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A bio-economic analysis of the hand-line and gillnet coastal fisheries of Pernambuco State, north-eastern Brazil

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SUMMARY: This paper presents a bio-economic analysis of the hand-line and gillnet coastal fisheries off Pernambuco State, north-eastern Brazil, in order to define management measures to support the decision-making process available to fisheries managers to reduce uncertainties about the sustainable development of the fisheries. The objective of applying a bio-economic model was to reproduce the biological and economic conditions in which the fisheries occur. This was done by carrying out projections and simulations, starting from the current situation and going forward into the future with the purpose of analysing the behaviour of the fishery under different conditions, particularly different management measures. Six scenarios are presented, defined by different management regimes: Scenario 1: increase in catchability; Scenario 2: reduction in fuel price; Scenario 3: closed season; Scenario 4: reduction in the number of active boats; Scenario 5: reduction of catches of juveniles; and Scenario 6: joint implementation of biological, economic and technical management strategies. Management events were always introduced in the fifth year of the simulation, with the exception of Scenario 1, in which the event was introduced in the first year. For each of the five scenarios, a deterministic simulation was carried out with a Beverton-Holt model of the stock-recruitment relationship. Simulations were carried forward through a 30-year period. The best management strategy, in biological and economic terms, seems to be the joint application of several management measures that satisfy the claims of stakeholders, and permit a biological and economic equilibrium between the activity and the efforts to rebuild stocks.

Keywords: bio-economic analysis, coastal fisheries, Pernambuco state, Lutjanidae.

RESUMEN: Análisis bioeconómico de las pesquerías costeras con liña y red de enmalle en el Estado de Pernambuco, nordeste de Brasil. – Este artículo presenta un análisis bioeconómico de las pesquerías costeras de liña y red de enmalle en el Estado de Pernambuco, Nordeste de Brasil, para la definición de medidas de gestión en el proceso de decisión para reducir las incertidumbres y buscar un desarrollo sostenible de las pesquerías. El objetivo de aplicar un modelo bioeconómico fue reproducir las condiciones biológicas y económicas en que las pesquerías ocurren, y el análisis mediante proyecciones y simulaciones, partiendo de la situación actual y proyectando hacia el futuro con el propósito de analizar el comportamiento de la pesquería bajo diferentes condiciones, particularmente diferentes medidas de gestión. Se presentan seis escenarios, definidos por distintos regímenes de gestión: Escenario 1: aumento en la capturabilidad; Escenario 2: reducción del precio del carburante; Escenario 3: paro biológico; Escenario 4: reducción del número de barcos activos; Escenario 5: reducción de las capturas de juveniles; y Escenario 6: aplicación conjunta de estrategias de gestión biológicas, económicas y técnicas. Los eventos siempre se introdujeron en el quinto año de la simulación, con la excepción del Escenario 1 en que el evento se introdujo en el primer año. Para cada uno de los cinco escenarios, se estableció una simulación determinista utilizando el modelo stock-reclutamiento de Beverton-Holt, y se proyectaron las simulaciones en un periodo de 30 años. La mejor estrategia de gestión parece ser la unión de los efectos de diferentes condiciones que permitiría satisfacer las demandas de grupos de interés en la actividad, y proporcionaría equilibrio biológico y económico de la actividad y la reconstrucción de las poblaciones.

Palabras clave: análisis bioeconómico, pesquerías costeras, Estado de Pernambuco, Lutjanidae

INTRODUCTION

Quantitative and qualitative biological and economic information is important when conducting an analysis of the dynamics of a renewable natural resource (Willmann and Garcia, 1986; Seijo *et al.*, 1998). However, complete records of historic data must be available, and generally a study is conducted at defined points in time. That is why, for practical purposes, static analysis is quite commonly used and, consequently, easier to handle. Modelling for fisheries management has been given special attention for defining strategies for fisheries development (Anderson, 1977; Clark, 1990; Defeo and Seijo, 1999).

Under these concepts, a series of techniques based on deterministic and stochastic simulations and computational statistics have recently been developed in the form of bio-economic models (Clark, 1990; Hannesson, 1993; Defeo and Seijo, 1999; Ulrich *et al.*, 2002; Lleonart *et al.*, 2003). The purpose of these tools is to facilitate analysis of the consequences and risks of different management measures applied to particular stocks. These models consist of using a stock simulator (operating model) and a simulator of the assessment process, both provided with different error sources. Using this procedure, the whole process of stock dynamics, fishing activity, fishery assessment and fishery management, as an adaptive process, can be simulated.

For example, a basic question that a bio-economic model should answer is the positive or negative impact on social and economic net benefits that any fishery has, which must lead to the local assessment and management of the fishery. Introducing a fishery can be considered as a disturbance to the ecosystem dynamics, and at the same time, a model of the fishery must consider the economic interests in exploiting this activity constrained by ecological factors in order to avoid overexploitation of some of the currently harvested species (Facó, 1988).

