, 2009). A Kruskal–Wallis test (non-parametric, p-value < 0.05) was employed to test for significant differences between fleets with respect to the number of crew members, the time of navigation required to reach the fishing spot, the number of trip days and the price of the total catch, since there was no guarantee that the data would be normally distributed.

To identify similarities between fleets ($n = 9$) in terms of their socio-economic performance, hierarchical cluster analysis was conducted using Euclidian Distances (unweighted pair-group average linkage method) (Manly, 1994). These calculations were based on: (1) the attributes listed in Table 2; (2) the values (as defined above) per fishing trip plus the average number of direct jobs (J); and (3) monthly indicators (Profit, CE, EE, RR, PP) and Net Present Value. Principal Component Analyses were performed to identify the major socio-economic factors that would group the fleets into

Table 1
Major characteristics of the fishing fleets based in the ports of the Santos region, in the South Brazil Bight.

Fleet	Gear	Target-species	Bycatch	Area of capture	Number of trips (2005)	Description	Source
Bottom-gillnetters	Bottom-gillnet	*Lophius gastrophysus*	Several fish and invertebrates.	21°S–34°S		Vessels length from 17 to 22 m.	Perez et al. (2002), Castro et al. (2005), Instituto de Pesca (2008).
Bottom-longliners	Bottom longlines	*Lopholatilus villarii, Pseudopercis* sp. *Epinephelus* sp.	*Urophycis* sp., *Helicolenus lahillei* and 15 over species.	7°S–35°S	12	Operate at depths of 50–600 m. Vessels length from 15 to 26 m and engines from 156 to 350 HP.	Ávila-da-Silva and Moreira (2003), Castro et al. (2005), Instituto de Pesca (2008).
Longliners	Surface longlines	*Thunnus spp, Xiphias gladius, Isurus* sp.	*Carcharhinus* sp., *Sphyrna* sp. and others.	17°S–35°S	64	Operate in depths up to 200 m. Vessels length from 16 to 33 m and engines up to 240 HP.	Amorim et al. (1998), Gasalla and Tomás (1998), Castro et al. (2005), Instituto de Pesca (2008);
Octopus pots	Pots and traps	*Octopus vulgaris*	Slipper lobsters.		316		Instituto de Pesca (2008), Duarte et al. (2010)
Pair-bottom trawlers	Bottom pair trawls	*Micropogonias furnieri, Macrodon ancylodon, Balistes capriscus*	Over 77 species from 25 families.	19°30′S–33°30′S	233	Operate in depths between 10 and 70 m. Vessels length from 17 to 24 m and engines from 188 to 406 HP	Gasalla and Tomás (1998), Castro et al. (2003), Instituto de Pesca (2008).
Pink-shrimp trawlers	Double otters trawls	*Farfantepenaeus* sp.	More than 165 fish species, 35 crustaceans, and 25 mollusks.	23°S–30°S	519	Operate in depths between 30 and 100 m. Vessels length from 18 and 27 and engines from up to 150 HP.	Gasalla and Tomás (1998), Tomás et al. (2003), Castro et al. (2005), Instituto de Pesca (2008).
Purse-seiners	Purse-seiners	*Sardinella brasiliensis*	*Trachurus lathami* and over 20 more species.	23°S–27°S	140	Vessels with an average length of 22 m and average engines of 292 HP. Operate in depths of 40 m.	Gasalla and Tomás (1998), Gasalla et al. (2003), Instituto de Pesca (2008).
Sea-bob-shrimp trawlers	Double otters trawls	*Xiphopenaeus kroyeri*	80 fish species, more than 20 crustaceans, and mollusk species.	23°S–30°S	517	Operate at depths less than 30 m. Vessels length less than 15 m, and engines from 115 HP.	Gasalla and Tomás (1998), Tomás et al. (2003), Castro et al. (2005), Instituto de Pesca (2008).
Surface-gillnetters	Surface gillnets	Pelagic sharks (*Micropogonias furnieri* during winter)	Sharks, fish, small cetaceans and turtles.	24°S–27°S	221	Vessels length from 8 to 23 m, power 80–350 HP	Gasalla and Tomás (1998), Tomás (2003), Instituto de Pesca (2008).

Table 2
Basic socio-economic attributes included in questionnaires for data-gathering interviews.

Yield-related	Effort-related	Economic
Total catch per trip (t)	Duration of fishing trips	Fuel cost per trip
Ex-vessel price of total catch per trip (R$)	Navigation time until the fishing zone	Fuel cost per month
	Crew size	Vessel and gear costs
	Fuel consumption (liter) per trip	Food cost per trip
	Monthly fuel consumption	Food cost per month
	Ice consumption (t) per trip	Capital investment
	Monthly ice consumption	Ice cost per trip, and per month
		Landing cost
		Bait cost
		Labour cost

the above clusters. To verify the patterns between vessels ($n = 81$), a hierarchical cluster was calculated by using the socio-economic information shown in Table 2 excluding the average capital investment. All statistical analyses were run with STATISTICA version 8.0 (StatSoft).

3. Results

3.1. Fleet characteristics and dynamics

Table 1 shows the main features of each fleet, such as fishing gear, target and by-catch species, area of capture, vessel description and the number of fishing trips carried out in 2005. The dynamics in terms of the vessels that operated in the region during the period of 1998–2007 are shown in Fig. 2. At the end of this period, the number of gillnetters and octopus-potters decreased proportionately greater than in other fleets, but this was after a proportionately greater increase in the mid-2000s. Conversely, purse-seiners and the sea-bob shrimp fleet, which is composed of small, flexible vessels, increased in 2007 (Fig. 2). An estimate of the total number of fishing trips and the time required to navigate

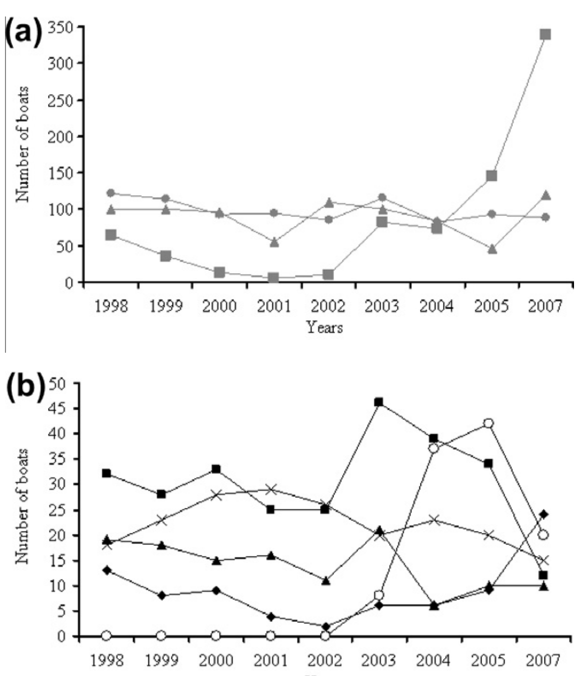

Fig. 2. Number of boats in each fleet from the Santos region (1998–2007). (Source: Instituto de Pesca, 2008.). (a) ■ = Sea-bob-shrimp trawlers, ● = Pink-shrimp trawlers, ▲ = Purse-seiners; (b) ♦ = Bottom longlines, ■ = Gillnetters, ▲ = Longliners, × = Pair-bottom trawlers, ○ = Octopus-pots.

to the fishing zone per trip for each fleet is shown in Table 3. The fleets that exploited a range of different species (such as longliners, bottom-gillnetters, pair-bottom trawlers and pink-shrimp trawlers) were significantly different from other fleets in both the duration of fishing trips (spending 3–16 days at sea) and the navigation time to the fishing spot (Kruskal–Wallis, $p < 0.0001$ and $p < 0.0002$, respectively).

