Application of a bioeconomic model for supporting management processes of the small pelagic fishery in the North Adriatic sea, north-east Italy

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SUMMARY: In this paper we attempt to verify the sustainability of small pelagic fishery in the Northern Adriatic sea, north-eastern Italy, by utilizing a bioeconomic simulation model. This model reproduces biological and economic conditions in which the fisheries occur. Starting from an initial condition, the simulation model incorporates the biological and economic processes of the resources and the fishing fleet and allows to compute the most probable future trajectory when some parameters in the model are changed, i.e. by implementing management actions. We analyzed the projection of selected indicators (biomass, recruitment, catches, profit and capital) under four different management scenarios, based on effort control, and we assessed the performance of these management measures against the current situation. The four scenarios are: *i*) increases in fuel price, *ii*) reductions in fuel price, *iii*) constraining the days at sea, *iv*) extension of the fishing period. Each management event was introduced in the third year of the simulation. For each scenario a stochastic simulation was carried out and the stock recruitment relations of Beverton-Holt are applied. Our results show that the impact of each management measure tested was not homogeneous across the fleet. In particular, comparatively smaller vessels display generally narrower profit margins and tend to be more sensitive to negative shocks, reinforcing the idea that management measures should be calibrated by stratifying the fleet before implementation.

Key words: Northern Adriatic, bioeconomic model, small pelagic, sardines, anchovies, mid-water pair trawl.

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INTRODUCTION

Measuring the biological and economic impacts of sustainability measures adopted in fisheries represents an important objective for policy makers. Maximizing the amount of stock harvested and the amount of stock left for future harvests is not an easy task. At the same time it is difficult to regulate the fishing effort for a series of reasons among which, as indicated in Sumaila (1999), are: i) renewable resources are often “common property”; ii) different fishing vessels affect stocks differently; iii) the catch of juveniles or mature fish can have important consequences for those species which are long lived; iv) capital embodied in the exploitation is often non-malleable.

Policy makers are constrained with decisions which maximize production and maintain employment today, but risk industry collapse in the near future due to fishery depletion. Measures of control are divided in two categories: the input control (including exclusive areas, seasonal closing, effort allocation, etc.) and output control (concerning the catches and their size and includes for instance TACs and individual quota). The fisheries management measures employed in the Adriatic sea are represented by effort control, through closed areas, periods of biological rest, restriction on nets dimension and fishing tools. From an economic point of view fisheries are managed through subsidies, taxes and penalties (AdriaMed, 2005). TACs (with the notable exception of large pelagics) are not implemented in the Nothern Adriatic Sea, due to the absence of a definite objective species.

Sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus)* are the most important species of small pelagic stocks within the Adriatic Sea. Small pelagic fisheries play significant economic and social roles in the total value of catches and the number of fishermen employed within the industry.

In previous years there have been decreases in pelagic catches, demersal resources, and the number of vessels, operators and operation hours (Ungaro, 2001; Cingolani *et al*., 2004a, b). The number of vessels was reduced for about 22 % between 2002 and 2005. Decreases of participation within this sector is principally due to high operation costs and deflated market prices; furthermore from the demand side it is linked to the reduction of wholesale and retail consumption, attributable to excessive prices. This produces a cutback in the net contribution margin for every kilogram of captured and/or commercialized product. Another factor is the reduction of the competitiveness linked to the opening of larger markets. In order to maintain the sustainability of these important fisheries, it is imperative to minimize these constraints.

Successful fishery management must take into account simultaneously biological and economic aspects. For this reason, bioeconomic models are employed to provide directions for fishery management (Defeo and Seijo, 1999; Ulrich *et al*., 2002; Lleonart *et al*., 2003; Maynou *et al*., 2006; Mattos *et al*., 2006). These tools quantify the effects derived from the application of specific management measures to particular stocks, to simulate different scenarios and to obtain an evaluation of risks associated with different levels of resource exploitation.