The similarities between the Pernambuco coastal fisheries and the Mediterranean fisheries are many: According to Martín (1991), the fishing activity in Catalonia, and the Mediterranean fishery in general, is characterised by a great diversity of exploited species and fishing gears, as well as by the seasonal variations of the catches, which are relatively small compared to large scale Atlantic fisheries. Fish is commercialised fresh, and with few exceptions the fleets work five days per week, returning to port every day. Fish production is commercialised at the local market. For Lleonart *et al.* (1999b), the Mediterranean small-scale fisheries are a variable activity with highly multi-species catches with fishing intensities and strategies showing very rapid fluctuations in space and time. The seasonal activity of the fleets is related to the ecology of the different species, meteorological conditions, the tourist season, etc. From the economic point of view, there are also similarities between the Mediterranean and Pernambuco fisheries, such as: lack of fishing industries; individuality of the economic agents; high dependency on the local market; and labour relationships based on the share system, not on fixed salaries. Other similarities between the Mediterranean and the Pernambuco coastal fisheries include the fisheries management regime: Mediterranean fisheries are not regulated by quantitative and adaptive management procedures, but rather by more or less static rules that include effort, power and gross tonnage limits, closed areas, and other technical measures. Many such regulations are not based on scientific advice (Farrugio *et al.*, 1993). Some bottom-up management measures are usually adopted, particularly at the small-scale level, as a feedback response to the experience and behaviour of fishermen (Lleonart *et al.*, 2003). Since the management of the Mediterranean fisheries is largely driven by self-regulation based on socio-economic and cultural criteria (Franquesa, 1994), monitoring these fisheries would greatly benefit from analysis based on a set of economic and social indicators (Bonzon, 2000), because the management of the Mediterranean fisheries is characterised by a large variety of complex and interdependent parameters for which the economic and social dimensions are often predominant (Hundloe, 2000). All these ecological, economic and structural similarities (highlighted also in Bas, 2002) justify a bio-economic model (Mediterranean Fisheries Management Tools, *MEFISTO*: Lleonart *et al.*, 2003) developed primarily for the Mediterranean fisheries, being applied to the Pernambuco fisheries.

The objective of the present paper is to conduct a bio-economic analysis of Pernambuco State, northeastern Brazil (Fig. 1), hand-line and gillnet coastal fisheries to reach a preventive management of the fisheries in the short, medium and long term. The aim is to reproduce the bio-economic conditions in which the fisheries occur by carrying out projections to simulate alternative management strategies.

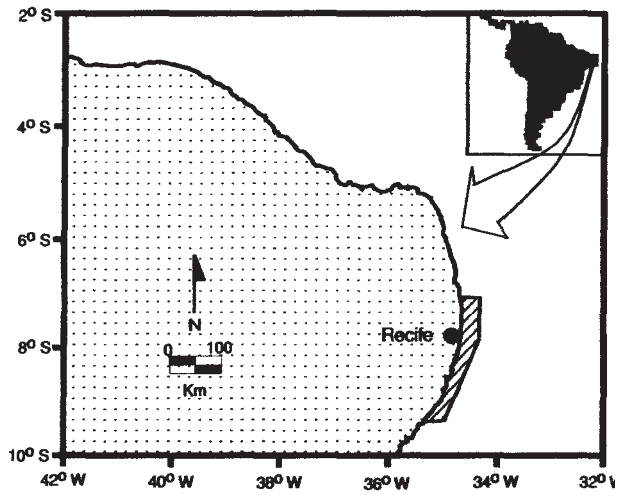

FIG. 1. – Area of the coastal fishery activity off Pernambuco State, north-eastern Brazil, continental shelf.

These start from the current situation that best describes a scenario and go forward into the future so as to analyse the behaviour of the fishery under different conditions, particularly different management situations.

MATERIAL AND METHODS

Bio-economic analyses of the coastal fishery of Pernambuco State were conducted by monitoring two representative small-scale fisheries, aiming at simulating different management strategies. The two fleets selected were the hand-line and gillnet coastal fisheries, consisting of 18 and 10 boats respectively. The catches and effort of these fleets were monitored for the period 1993-2002. Biological data on the target species as well as economic data on the fisheries were collected (Mattos, 2004).

The Pernambuco State fisheries are mainly conducted in the coastal zone by artisanal fishermen operating small fishing vessels. These small-scale fisheries produce 97% of the total fish production of the State (Mattos, 2004), which is consumed locally. The fisheries are conducted over a relatively narrow continental shelf (*ca*. 30 km wide, Fig. 1), influenced by the warm and nutrient-poor westward tropical divergence, with low biological productivity. Official catch statistics combined with field sampling for the period 1993-2002 allowed us to estimate the total production in 2002 to be 5,885 t, combining marine and estuarine species (Mattos, 2004). Fish species represented 3,923 t, producing 51% of the economic value, while crustaceans yielded only 600 t but represented 38% in economic terms. Other groups, such as molluscs, represented around 20% in weight and 10% in value.

The two fleets analysed, hand-liners and gill-netters, produced an average 918 and 939 t respectively for the period 1993-2002 (Mattos, 2004). The main species caught by the hand-line fleet are coastal reef fishes: yellowtail snapper (*Lutjanus chrysurus*), mutton snapper (*L. analis*), dog snapper (*L. jocu*) and black grouper (*Mycteroperca bonaci*), and coastal mid-size pelagics: king mackerel (*Scomberomorus cavala*), dolphin fish (*Coryphaena hippurus*) and barracuda (*Sphyraena barracuda*). The gillnet fishery mainly targets the blue runner (*Caranx crysos*), the Spanish mackerel (*Scomberomorus brasiliensis*) and the lane snapper (*L. synagri*). Coastal sharks are also caught by this fleet, especially *Rhizoprionodon porosus*.

The bio-economic model used, MEFISTO, is a simulation model described in detail in Lleonart *et al*. (1999a; 2003). The MEFISTO model includes a biological box describing the age-structured population dynamics of the main species with an additional pool of secondary species (*i.e*. species contributing significantly to the economy of the fleet but whose population dynamics are not known). In the model, the fish catches are converted to revenues by means of species-specific price equations. At the economic level, the model is disaggregated by vessel. From the total revenue obtained by each vessel, different types of costs are deducted. According to the net revenue obtained, each vessel follows a set of rules that will determine its behaviour during the next time step: increase or decrease effort, increase or decrease investment or quit the fishery.