3.1.1. Crew size (CS) and jobs (J)

Table 3 shows the average crew size of each fleet, from which the number of jobs per fleet can be estimated. Significant inter-fleet differences ($p < 0.001$) were found, and these differences appear to be related to the type of gear used. Fig. 3 compares the percentage of direct jobs per fleet and the corresponding number of vessels providing an indicator of social benefits. 'Purse-seiners' demonstrated the greatest number of total direct jobs (15 men/vessel; 49% of the total) (Fig. 3). Although the 'sea-bob-shrimp fleet had the lowest crew size per vessel (2.5 men), it generated the second greatest total number of direct jobs (23%) due to the large number of boats (Fig. 3).

3.1.2. Catching efficiency (CE)

The average catch per fishing trip ranged from 41 tons for purse-seiners to 2 tons for the sea-bob-shrimp trawlers (Table 3). Table 3 also shows the technological or catching efficiency (CE) estimates per fishing trip for each fleet, ranging from 0.04 to 0.55. The purse-seiner fleet was the most technically efficient (0.55), followed by the pair-bottom trawler fleet (0.26) (Fig. 4).

3.2. Cost structure and profit

3.2.1. Capital investment (CI)

The average capital investment with a breakdown of contributions from the vessel and the gear used by the nine different fishing fleets is shown in Table 4. Sea-bob-shrimp trawlers have smaller boats and simpler engines resulting in a lower total average investment (around R$ 78,000) in contrast to the purse-seine fleet whose initial investments required around R$ 1 million. Purse-seiners and the octopus-pot fleet had the greatest relative contribution of gear to total capital investment, corresponding to more than 40% and 30%, respectively (Table 4).

3.2.2. Profile of crew income

In all fleets, fishers are 'partners' of the vessel owners and have no fixed salary. The division of income between the crew is made in parts, depending on their function on-board (Fig. 5). The owners usually subtract the variable costs of fishing (fuel, food, ice, etc.) from the net value of the catch (gross income) and divide the rest into three parts: (a) repair costs (for gear and vessel maintenance), (b) the owner's portion (profit) and (c) the crew's portion (labour payment). In all fleets, the vessel's owner or '*armador*' keeps more

Table 3
Technical attributes of the different fishing fleets estimated as the mean per fishing trip.

Type of fleet	Navigation time to the fishing zone (hours)	Crew size	Duration of fishing (days)	Average catch (t)	Catching efficiency
Bottom-gillnetters	18.5	7.0	15.5	4.8	0.04
Bottom-longliners	32.5	6.5	15.0	4.3	0.04
Longliners	67.0	8.0	19.0	13.0	0.09
Octopus pots	15.6	6.0	15.0	5.0	0.06
Pair-bottom trawlers	11.5	8.6	10.7	24.0	0.26
Pink-shrimp trawlers	10.6	5.1	15.4	7.2	0.09
Purse-seiners	5.0	15.0	5.0	41.0	0.55
Sea-bob-shrimp trawlers	3.1	2.5	7.5	2.3	0.12
Surface-gillnetters	7.0	5.0	8.0	4.0	0.10

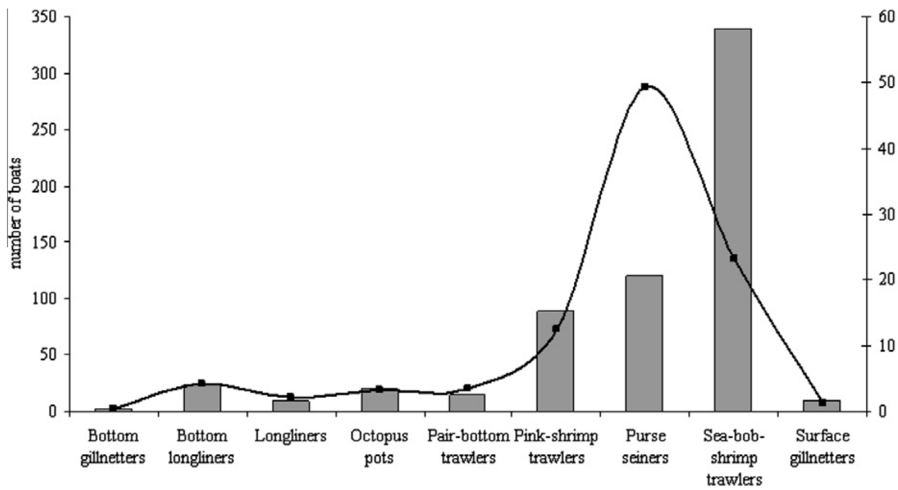

Fig. 3. Number of vessels (bars) and estimated percentage of direct jobs (solid line) per fishing fleet of the Santos region in 2007.

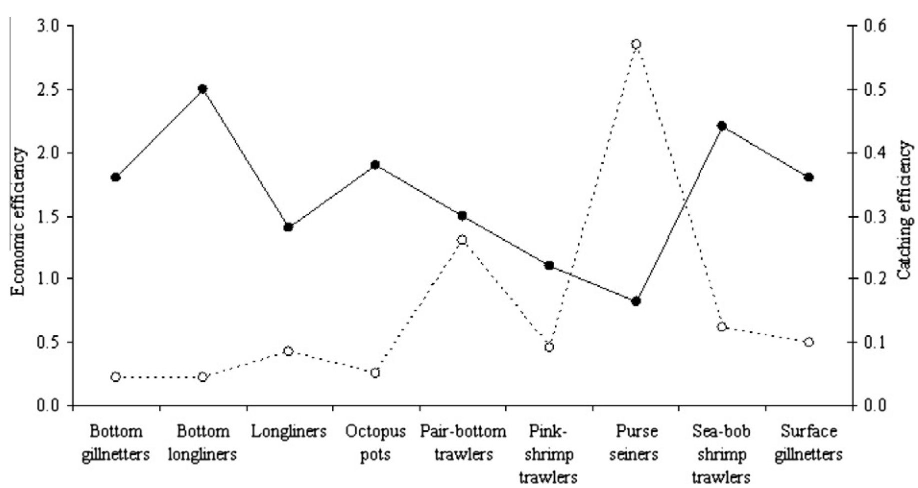

Fig. 4. Catching (dashed line) and economic (solid line) efficiencies per fishing fleet.

than 50% of the net catch value, including repair and his own portion.

3.2.3. Operating costs

A synthesis of average costs of the different fishing fleets is presented in Table 5. Gross income (GI) per fishing trip ranged from R$ 5454 for the sea-bob-shrimp trawlers (smallest boats) to R$ 66,750 for the longliner fleet, which also had higher total costs (TC) (R$ 52,703/trip) than the sea-bob shrimp trawlers (R$ 4475/trip). On a monthly basis, the scenario changed due to the variable number of fishing trips per month for each fleet. The purse-seiner fleet had the highest monthly total costs, while bottom-longliners had the lowest values (Table 5).

The estimated monthly costs of the purse-seiners suggest that if the average gross income and costs remain the same during all fishing trips (five trips/month in average), this fleet operated with higher costs than gross income resulting in monthly deficits (Table 5).