The model applied in this work, MEFISTO (Mediterranean Fisheries Management Tools, Lleonart *et al*., 2003), was developed specifically for Mediterranean Sea fisheries. Before employing this model, it is important to understand fishing fleet labor forces and the principal characteristics of the model that allow its application to fishery of small pelagics in the Northern Adriatic sea. According to Martin (1991), the fishing activity in Mediterranean is characterised by a wide diversity of exploited species and fishing technology, as well as by the seasonal variations of the catches, which are relatively small compared to large scale Atlantic fisheries. With non-industrial fisheries, where catches are marketed fresh locally, fleets work five days a week and return to port every day. Seasonal activity of the fleet is related to the ecology of the different species, meteorological conditions, and tourist seasons. Labour relationships are based on share system, not on fixed salaries. All these ecological, economic and structural similarities justify the application of the MEFISTO model to the Adriatic fisheries.

The objectives of this work are to analyze the effects of different management regimes on small pelagic fisheries based on a bioeconomic simulation model disaggregated at the vessel level, and to examine the trends in biological and economic indicators, for the markets of the Veneto region, located in the Northern Adriatic Sea (Fig. 1).

MATERIAL AND METHODS

Bioeconomic analysis of small pelagic fisheries which occur in the Veneto Region (North Adriatic sea) is utilized to simulate the consequences that various management measures can have on this sector. Pelagic fishing is performed with a *volante* vessel.

The mid-water pair trawl *volante* is towed by two fishing boats working in pair and holding a tow-line, each one tethered to the head rope, and the other one to the foot rope. *Volante* vessels generally fish by daylight, and land their catches every evening. Each fishing trip lasts around 11-15 hours. Boats leave the harbour from 2.30-3.30 a.m. and return between 11.00 a.m. to 7.00 p.m. depending on the success of the fishing day. The work week is from Monday through Friday (Commission of the European Communities, 2004). Sardines and anchovies captured from Veneto fishermen are commercialized at six local markets. A part of these products does not pass through markets because it is withdrawn from the part of the local producers organization in order to allow maintaining the price at a certain level.

21 pairs of *volante* fishing vessels operate usually within this area, their average engine power is 470 HP and the average size is 88 GRT, however there are wide variations in both size and engine power. In this study we divided the fleet into 4 classes according to vessel size, including vessels of 12 GRT as well as vessels of 200 GRT. The classes are labelled as: volante 1, volante 2, volante 3 and volante 4. The fleet stratification in four classes allows us to assign each group a different effort level. Each vessel class was allocated a specific value of catchability.

In 2004 the total catch of small pelagic fish in the Veneto region amounted to 12400 tons, corresponding to 41 % of the total regional production, of which, 1300 tonnes were sardines and 11130 tonnes were anchovies.

The target species of the mid-water trawl are mainly sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus*), other mid-water species targeted are mackerel (*Scomber* spp.), sprat (*Sprattus sprattus*) and horse mackerel (*Trachurus* spp.). Fishing for other pelagics and also "white fish" (Sparidae, Mugilidae, *Merlangus merlangus*, etc.) can be possible occasionally and opportunistically, but it is considered rather rare (Santojanni *et al*., 2005).

The bioeconomic model called MEFISTO, is a multispecies, multifleet and multigear simulation model described in detail in Lleonart *et al*. (1999; 2003). Starting from an initial condition, the simulation model incorporates the known trajectory of resources and fishing fleets, disaggregated by vessels or homogeneous vessel class, and allows to compute the most probable future trajectory when some parameters in the model are changed, simulating management actions. This model is a dynamic model built on three modules or boxes: a *stock box*, a *market box* and a *fisherman box*.

The *stock* module simulates resource dynamics in the sea, from reproduction to growth and death and considers two kind of species: the main species, whose dynamics are completely known, and the secondary species, whose dynamics are not known but their catch is empirically related to the catch of the main species. In this study we consider only two main species, other secondary species are not considered due to low relevance in terms of catches and value. Model inputs are fishing effort and catchability (these derive from the fisherman box) whose product represent the fishing mortality applied to the stock. Output are fish catches that are converted to revenues by means of species-specific price equations.