From the bio-economic point of view, and considering the *stock box* of the MEFISTO model (Lleonart *et al*., 1999a; Franquesa and Lleonart, 2001; Lleonart *et al*., 2003), there are two kinds of species: the main species, whose dynamics are completely explicit, and the secondary species, whose dynamics are not known but whose yields are computed as a function of the main species. Five species were considered for the hand-line fishery: yellowtail snapper, mutton snapper and king mackerel as the main species, and dog snapper and dolphin fish as accessory species. For the gillnet fleet, only Spanish mackerel was considered as a main species, while the blue runner and the lane snapper were modelled as secondary species.

TABLE 1. – The von Bertalanffy growth parameters (L_∞, K and t), parameters of the length-weight relationship (a and b), natural mortality (M) and the initial recruitment, the mean stock biomass (Bmean) and the spawning stock biomass (SSB) of the four main species for both fisheries. YTS, Yellowtail Snapper; MS, Mutton Snapper; KM, King mackerel; SM, Spanish mackerel.

	Species			
Parameters	YTS	MS	KM	SM
L_∞ (cm)	76.67	108.2	142.8	103.86
K (yr-1)	0.158	0.168	0.137	0.165
t (yr)	-0.728	-0.89	0.137	-0.084
a	0.0183	0.01122	0.0219	0.0094
b	2.7753	3.002	2.7312	2.9446
M (yr-1)	0.112	0.152	0.309	0.382
Recruitment (ind.)	78,478	38,542	156,908	156,831
Bmean (t)	49.07	139.78	795.36	106.88
SSB (t)	38.05	119.64	507.08	76

The von Bertalanffy growth parameters for yellowtail and mutton snappers were estimated using length frequency data collected in this study, while for king mackerel and Spanish mackerel the parameters used were the ones reported by Nóbrega *et al*. (2001a), Lucena *et al*. (2001) and Nóbrega *et al*. (2001b). The necessary information on the population structure concerning the number of individuals, the maturity ratio and the natural mortality (*M*) vector were estimated by means of Virtual Population Analysis using the VIT program (Lleonart and Salat, 1997). In order to validate the data provided to MEFISTO, a first simulation was run with constant recruitment, afterwards the Beverton-Holt spawning stock biomass and recruitment relationship model was applied. Table 1 shows the von Bertalanffy growth parameters (L_∞, K and t), those of the length-weight relationship (a and b) and the summary of the results of a standard VPA that was run with the VIT program. This permitted us to define the initial recruitment, the mean stock biomass (*Bmean*) and the spawning stock biomass (*SSB*) of the four main species for both fisheries.

Additive relationships between the main and the secondary species, defined in the *market box* of the MEFISTO model, were established for both fleets ($Y = a + bC$). Parameter b of the equation was estimated, where Y is the catch of the secondary species and C is the catch of the main species. Parameter a was considered equal to zero, because it can only be estimated when a time series of catches and prices is available, and means that when catches for the main species do not occur, there are no catches for accessory species. The reference prices were obtained through the official statistics bulletin for the year 2002 (IBAMA, 2003). The economic parameters concerning the costs that fishers may incur, established through the *fisherman box* of the MEFISTO model, are presented in Table 2.

An initial stock and fisheries situation was established based on the current fishing conditions. A deterministic scenario was set up for the initial conditions, and recruitment was considered constant, aiming at validating the provided parameters. Simulations were projected over a 30-year period.

Six scenarios are presented, which are defined by different events. The events are always introduced in the fifth year of the simulation, except for Scenario 1, in which the event was introduced in the first year. For each of the five scenarios, a deterministic simulation was set up and the Beverton-Holt stock-recruitment relationship model was applied.

TABLE 2. – Economic parameters defined for the hand-line and gillnet fleets of Pernambuco State, north-eastern Brazil. Values in Brazilian currency (Real - R$). Brazilian minimum salary (= R$ 240.00). Exchange rate in December 2002: 1.00 € = R$ 3.50.

Fishermen's Expenses	Parameter	Hand-line Fleet	Gillnet Fleet
Trade Cost (C1)	Trade cost (landing) (c1.1)	10%	Zero
	Social Security (c1.2)	0.1%	0.1%
	Fisherman Association (c1.3)	0.05%	0.05%
Daily Cost (C2)	Fuel price (2002 average) (c2.1)	R$ 0.95/l	R$ 0.95/l
	Fishing days (c2.2)	190	230
	Daily fishing hours (c2.3)	10h	10h
	Daily ice expense (c2.4)	R$ 6.60	R$ 1.00
	Fishing gear repair (e.g. net mending) (c2.5)	Zero	R$ 1,125.00
	Operating fishing cost/day (c2.6)	R$ 29.56	R$ 21.06
	Other daily costs (c2.7)	R$ 15.25	R$ 11.97
Labour Cost (C3)	Owner's share (c3)	25%	37.5%
Compulsory Cost (C4)	Total Fixed Cost (c4)	15.43%	15.43%
	Boat License	5.62%	5.62%
	Boat Insurance	9.81%	9.81%
Maintenance Cost (C5)	Maintenance Cost (c5)	84.57%	84.57%
Opportunity Cost (C6)	Opportunity cost (c6)	5.9%	5.9%
Financial Cost (C7)	Maximum Credit (c7.1)	30%	30%
	Interest (financial cost) (c7.2)	Zero	Zero