Table 6 and Fig. 6 show the relative importance of each type of cost within each fleet per fishing trip (Table 6a) and per month (Table 6b). Considering all fleets together, the main costs per trip were due to fuel (37%), labour (22%), and vessel repair and maintenance (~22%) (Table 6). Variable costs, which consist of running costs, were mainly due to fuel (Tables 6 and 7). Sea-bob-shrimp trawlers

Table 4
Mean capital investment (CI) of the different fleets and percentage between major assets.

Fleet	Average (BrReais $)	Boats (%)	Fishing gear (%)
Bottom-gillnetters	300,000	93.3	6.7
Bottom-longliners	175,000	94.8	5.1
Longliners	387,500	98.9	1.1
Octopus pots	600,000	66.7	33.3
Pair-bottom trawlers	473,733	94.3	5.7
Pink-shrimp trawlers	387,222	95.8	4.2
Purse-seiners	1005,556	59.2	40.8
Sea-bob-shrimp trawlers	78,889	89.2	10.8
Surface-gillnetters	173,333	91.3	8.7

had the highest variable costs per trip (74%). The highest expenditures on fuel corresponded to sea-bob-shrimp and pink-shrimp trawlers and purse-seiners (56%, 50% and 46% of gross income (GI), respectively) (Table 6a).

An inter-fleet comparison of all costs, suitable for ecosystem modeling purposes, is shown in Table 7. Relatively higher costs were estimated for tuna longliners, however this was not the fleet with highest profitability since relatively higher profits were recorded for the bottom-longliner and pair-bottom trawlers. Labour costs ranged from 1% to 21% of the total GI, and was the lowest for both shrimp trawlers.

3.2.4. Economic efficiency and Net Present Value

Assessing the economic efficiency per trip (EE), we found that purse-seiners had the lowest EE together with both of the shrimp fleets (Table 5). Bottom-longliners and both surface and bottom-gillnetters appeared to be the most economically efficient fleets. Thus, for every R$1 invested, purse-seiners had an income of R$1.20 per trip, and bottom-longliners had an income of R$2.50 (Table 5). On a monthly basis, the EE showed a different pattern in which the bottom-longliners were the most efficient, followed by the sea-bob-shrimp trawlers (Fig. 4).

However, the assessment of the fleets sustainability, based on a measure of the financial viability of capital investment (NPV) (Table 5), shows that for seven out nine fleets the NPV was greater than zero, i.e. their activities are net gainers. Purse-seiners and pink-shrimp trawlers' activities appeared to be net losers (NPV < 0), since the present value of the expenses is greater than the earnings. The highest NPV values were found for sea-bob shrimp trawlers, pair-bottom trawlers and bottom-longliners.

3.2.5. Profitability indicators (RR and PP)

In terms of rate of return (RR), results diverged between fishing trips on a monthly basis since vessels undertook variable numbers of trips per month. Bottom-longliners showed the greatest profit performance both per fishing trip and per month (RR = 5.4% and 5%, respectively) (Table 5). On a fishing trip basis, purse-seiners

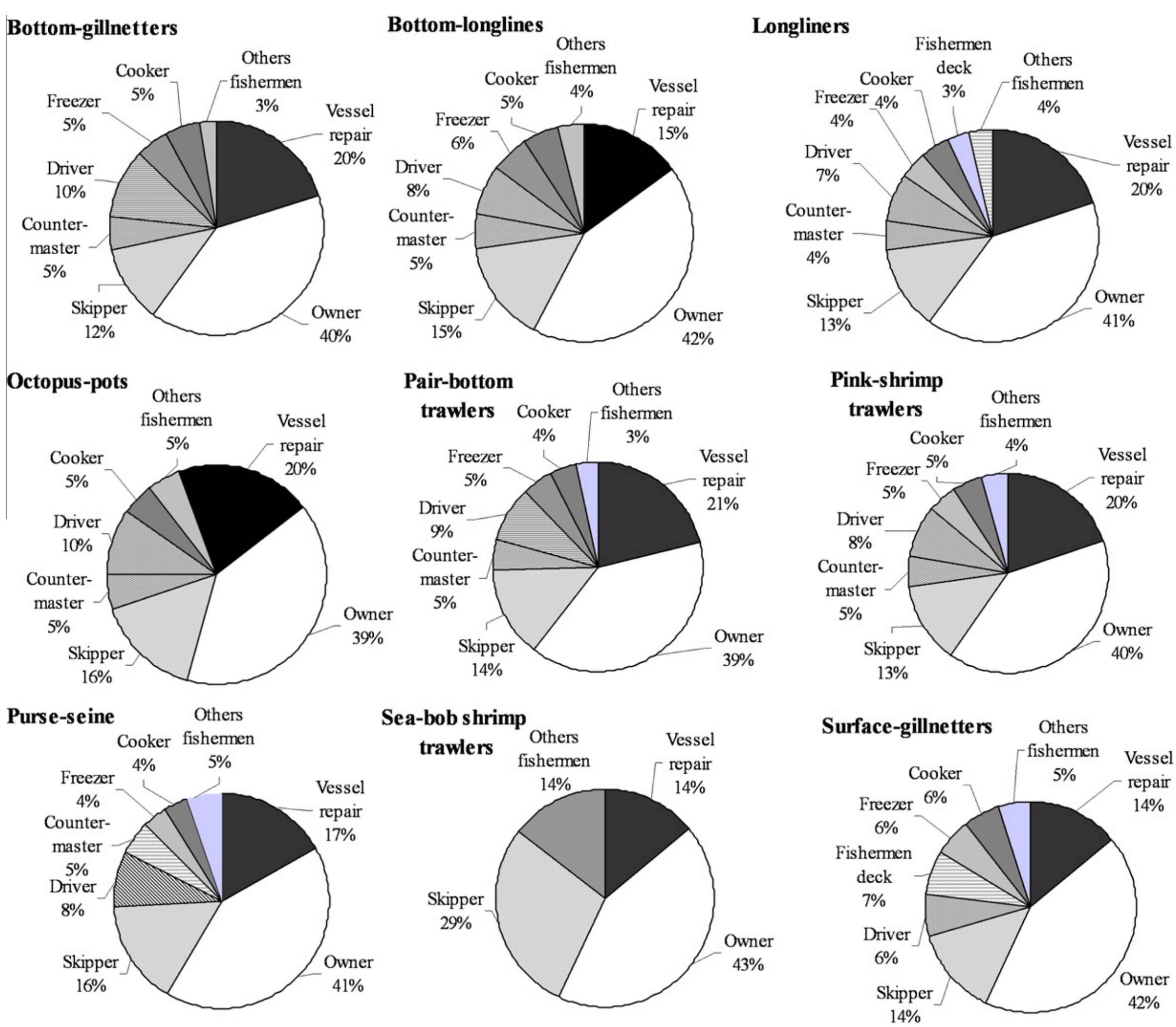

Fig. 5. The division of income (GI–VC) between the crew, repair costs (vessel's maintenance) and owner's profit. .

Table 5
Performance indicators of the different fishing fleets, as mean values per fishing trip and monthly. (EE: Economic efficiency; RR: rate of return profit; PP: investment payback period, NPV: Net Present Value.)

	Bottom-gillnetters	Bottom-longliners	Longliners	Octopus pots	Pair-bottom trawlers	Pink-shrimp trawlers	Purse-seiners	Sea-bob-shrimp trawlers	Surface-gillnetters
Per fishing trip									
Catch (t)	4.8	4.25	13	5.0	24	7.16	41.0	2.3	4.0
Standard deviation	0.4	3.2	4.0	3.0	11.05	4.1	24.5	1.9	2.8
Gross income (GI)	25,750	31,500	66,750	26,938	46,222	30,127	38,850	5454	11,609
Standard deviation	8131	30,406	21,654	20,857	21,919	30,367	22,975	3453	7939
Total costs (TC)	13,118	12,463	52,703	17,114	29,156	25,773	31,089	4475	5160
Fixed costs (FC)	5150	3359	13,350	5388	9501	5930	6043	758	1596
Variable costs (VC)	7968	9104	39,353	11,727	19,655	19,844	25,045	3718	3564
Profit (Pr)	6316	9406	6672	4912	8533	2039	3881	490	3224
Labour cost (LC)	6316	9630	7375	4912	8533	2184	3838	490	3224
Crew size	7	5–8	6–9	5–9	5–14	3–6	11–19	1–3	2–6
Trip by month	1.0	1.0	1.33	2	2.2	1.9	5	7.3	3.0
EE	2.00	2.50	1.30	1.60	1.60	1.20	1.20	1.20	2.30
RR (%)	2.1	5.4	1.7	0.8	1.8	0.5	0.4	0.6	1.9
Monthly									
Catch (t)	4.8	4.25	17.3	10	52.8	13.5	205	16,8	12
Gross income	25,750	31,500	89,000	53,876	102,349	56,908	198,135	39,814	29,021
Total costs	14,365	12,463	69,157	28,675	72,311	50,192	266,083	18,410	16,024
Variable costs	7215	9104	49,857	16,900	47,021	36,524	228,183	12,225	10,867
Fixed costs	7150	3359	19,300	11,775	25,290	13,668	37,900	6185	5157
EE	1.80	2.53	1.28	1.88	1.42	1.13	0.74	2.16	1.80
RR (%)	2	5	2	2	4	1	2	5	5
PP (in months)	46.5	18.6	42.6	60.0	24.1	99.5	54.1	21.0	20.5
Annualy									
NPV	195,916	654,228	467,166	497,724	834,685	−94,681	−3991,595	853,442	392,800
EE	1.80	2.53	1.28	1.88	1.42	1.13	0.74	2.16	1.80

Table 6
Relative importance of costs within each fishing fleet as estimated (A) by fishing trip, and (B) monthly. (Fees are always per month).

	Cost (%)						
	Fuel	Ice	Food	Bait	Landing	Repair and maintenance	Labour cost
A							
Bottom-gillnetters	23	12	6			26	33
Bottom-longliners	30		6			21	43
Longliners	34	4	4	22	1	23	12
Octopus pots	42	4	7			25	22
Pair-bottom trawlers	32	7	4		9	25	23
Pink-shrimp trawlers	50	6	5		10	21	8
Purse-seiners	46	3	6		17	18	10
Sea-bob-shrimp trawlers	56	11	7			16	10
Surface-gillnetters	26	4	9		4	19	38
Mean	37	6	6	22	8	21	22
World Bank (2008)	10–25					5–10	30–50

	Cost (%)							
	Fuel	Ice	Food	Bait	Landing	Repair and maintenance	Fees	Labour cost
B								
Bottom-gillnetters	17	11	6			25	10	31
Bottom-longliners	30		5			21		43
Longliners	32	3	4	23	1	23	2	12
Octopus pots	28	5	9			29	3	26
Pair-bottom trawlers	28	5	4		8	31	3	21
Pink-shrimp trawlers	48	5	5		10	20	5	8
Purse-seiners	57	3	2		11	17	2	6
Sea-bob-shrimp trawlers	43	7	5			25	3	16
Surface-gillnetters	24	4	8		3	25	4	33
Mean	34	6	5	23	7	24	4	22
World Bank (2008)	10–25					5–10		30–50

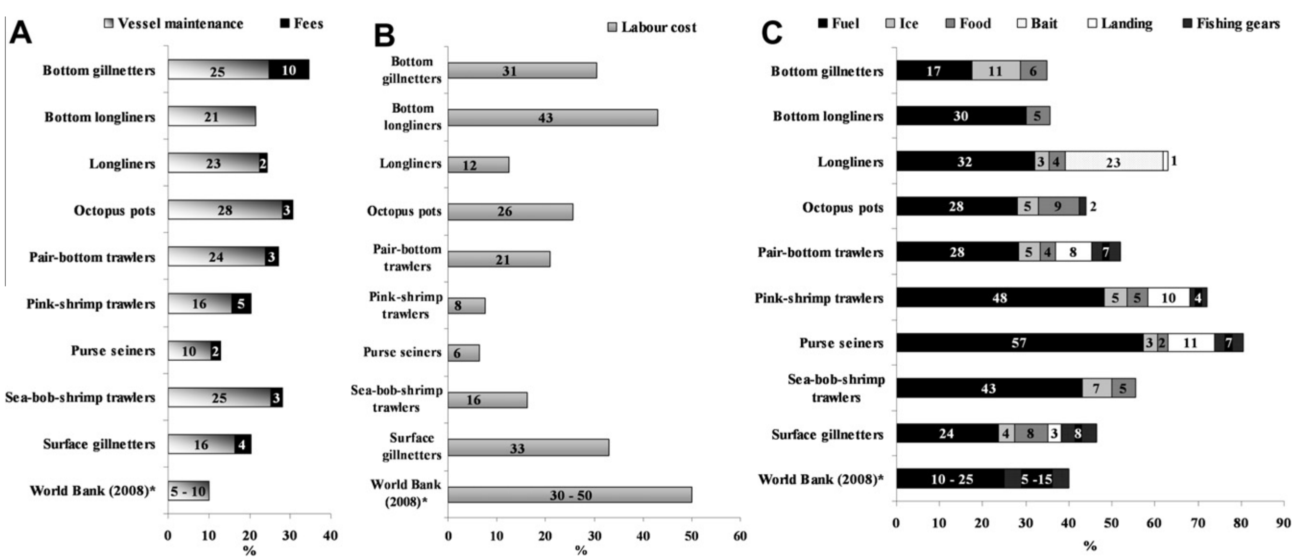

Fig. 6. Composition of monthly costs by fishing fleet. A-Fixed costs (FC), B-Labour cost (LC) and C-Variable cost (VC).

Table 7
Inter-fleet comparison of the relative importance of costs and profit, as estimated by fishing trip.

	Bottom-gillnetters	Bottom-longliners	Longliners	Octopus pots	Pair-bottom trawlers	Pink-shrimp trawlers	Purse-seiners	Sea-bob-shrimp trawlers	Surface-gillnetters
Total costs (TC %)	6.8	6.5	27.5	8.9	15.2	13.4	16.5	2.3	2.7
Fixed costs (FC %)	10.1	6.6	26.1	10.5	18.6	11.6	11.8	1.5	3.1
Variable costs (VC %)	5.7	6.5	28.0	8.3	14.0	14.1	18.2	2.6	2.5
Profit (Pr %)	14.0	20.8	14.8	10.9	18.9	4.5	7.9	1.1	7.1
Labour cost (LC %)	13.7	20.8	16.0	10.6	18.5	4.7	7.7	1.1	7.0

and the shrimp-trawler fleets showed the lowest profitability while on a monthly basis the bottom-longliners, surface-gillnetters, and the sea-bob-shrimp trawlers had the highest RR values (5%). This high monthly rate of return on profit for the sea-bob-shrimp fleet may have been due to its high number of fishing trips per month (Table 5).