Scenario 1. Increase in catchability from two sources: *i)* by a constant factor of 1%, which means that each year the catchability will increase automatically by 1%, and *ii)* by a factor relating catchability to the capital invested, by a factor of 5, which means that doubling the initial capital results in a 5% increase in catchability due to investment of profits. This simulation was set for all the following scenarios for the hand-line fishery;

Scenario 2. Reducing the price of fuel by 80% (a long-standing claim of the fishermen to the fisheries administration). Fuel is the second most representative cost item for hand-liners (26.04%) and the most representative for gill-netters (38.39%);

Scenario 3. A reduction in the number of fishing days was simulated by imposing a closed season (biological closure of fishing) for a period of 1 month. This closure means a reduction of 15 fishing days for the hand-line fleet (7.9%), and 20 fishing days for the gillnet fleet (8.7%);

Scenario 4. A reduction in the number of hand-liners and gill-netters was simulated by deactivating the 4 largest hand-liners and the 3 largest gill-netters (by cancelling their licenses), which means reducing fishing effort by 22.2% and 30% respectively;

Scenario 5. A 10% reduction in the catch of juveniles was simulated, considering that between 30 and 40% of individuals caught by the two fleets are immature. This reduction in the catch of juveniles would be implemented through enhanced protection of nursery grounds; and

Scenario 6. The joint implementation of three management measures mentioned above was simulated: reducing the price of fuel (Scenario 2); the biological fishing closure (Scenario 4); and reducing the catch of juveniles by 10% (Scenario 5).

RESULTS

The results of the simulations defined will be presented separately, for the hand-line fleet (Fig. 2) and stocks (Fig. 3) and for the gillnet fleet and stocks (Fig. 4). A bio-economic equilibrium can be assumed in the short-run, because in the study period 1993-2002 we observed relatively constant catches and effort (Mattos, 2004). In the initial scenario (projecting current conditions towards the future with no management events) a sharp decrease in total annual catches and the catch per unit of effort for the hand-line (30%) and the gillnet (45%) fisheries would be observed until year 20, slowly increasing afterward, reaching values *ca*. 10% and *ca*. 26% less than the current condition respectively.

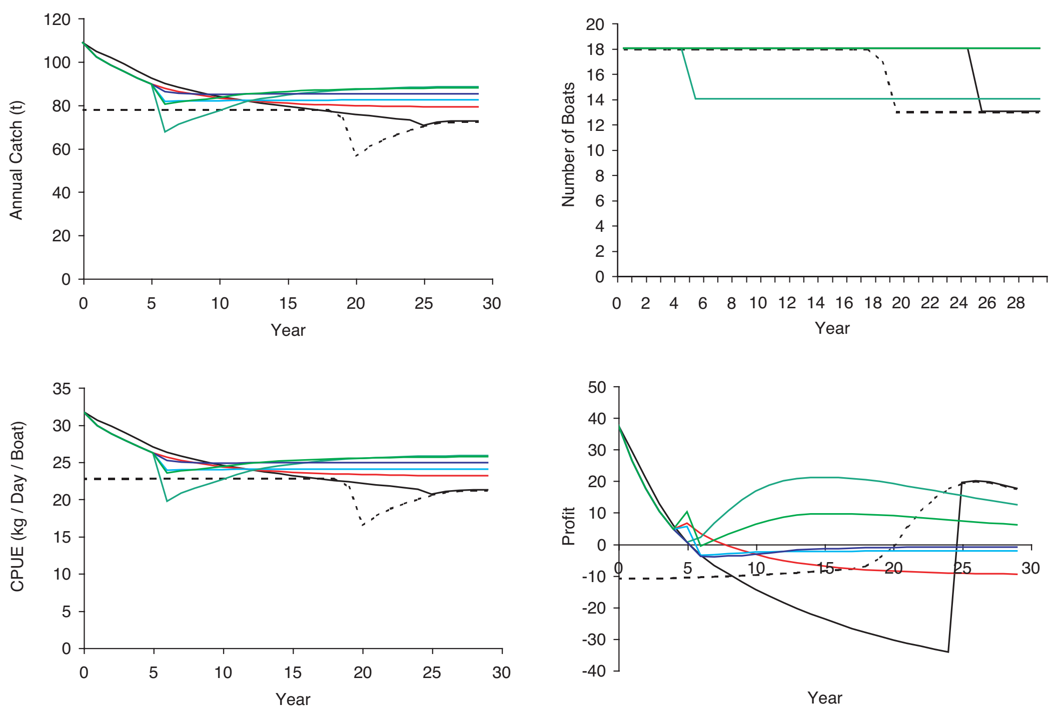

FIG. 2. – Bio-economic simulations for the hand-line fishery, in a 30-year projection. Colour legend: black, dotted line: Initial conditions; black line: Scenario 1; red line: Scenario 2; cyan line: Scenario 3; dark green: Scenario 4; dark blue: Scenario 5; light green: Scenario 6.

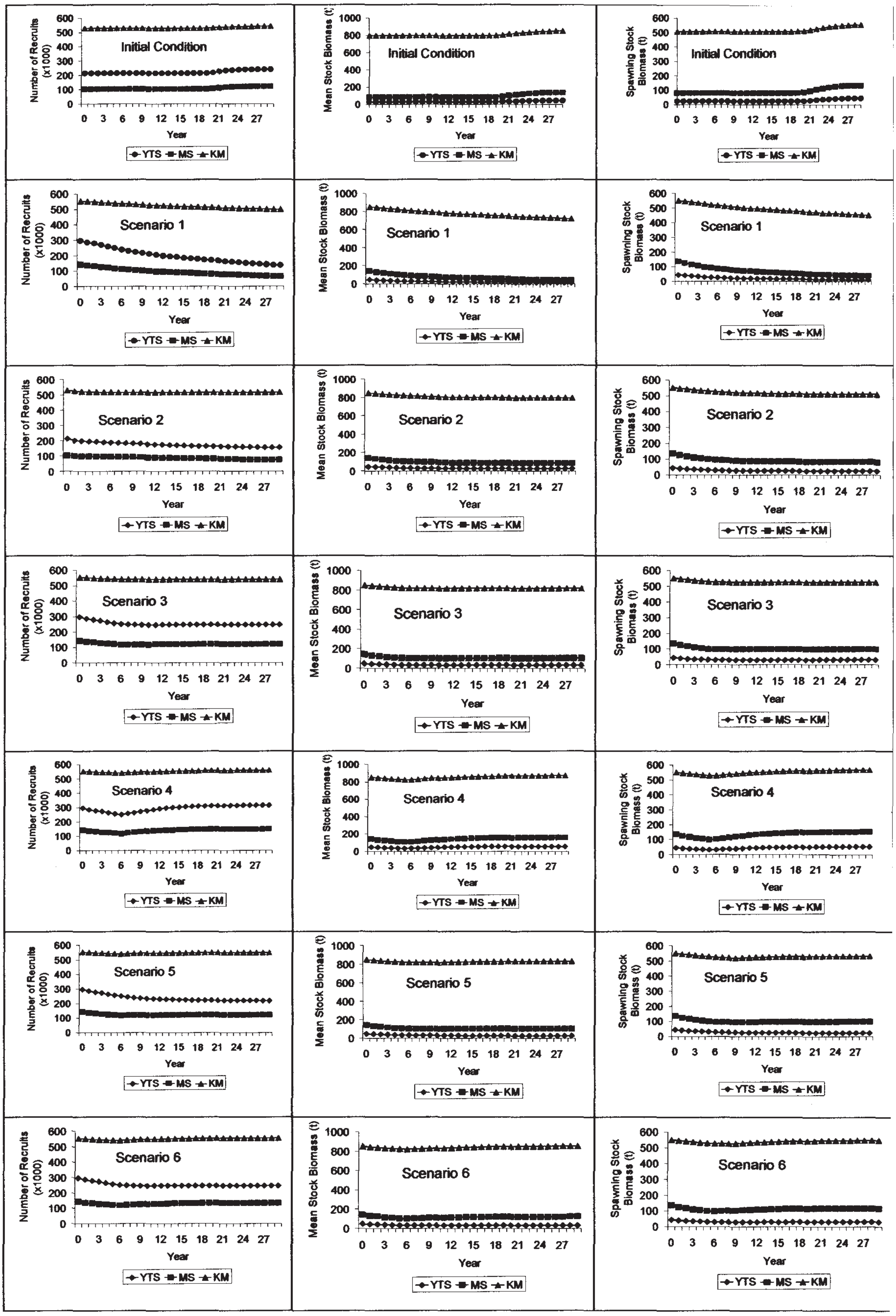

FIG. 3. – Bio-economic simulations for the yellowtail snapper (YTS), mutton snapper (MS) and king mackerel (KM) stocks, caught by the hand-line fishery, in a 30-year projection.