The pink-shrimp trawlers had the lowest monthly RR (approximately 1%), which implies an investment payback period (PP) of around 99 months (Table 5). Bottom-longliners had the lowest investment payback period (approximately 19 months).

Higher profits occurred in fleets with lower variable costs. Profits (Pr) ranged from 30% to 18% of GI when the variable costs (VC) were between 43% and 29% (of GI), and tended to decrease (to less than 10%) when the variable costs were greater than 50% (Fig. 7). Thus, the fleets that showed the greatest profits (bottom-longliners, surface-gillnetters, bottom-gillnetters, octopus-pots and pair-bottom trawlers) were those with lower costs, which resulted in allocation of a proportion of the gross income for the crew's payment. The opposite occurred with the longliners, purse-seiners and the shrimp-trawler fleets, which had the highest total costs. In these fleets, lower profits were observed and a smaller percentage of the gross income was allocated for the crew's payment.

3.3. Patterns of fleet performance

3.3.1. Similarities between fleets

Hierarchical clustering was used to illustrate the similarities between fleets in terms of their socio-economic attributes based on trip-related data in Table 2, excluding capital investment and gear costs. The results (Fig. 8a) identified three main groups: a fleet with both higher fuel costs and catch values (A: purse-seiners), an intermediate group (B: pink-shrimp, pair-bottom trawlers, and longliners), and a third group with lower fuel costs and lower catch (C: surface-gillnetters, sea-bob-shrimp trawlers, octopus-pots fleet). The major factors contributing to this clustering seem to be 'fuel cost' and 'total catch value', consistent with the Principal Component Analysis shown in Fig. 8b.

Clustering of fleets based on each cost and indicators (i.e., J, Pr, CE, EE, RR) obtained per fishing trip is presented in Fig. 9a. The major factor explaining the four main clusters was GI and TC (Fig. 9b). However, when considering the monthly indicators and NPV (as in Table 5), three main groups are identified (Fig. 10): (A) purse-seiners; (B) pink-shrimp trawler fleet, both with negative NPVs; and (C) sea-bob-shrimp trawlers, pair-bottom trawlers, bottom-longliners, surface-gillnetters, longliners, octopus-pots and bottom-gillnetters, with NPV > 0. In this third group, a subgroup with the sea-bob shrimp trawlers, pair-bottom trawler and bottom-longliners fleets identifies the fleets with higher NPV values.

3.3.2. Vessel similarities

Hierarchical clustering of fishing vessels (based on attributes in Table 2) after disassociation from fleet categories, showed three major groups (Fig. 11a). The major attribute explaining the

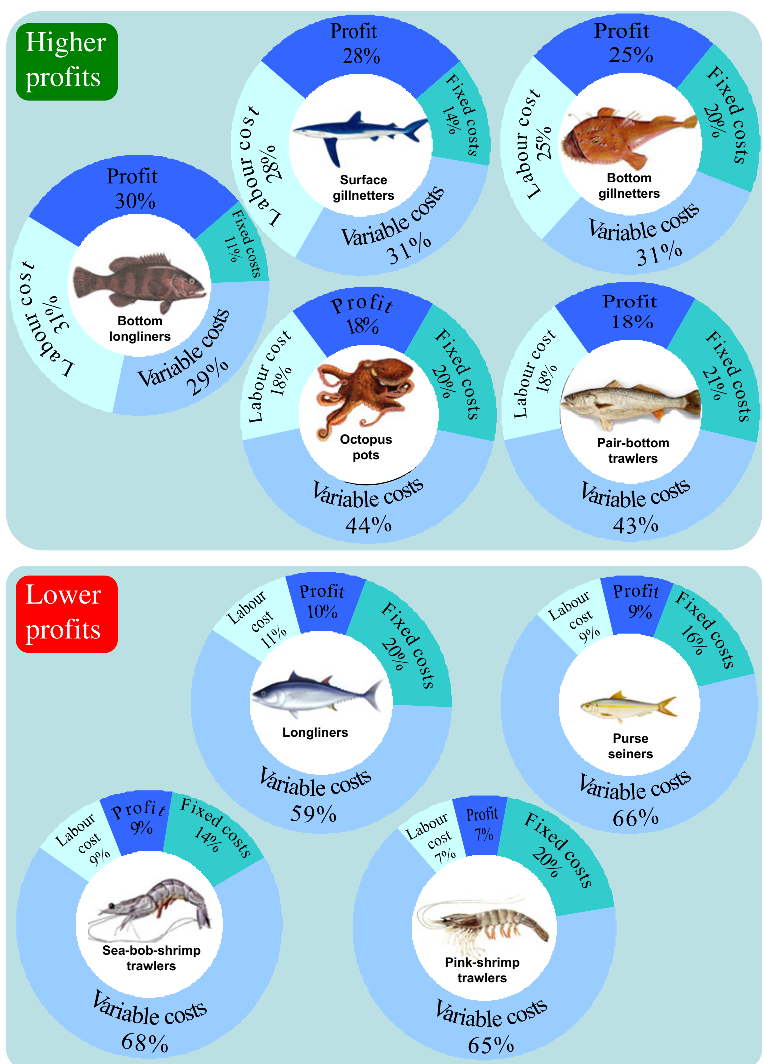

Fig. 7. Profit and composition of costs (proportion of the total GI) per fishing trip by each fleet.