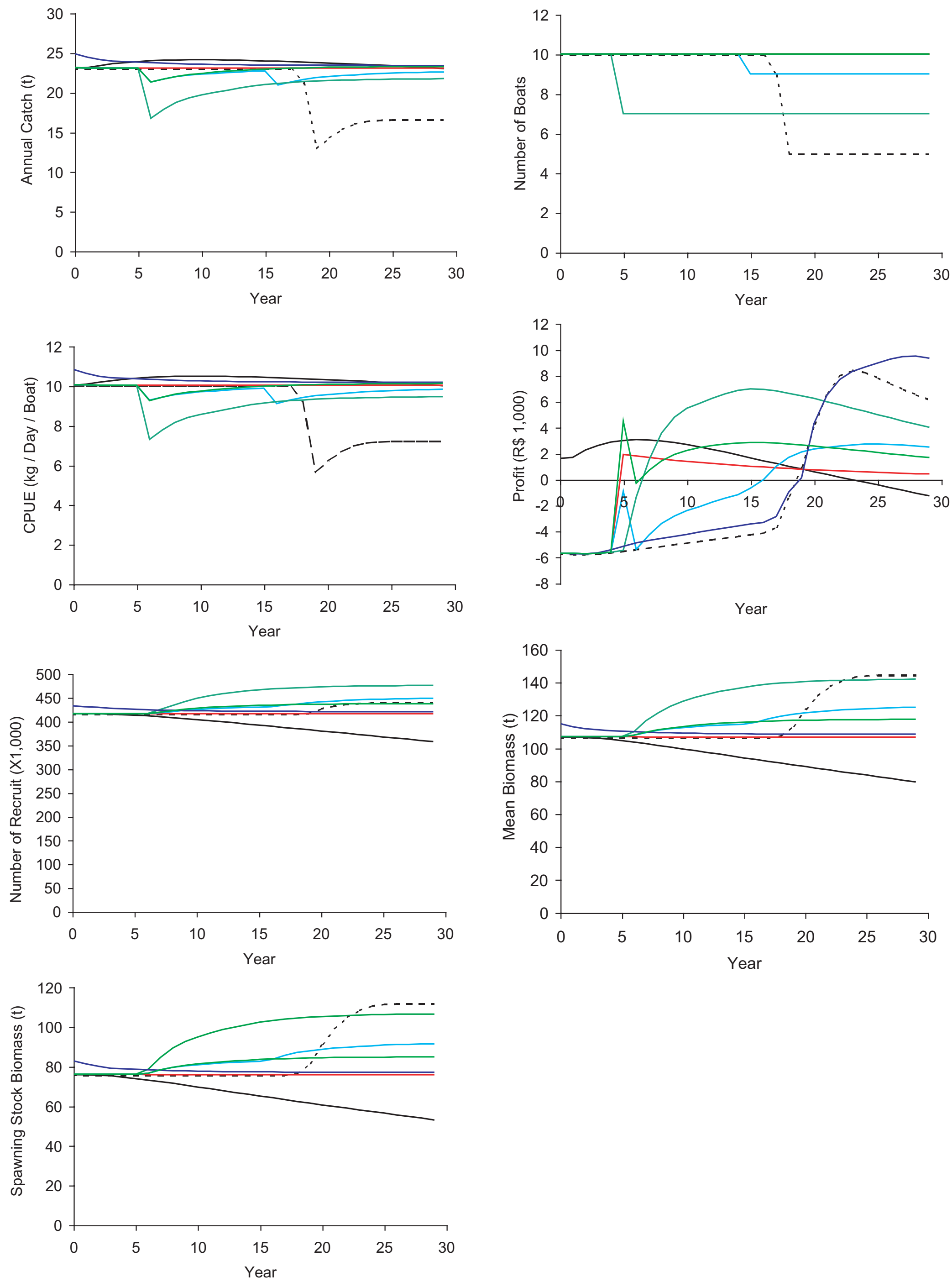

FIG. 4. – Bio-economic simulations for the gillnet fishery and for the Spanish mackerel stock, in a 30-year projection. Colour legend: black, dotted line: Initial conditions; black line: Scenario 1; red line: Scenario 2; cyan line: Scenario 3; dark green: Scenario 4; dark blue: Scenario 5; light green: Scenario 6.

Both fleets are operating with losses, but after deactivating boats, a sharp increase can be observed with a maximum in year 25 and 22 respectively.

After year 20 stocks slightly recover. The spawning stock biomass (SSB) of yellowtail snapper (YTS) (86.1%) and the number of recruits (17%) of the mutton snapper (MS) stock recover more, and both mackerel species recover less. The recuperation of the spawning stock biomass of the snappers seems to indicate that the stock-recruitment relationship is density-independent. However, although it has been observed that recruitment for coastal pelagic species is stock density-dependent, the results showed that such a pattern is likely to occur for king mackerel, while it is not so evident for Spanish mackerel.

This trend is followed by the deactivation of 5 hand-line and 5 gillnet boats. As 4 out of 5 hand-liners, whereas 3 out of 5 gill-netters, which disappear from each of the fisheries, are the largest ones, it seems that these boats have high catching power and operate with excessively high costs. The remaining smaller boats obtain higher profits, through a sharp increase in their catches, raising individual total income by an average of 40%. The greater fishing power of the larger boats seems also to exert their fishing pressure more strongly on the adult portion of the target species stocks, because stock recovery probably would benefit the remaining boats with higher catches and income.

Considering Scenario 1, the hand-line fishery showed a decreasing trend in catches and CPUE (Fig. 2). This decrease in the fish production led to a sharp, large decrease in profits, which became zero in year 5 and negative afterwards (Fig. 2). The economic losses would force the five aforementioned larger hand-line boats to disappear from the fishery, making it possible for the remaining boats to obtain profits after year 25. It can also be observed that after this year catches and CPUE seems to stabilise. All three analysed stocks showed decreasing trends in recruitment, mean biomass and spawning stock biomass, denoting that any increase in catchability would affect stock sustainability, and may indicate that currently these stocks are fully exploited (Fig. 3).

As for the gillnet fishery, the picture for the present simulation seems more stable than the one presented previously (Fig. 4). Although a decreasing trend may be visualised for the fishery and the Spanish mackerel stock, it is not as accentuated as for the hand-line fishery. Profit has a decreasing trend, but seems not to affect the profitability of boats in the long run, and recruitment, mean biomass and parental stock of the Spanish mackerel would decrease (Figs. 3 and 4).

The reduction in the price of fuel, simulated in Scenario 2, seems to drive the hand-line and gillnet fisheries to economic stability, clearly visualised for the latter (Figs. 2 and 4). The smooth downward production and CPUE curves for the hand-line fleet showed a decreasing trend (Fig. 2). Profits, before year 5, decreased sharply, smoothing afterward with losses that seemed to be affordable for hand-line boat owners, as none disappeared from the fishery (Fig. 2). This equilibrium leads to an increase in the level of exploitation of the three studied stocks, which stabilised in the long-run (Fig. 3). For the gillnet fleet, with the exception of the profit curve that sharply increased to a maximum in the same year the scenario was implemented and then slightly decreased towards stabilisation, the other curves (production, CPUE and stock-recruitment relationships) did not show any difference from the initial conditions. This denotes that this measure should have a significant impact on this fishery, probably because fuel is the most expensive item in the costs of the gillnet fleet (Fig. 4).

The results for Scenario 3 showed that the gillnet fishery seems to take better advantage of this management measure, with stabilised production and productivity, even though the largest boat disappears from the fishery. It shows, in the long run, profit and increasing trends for the Spanish mackerel recruitment, biomass and spawning stock biomass (Figs. 3 and 4). All curves show two inflection points, one which represents year 5, when the event takes place and the other in year 15, when a gill-netter boat disappears from the fishery. In the hand-line fishery, none of the 18 boats disappear from the fishery and after year 5 the results show a clear stabilisation of the fishery and in the stocks levels (Fig. 2). It can be seen that stabilisation in the stock level takes place after year 6, the year just after the management measure is implemented (Fig. 2).

Although a simulation aiming at reducing fishing effort by withdrawing the less productive boats (Scenario 4) means the possibility of direct unemployment which is always socially undesirable, this simulation, after implementation, showed a clear increase in fish production, productivity and profit, as well as in the stocks levels for both fleets, as production stabilised in the long term due to biological and economic stabilisation (Figs. 2 and 4). For the hand-line fleet, the three analysed stocks stabilised at levels registered for the initial condition, while in the gillnet fishery the Spanish mackerel stock stabilised at a higher level (Figs. 2, 3, 4). Once more it seems that the gillnet fishery takes more advantage of the management measures implemented (Fig. 4).

A management measure that reduces the catch of juveniles (Scenario 5) seems to go effectively towards stabilisation of the fisheries and the studied stocks after its implementation in year 5 of the simulation. It achieves stable catches and profits, and all the boats remain active, which seems socially desirable. Nevertheless, the stocks caught by the hand-line fleet showed different trends, with decreasing recruitment, biomass and spawning stock biomass presented by the yellowtail snapper stock, while increasing trends for the mutton snapper and king mackerel stocks, although at low levels (Fig. 3). The Spanish mackerel stock, caught by the gillnet fleet, presented a slightly decreasing trend after the implementation of the management measure. These results demonstrate the efficacy of the present scenario, and seem to indicate that the mutton snapper and king mackerel stocks would be advantaged if this management measure was implemented, and that the hand-line fleet probably exploits juveniles of these species more heavily.

From the aforementioned results, a sixth simulation was performed, joining three scenarios, which is justified for two reasons: (1) the reduction in the price of fuel, through subsidies, is an old claim of the fishermen; and (2) Scenarios 3 and 5 demonstrated to have positive effects on the resources as well as the activity.

It can be seen that the decision to join the effects of a reduction of fuel price, which would satisfy fishermen's wishes, with the establishment of a closed season and the protection of young fishes, which should allow the reconstruction of the populations of the analysed stocks in the long run, would have positive effects. It can be seen that, from the sixth year onward, all boats remain actively fishing, with increasing total catches and CPUEs for hand-liners and gill-netters; profits increase greatly (124.9% for hand-liners and 144.4% for gill-netters); and the stocks caught by hand-liners show two different curves, from year 6 to 10, and from year 11 to 30, while Spanish mackerel showed increasing trends with a more stabilised scenario. This management strategy seems to have a positive impact for mutton snapper, king mackerel and Spanish mackerel stocks, while it did not benefit the yellowtail snapper stock, which shows that this stock is susceptible to any increase in fishing effort.

DISCUSSION

The MEFISTO bio-economic model was successfully applied to the Pernambuco fisheries, with some adjustments to the realities and specificities of the Pernambuco State local fisheries, particularly regarding the commercial and the socio-economic structures and focusing on the individual boat and its fishing capacity as the main economic agent. The model allowed us to assess the problem of Pernambuco coastal fisheries, to understand the local institutional and productive structures and to propose assessment and management measures that can lead to a sustainable development of the fisheries. Moreover, we could study the shortcomings of present assessments and the non-existence of management policies. Multispecies biological models with technical interactions developed for Mediterranean-type fisheries are clearly of general applicability to the Pernambuco fisheries and other small-scale fisheries in the developing world. Mackinson *et al.* (1997) emphasised in their study the key point that economic factors are important driving forces in fisheries, but they must be incorporated into suitable biological models when modelling the dynamics of fisheries.

The statement made by Ulrich *et al.* (2002), considering the improvement of the BECHAMEL Model (BioEconomic CHAnnel ModEL), holds true for the present bio-economic fishery case study, whose benefits are twofold: first, it represents the first attempt to model a fishery including different fleets, gears and a diversity of species and life history characteristics, and with such a low level of previously available and reliable data; second it highlights the potential benefits of multidisciplinary and collaborative work. It represents an improvement in the emerging, and yet scarce, knowledge on this fishing area.

In a broad sense, a biological equilibrium of the analysed stocks can be assumed, considering data series (1993-2002; Mattos, 2004) and the levels of recruitment and biomass, because the low number of initial recruitment estimated through VPA for the snappers may be related to the small sample taken for the estimation of the von Bertalanffy growth parameters through length frequency distribution (529 for yellowtail snapper, and 252 for mutton snapper). The total stock biomass and the spawning stock biomass appear to reach a sustainable biological level, although fully exploited, because any increase in fishing effort would drive stocks to an unsustainable situation. Some, such as the snappers, could be driven to local commercial extinction, because total effort would decrease only when the increased cost makes it unprofitable. Effort must change with changes in the population size in order to keep an equilibrium. However, as pointed out by Pereiro (1995), a reduction in fishing mortality would increase the spawning biomass and thus future recruitment, because a density-dependent effect on the increase in eggs on larval mortality is not probable, at least at low levels of abundance.

For the relationship of cost and revenue, however, it seems that fishermen have developed a self-protection to obtain profit, because as production falls after years of increasing effort they may understand that if effort rises even more, production would continue to fall and the resource be wasted. Otherwise, as Bonzon (2000) pointed out, low or negative profitability would usually indicate that fisheries resources are exploited in an economically wasteful way, often through excessive fishing capacity and effort.