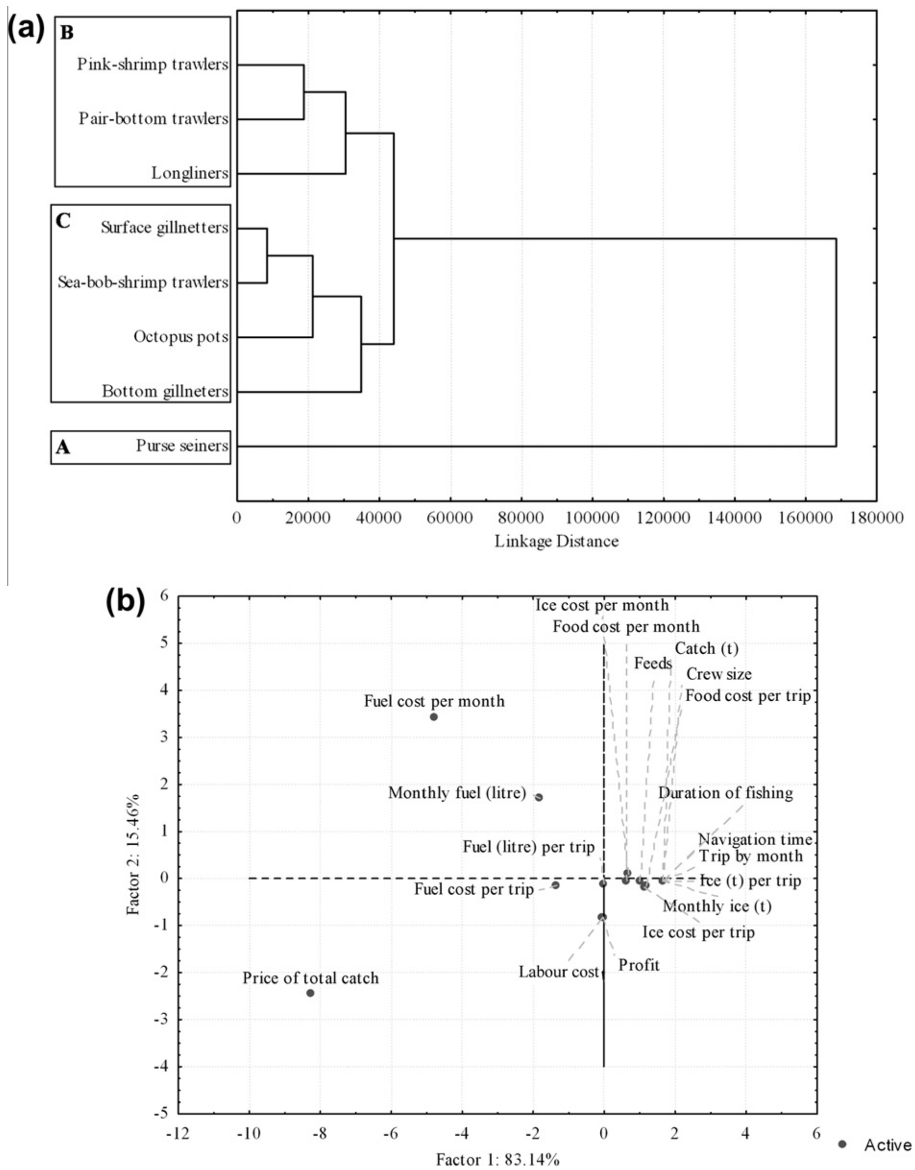

Fig. 8. Hierarchical clustering (average linkage method) showing the similarities between fleets (a), and Principal Component Analyses (PCA) of socio-economic variables (b), both based on the socio-economic variables in Table 2 excluding capital investment and gear price. PCA was based on the differences between the groups identified in (a).

grouping was average capital investment (CI), independently of which fleet a vessel belonged to, and three main groups seemed to be emphasized: (A) vessels with values from R$ 60,000 to 350,000; (B) vessels with values between R$ 500,000 and 1000,000; (C) vessels with values from R$ 1500,000 to 4000,000 (Fig. 11a and b). It can be noted that the most expensive vessels, i.e., those that required the highest capital investment, were not the ones with higher catch values per trip (Fig. 11b).

4. Discussion

The examination of fishing behavior and performance in a multi-fleet context within an ecosystem provides a useful overview for ecosystem-based fisheries management. As in the case of biological predators, each fishing fleet operates with its own strategic behavior and energy-budget, translated here as currency flux. This seems to be a key contribution to integrating various intrinsic relationships, such as environmental, economic, social and technological, within and between the different components of the fisheries. In practice, although most fisheries involve many species, management recommendations are often made on a single-species or single-fleet basis, failing to meet the operational needs that can be addressed by an ecosystem approach. In this study, the richness of both marine biological species and fishing vessels indicates that a multi-fleet approach is more appropriate for such a purpose.

If one of the main issues of fishery management is the adoption of mechanisms that promote economically successful fisheries with less ecological impact, then it is important to understand how fishing fleets could maximize their profits, not by catching fish faster, but by catching fish efficiently, increasing the quality of the product and the price they receive (Hilborn et al., 2005). In this sense, we detected a series of deficiencies among the fleets operating in the South Brazil Bight area. Some of these deficiencies correlated with the intrinsic characteristics of the fleet and the ecosystem.

First, fleet size and mobility was correlated with vessel size. Smaller boats (e.g., sea-bob-shrimp trawlers) tended to make a larger number of shorter trips over the course of the month, and

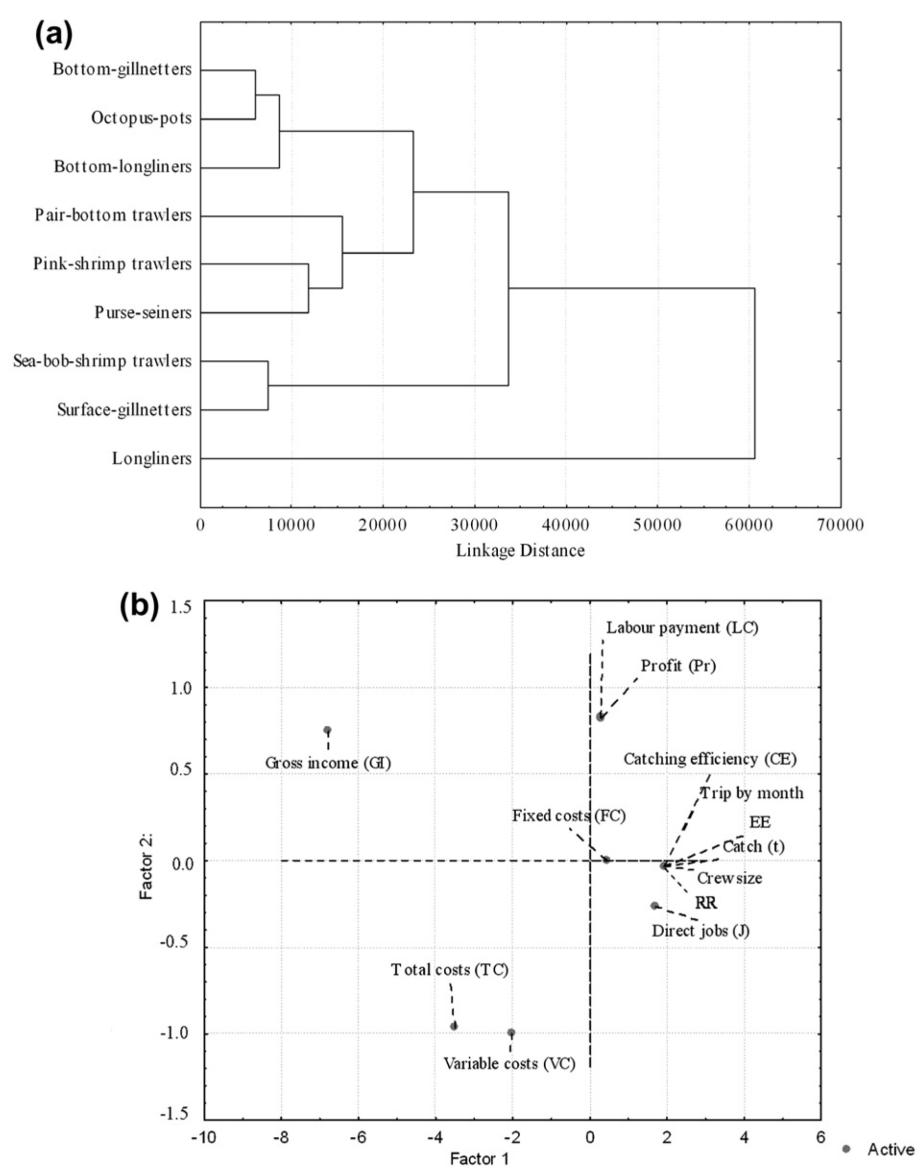

Fig. 9. Hierarchical clustering (average linkage method) showing the similarities between fleets (a) and Principal Component Analyses (b), both based on the data per fishing trip as listed in Table 5 plus the data on average direct jobs (J). PCA was based on the differences between the groups identified in (a).

tended to concentrate their efforts in near-shore areas because of limited fuel and ice capacity. Larger boats (e.g., longliners and purse-seiners) adopted more itinerant strategies covering a larger total area and consequently placed less emphasis on one particular fishing ground. The size and type of gear usually determined the crew size (Piniella et al., 2007). The purse-seiner fleet had the largest crew since more hands are required to operate that gear, followed by pair-bottom trawlers. However, in terms of the total number of direct jobs offered, the shrimp-trawler fleets (both pink-shrimp and sea-bob-shrimp) generated the second highest percentage of jobs (36%) due to the higher number of vessels. The crew sizes of the fleets analyzed here were similar to those landing in relatively close ports such as Rio Grande and Santa Catarina (Haimovici et al., 2006; Sunye, 2006). This higher level of employment associated with trawl fleets also occurs in other countries such as Indonesia and Mexico, where the shrimp fleets offer a vastly greater number of jobs on-board than local larger vessels (Gillett, 2008).