The results presented show that currently coastal hand-line and gillnet fishery boat owners are accumulating losses, although at a very low level. The explanation for this situation is two-fold: (1) from an economic point of view it seems that the boat owners borrow money continuously to pay for the expenses to go fishing, and this only stops when fishing production value does not cover expenses and investors cannot support continued losses; (2) most of the local boat owners are middlemen and retailers, also owners of small fish shops, where they can make extra money.

This demonstrates one of the main characteristics of the artisanal fisheries, where the market forces prices to be regulated, which affects the potential value of the catch. Quoting Smit (1996), Lleonart *et al*. (2003) recognised that the potential fishing capacity of a boat can be measured as the gross proceeds of the boat. If the investment is related to the proceeds, the proposition is that the total investment in the boat (capital) is related to the fishing capacity (catchability). These trends can be clearly identified in Scenario 1, where production not only falls, but boats also disappear, losses appear and the stocks become more heavily exploited, especially yellowtail and mutton snappers, which could collapse. In all cases these undesirable results stem from the open access nature of the fishery, because the increase in profits that these changes provide encourages changes in the level of effort. It is worth stressing that the fishery is operating at a sub-optimal position both before and after the change. Pauly *et al*. (2002) stressed that the technological advances, and the resulting increase in catchability, is also the reason why fishers often remain unaware of their own impact on the resource they exploit and object so strongly to scientists' claims of a reduction in biomass.

In Pernambuco State coastal fishery it seems that catchability can be regarded as a traditional-dependent knowledge factor, because, for example, the size and type of hook are determined by the target species and on the fisherman's empirical knowledge. As local administration has no infrastructure to control the activity, this empirical relationship prevails in determining the technological process as well as effort control. Otherwise, in the short term a bio-economic equilibrium exists, but it is not sustainable in the long run. The results also show that larger boats represent over-capacity and over-capitalisation of the fleet that, if maintained, will put the fishery in a dangerous unsustainable condition.

Government subsidies, as simulated in Scenario 2, showed that although there is no withdrawal of boats from the analysed fisheries, profit would only be attractive on a short term basis and the resources are negatively affected, also threatening the snapper stocks. As stressed by Lleonart *et al.* (2003), building the stock to sustainable levels, probably giving higher yields, implies overcoming a short term crisis. That is why there is a growing awareness from the scientific community against subsidies. Pereiro (1995) pointed out that in a situation of overfishing, moderate increases in fishing mortality would lead to a small reduction in biomass and CPUE, which would be undetectable with the tools available to measure them, especially if they could be masked by natural fluctuations of recruitment and natural mortality. The opposite would occur with moderate reductions in fishing mortality, and, in both cases, it would not be possible to see in the short term the beneficial consequences of moderate reductions in effort. According to Mackinson *et al*., (1997), conducting a bio-economic analysis that considers a constant CPUE model, when fishers fail to co-operate or are subsidised, profits accrue so quickly for fishers that they continue to invest in fishing even when a stock collapse is imminent.

It is not always the case that powerful and biologically correct management measures increase production and profitability on a short term basis. Biological fishing closure (Scenario 3) seems quite effective, according to the obtained results, because it allows a sustainable fishery to be maintained from the biological and economic point of view.

Scenario 4, although implementing the measure that clearly presents the most favourable impact on the resource, by increasing recruitment, biomass and parental stock, would in the short-run produce unemployment and would be difficult to accept by those affected, although a value in concept of retirement is always foreseen. Nevertheless, it is a measure that should be put into force if resource exploitation levels are above maximum sustainable yields. If fleet reduction is done properly, it should result in an increase in net profit (rent) from the resources, as predicted by the basic theory of bio-economics.

Scenario 5, whose objective was to protect young fishes, means, in general terms, increasing selectivity aiming at catching, as much as possible, mature individuals of the exploited stock or population. In a context of multi-species fisheries, however, with several species being caught simultaneously, as is the case of the Mediterranean and Pernambuco State fisheries, it is hard to rely solely on fishing gear selectivity, since some equipment, like nets, take in large and small species without distinction. The proposal therefore may encompass a set of measures that focus on the same goal, such as letting the largest possible number of young fish reach maturity to replenish stocks.

The simulation of a sixth scenario permitted us to diagnose that joining management measures should be an interesting issue and strategy to be taken into consideration by the administration, whose results may clearly favour the implementation of socially desirable governmental fishing rules. Simulations are generally conducted under a constant activity pattern hypothesis, but changes in this pattern might also be introduced. The attempt was to create a favourable economic, biological and technical condition. The results showed that the fishery and the stocks performance simulating three management measures—Scenario 2, reducing the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, reducing the catch of juveniles by 10%—allowed positive benefits when compared with applying each measure on its own. The measures improved stock rebuilding if compared with Scenarios 3 and 5 alone, the exception being the yellowtail snapper stock. The results showed that yellowtail snapper stock is more susceptible to fishing pressure, which could be related to the current level of exploitation and spatial and temporal variability of stock size and abundance. Increasing effort due to increasing revenues could put this stock in risk of collapse.

From the results analysed and from the biological and economic points of view, the local conditions show that the fisherman's strategy to increase profit is always dangerous for the maintenance of the bio-economic equilibrium that seems to effectively occur in the Pernambuco fisheries analysed. Thus, administrators and decision makers must face the problem that any intervention must be carefully put into practice, because if erroneously implemented, negative socio-economic impacts could occur in the short run, and it is not clear what would be the resource response to other management measures afterwards. Future work is needed to assess the risk and uncertainties involved before decision-makers can implement the results of the bio-economic analysis conducted for Pernambuco fisheries

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