4.1. Catching versus economic efficiencies

Catching efficiency parameters provide an overview of fishing performance taking account of different gear and technology (Trinidad et al., 1993). Purse-seiners appear to be more technically efficient (CE = 0.55) than other fleets, even with the lowest EE values. When the target-species is reduced or overfished, the skippers' experience can greatly influence the catching efficiency (Sharma and Leung, 1998). However, when catching is analyzed together with economic efficiency, the fleets that are most efficient in catching are not necessarily the most economically efficient. This was the case for purse-seiners that fish for sardines. The *Sardinella brasiliensis* stock forms dense schools that are efficiently caught by fishers in a single operation. Nevertheless, sardine prices are relatively low and stable both monthly and annually which tend to result in low economic efficiencies (Gasalla et al., 2003). This is similar to purse-seining for skipjack tuna in the western and central Pacific Ocean (Barclay and Cartwright, 2007).

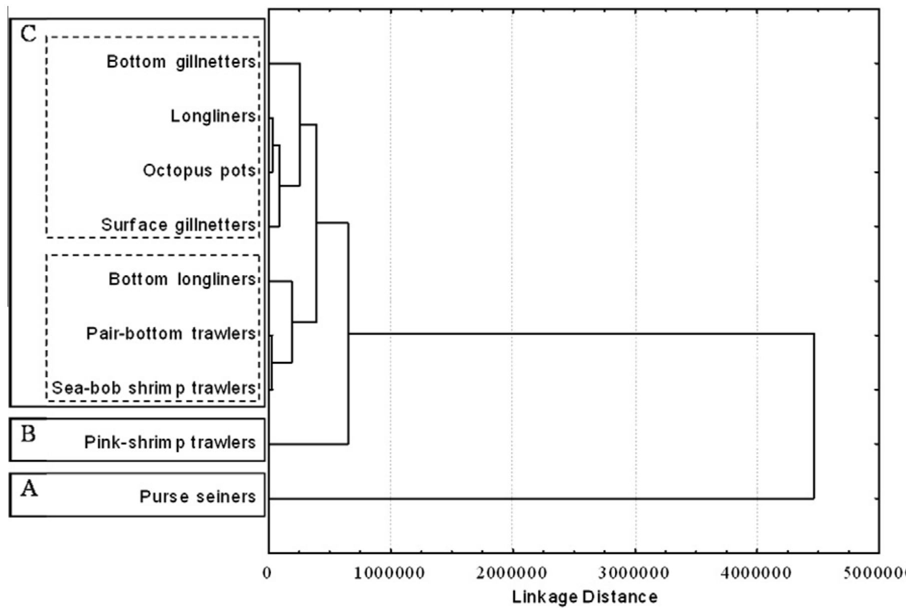

Fig. 10. Hierarchical clustering (average linkage method) showing the similarities between fleets considering monthly indicators (Profit, CE, EE, RR and PP) and NPV.

It is important to mention here that because of the intra-fleet variability found for purse-seiners, an apparent discrepancy appears between monthly and per fishing trip cost values. The former are much higher because a small part of the fleet reached a high number of fishing trips per month. For this fleet, the higher costs are explained by high variable costs, mainly fuel.

Bottom-gillnetters showed one of the lowest values of catching efficiency (0.04), possibly due to the duration of fishing trips (15.5 days in average). However, this fleet was the third most economically efficient (2.00), probably due to the catch of the internationally highly valued monkfish *Lophius gastrophysus,* and its associated increasing export opportunities to European and Asian markets (Perez et al., 2002).

4.2. Economic indicators and sustainability concerns

From the economic analyses of EE, RR and PP per fishing trip, it can be seen that bottom-longliners, and both bottom- and surface-gillnetters, showed high profitability rates and relatively lower investment payback periods. Purse-seiners and shrimp trawlers had the worst economic indicators per fishing trip, possibly due to their high variable costs (e.g., fuel, ice, food). However, paradoxically, these fleets were the ones that have increased in number in recent years (Fig. 2) and that target fully fished or overfished species. It is likely that changes in fleet size may represent shifts in landing sites from/to other areas. In addition, the replacement of gear and the adaptation of old vessels to new gears was also commonly cited during interviews and may explain some findings. The values of costs and payback periods found in this study by sea-bob shrimp trawlers, are in the range of those found by Souza et al. (2009).

Malthusian overfishing (Pauly, 1994) may be occurring. As the fishing pressure on the practically unmanaged resources becomes stronger, their production gradually declines (first in terms of valuable species, then in terms of the species that replace the original stock), and both economic overfishing and reduction of incomes occur together with biological overfishing. This may be what is occurring with traditional purse-seining for sardines and trawling for shrimps in the Southeastern Brazil Bight, whose target-species are considered over-exploited and their NPV was found in this study to be negative.

Purse-seiners and pink-shrimp trawlers were among the fleets with higher fuel costs, as shown in the cluster and PCA analyses (Fig. 8a and b). Fuel is a central issue in the economics and dynamics of many fisheries. The reduction of physical productivity and the increasing costs, mainly of fuel, that negatively impact fleets have been reported elsewhere, especially in Europe (EAEF, 2006; Barclay and Cartwright, 2007; Ceriola et al., 2008). Thus, if the amounts spent on fuel and other fishing costs have risen more than the general price level for these items, this is probably evidence that a greater effort is being applied. If there were no consequent increase in the catches, the return would fall and the fishery would not be sustainable (Hundloe, 2000), which seems to be the case here.

In this study, fuel was the principal component of the costs in six of nine fleets, as reported by skippers and owners and verified in the statistical analysis. This is consistent with what was found in France where there are proportionally greater fuel costs for fishing gear that is towed. Fuel costs were found to represent 24% of the total costs for vessels over 12 m in length using towed gear, but only 11% for those using set gear (Binet, 2007).

A recent study by FAO indicates that fuel use by shrimp trawling vessels is generally greater than in other fisheries and the cost base of producing a kilo of prawns is spiraling upward rather than flat-lining or declining (Gillett, 2008). It was reported that otter-trawlers in Norway use four times as much fuel to catch one ton of fish compared to local coastal gillnet and line vessels (Smith, 2007). Declining real and nominal prices, along with increasing costs of operation, have created large difficulties in maintaining financial solvency for commercial shrimp vessels in the Gulf of Mexico and southern Atlantic regions of the United States (Ward et al., 2004), as well as for herring vessels in the Baltic Sea (EAEF, 2006).

Fuel has been considered as a factor that could change the economics of the fishing industry (FAO, 2007). By reducing profitability it could also contribute to reductions in overfishing. However, this is not often observed in practice because of subsidies given to the fishing sector by governments, including that of Brazil (0.11 US$ per liter of fuel) (Haimovici et al., 2006; Sumaila et al., 2008). By restoring profitability due to reducing costs, subsidies create incentives for continued fishing despite declining catches. This policy induces and masks economic imbalances in the fishing

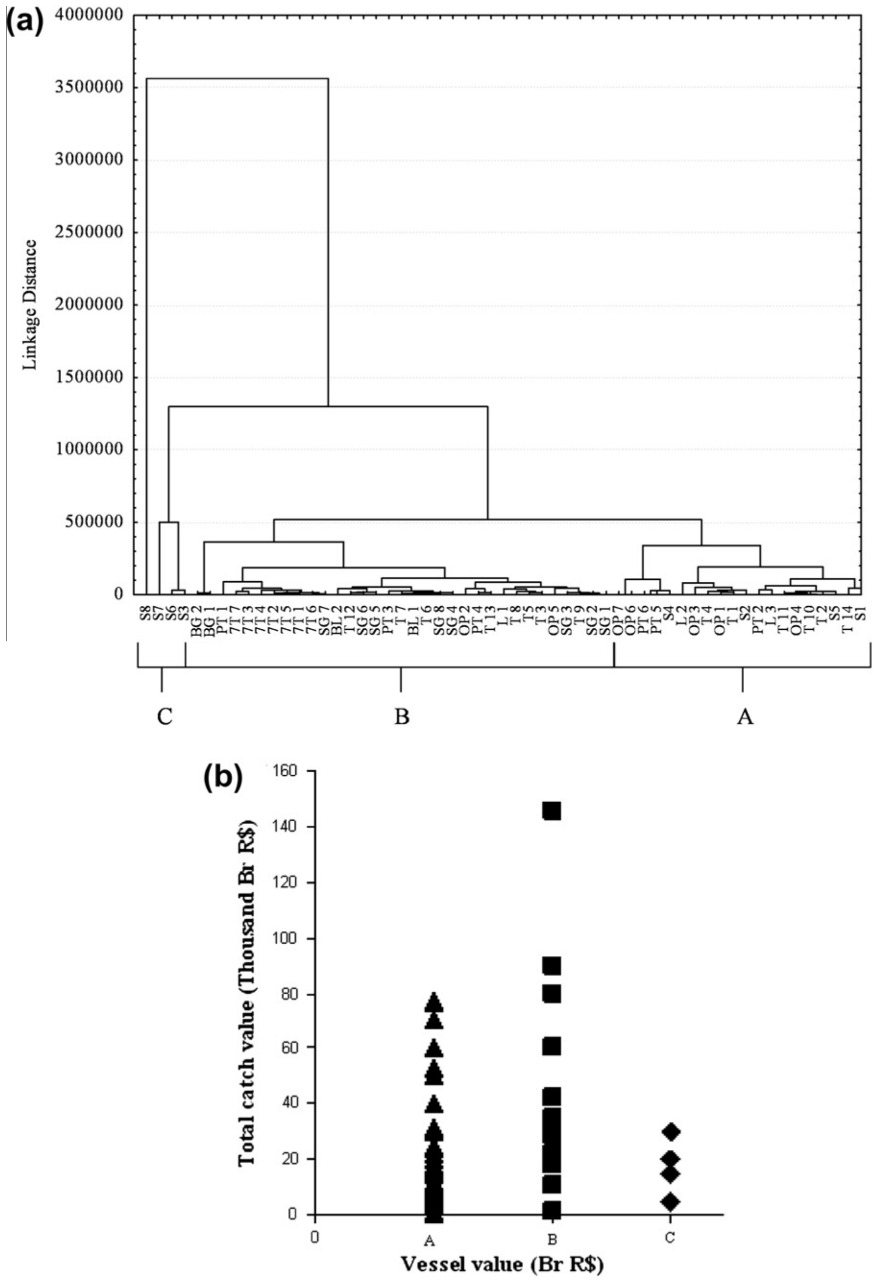

Fig. 11. Hierarchical clustering of fishing vessels (average linkage method) showing the similarities between individual socio-economic attributes shown in Table 2 (a), and the Total value of the catch (GI) for the three major groups (b) (Group A, vessels with values from R$ 30,000 to 350,000; group B, vessels with values between R$ 500,000 and 1000,000; group C, vessels with values from R$ 1500,000 to 4000,000). (S is purse-seiners, SG, surface-gillnetters, BL, bottom-gillnetters, OP, Octopus-pots, L, longliners, T, pink-shrimp trawlers, PT, pair-bottom trawlers, and 7T, sea-bob-shrimp trawlers).

industry, stimulating fleet overcapitalization, the reduction of economic efficiency and resource rent dissipation, all of which promote rather than prevent overfishing (Schrank, 2003).

In terms of the global context of our findings, it can be noted that comparing the average costs of these local fleets to those reported by the World Bank (2008), fuel and vessel maintenance costs are above the world average, while crew payment is below the mean values, which could also reflect the high costs of the fleets from Southeastern Brazil.

4.3. Implications for management and the ecosystem approach

Fisheries in the South Brazil Bight may be regarded as one large and diverse multi-gear and multi-species fishery, although they are rarely studied as such (Gasalla and Rossi-Wongtschowski, 2004). Therefore, multi-fleet cost and technological analyses should be incorporated as an important aspect of fishery management recommendations. Our results may be useful for considerations concerning fishing capacity, management trade-offs, or the analysis of conflicting use by different fleets. In many countries, the gross value of the shrimp catch is often used by fishery managers for making decisions (Gillett, 2008).

Analysis of financial measures for each fleet can also improve understanding of the correlation between different types of gear and their associated environmental damage. This analysis may be useful for the proposition of input and output controls such as license systems, the reduction of fishing capacity and ecosystem approaches to fishery management.

Some findings will require additional attention such as the cost/benefit analysis of shrimp and purse-seiner fleets. Employment associated with these fisheries is often thought to be one of the main benefits, but low profitability may indicate a decline of the target-species. It is likely that the fleets that (1) showed better economic performance (such as bottom-longliners, bottom-gillnetters and surface-gillnetters), (2) those that are important for seafood supply (pair-bottom trawlers, longliners), and (3) those that are considered socially important (trawlers and purse-seiner), can be reluctant to approve reduction measures that would be suggested based on the present results. It has been suggested that a fundamental problem of many of the world's shrimp fisheries is their lack of regulation and their open-access – the right of the entire public to participate in fishing (Clark, 2006). In general, if there are no barriers to entry, fisheries typically end up at the point where the total revenue equals the total cost (profitability shrinks to zero) or beyond if subsidies are provided. The history of shrimp' fishery management shows that management interventions (e.g., catch limits, closed seasons) that do not address real participation are usually ineffective at preventing overcapacity and economic overfishing in the long term (Gillett, 2008). Thus, the present situation of fishery management in the Southeastern Brazil Bight area, with a particular emphasis on the pink-shrimp fishery, should be further reviewed.

The situation of purse-seiners seems to be also critical. Our findings on both poor economic efficiency and viability (NPV < 0) of this fleet are expected to be particularly relevant for consideration into the policy arena, especially with regard to fleet size optimization and effort reduction needs based on biological reference points. This is one example of how this type of economic information could be used to address specific policy questions regarding the management of Brazil's fisheries and elsewhere.

The trends in the costs of each aspect of production are relevant not only for an understanding of the historical patterns in fisheries, but also to provide a basis for future projections, for example the effect of rising fuel prices, economic trends related to particular costs of supplies or species, or other scenarios (i.e., potential climate change). In this sense, the adaptability of the different fishing fleets and markets could be better understood taking into consideration this multi-fleet cost analysis.

Suggestions that could improve the current situation of poor profitability include the avoidance of open-access regimes, a significant fleet reduction that could eliminate overcapacity, and the calculation of management trade-offs between ecological, economic and social aspects of sustainability, which can be done through further ecosystem modeling exercises.

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