The von Bertalanffy growth parameters were taken from the *FishBase website* (http://www.fishbase.org/home.htm). 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). Table 1 shows the growth parameters of the von Bertalanffy growth function ($L\infty$, *k* and *t*) established for the sardines and anchovies, as well as the parameters of 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 two species considered.

The *market box* converts the fish catches of each species generated by the stock model into money, through price functions. In terms of market price, sardines are considerably more valuable than anchovies, and they are required above all for the processing industry. In 2004 the average sale price of for the markets of the Veneto region amounted to 0.852 €/kg for anchovy and 1.727 €/kg for sardine (data token from the six local Veneto fish markets).

The reference price was estimated as average price of the six fish markets of the Veneto Region. The *fisherman box* simulates the fishermen's economic behaviour and decisions. Based on money generated in the market module, fishermen can increase the capital invested in fishing. The outputs are effort (within a system where maximum effort is fixed by law) and catchability, which the fishermen can affect by investing capital in the vessels.

Discarding does not occur in relevant quantities, as declared from the operators and confirmed in Santojanni *et al*. (2005), and hence fishing mortality due to discards was not included in the model.

Almost no previous data on costs and revenues were available for these fleets, and the data presented here was obtained by interviews or hypothesis (Table 2).

We interviewed the crew belonging to the representative vessels of each of the four classes. In total we interviewed nine vessels divided in this way: one belonging to vessel 1, four to vessel 2, three to vessel 3, one to vessel 4. Simulations were run at the basic time unit of 1 year for a projection horizon of 10 years, using 2004 as the reference year and the number of stochastic iterations for each simulation run was 1000. The results are presented as mean value of the simulation runs with 5 and 95 percentiles. Five scenarios are presented, simulating a set of four alternative management measures against the status quo (scenario 0). The events are introduced in the third year of the simulation. For each scenario a stochastic simulation was carried out and the stock recruitment relations of Beverton-Holt are applied.

Scenario 0 was the base scenario, simulating the probable development of the fishery if no management action was taken.

Scenario 1 simulated the increase in the fuel price by a factor of: 10 %, 20 %, 30 % and 40 %, resulting in an increase of the costs of the fishing effort. The tax exemption of the fuel price currently amounted to 84 % of the price of fuel, but, we cannot considerer this price hypothesis because it turns out to be unsustainable for about 86 % of the *volante* vessels.

Scenario 2 simulated the reduction in the fuel price by a factor of 20 %, resulting in a decrease of the costs of the fishing (the fuel cost represents the first cost item amounting about 80 % of the total fixed common costs).

Scenario 3 simulated restriction on number of the days at sea, assessing the impact of management measures aimed at limiting the effort with respect to current levels. The effort hypothesis in terms of number of days at sea were respectively: 185, 205, 215 days.

Scenario 4 simulated the extension of the fishing period up to a maximum of: 235 and 245 days.

RESULTS

In addition to current management corresponding to scenario 0 and at a no change in status quo of 2004 (Fig. 2), we evaluated 4 management strategies for the four classes of vessels and for the two species considered. We compare the performance of the four strategies using 4 indicators: catch, profits, recruitment, biomass. The results of the simulations defined are presented separately for the two stock considered and for the four classes in which the fleet was divided (Fig. 3 and 4).

The base scenario (Scenario 0) showed a different behaviour for the two species considered. The virtual population analysis highlighted the overexploitation signal for the stock of sardines, for which, if the conditions of exploitation remain at the current level, the biomass and the spawning stock biomass would decrease over time. Also the anchovies stock would not maintain stable these parameters, but, unlike sardines, there will be a recovery of both indicators starting from 2010. The sardines' recruitment remain stable in the period of simulation but anchovies recruitment would increase.

Catches would increase slightly from a production of 11300 t in 2004 to around 11800 t at the end of the simulation run, probably as a consequence of effort intensification (Fig. 3).

The profit for the fleet would be negative after year 2009 with a probability of 14 % that could reach 21 % in year 2013. The profit presents a negative trend for the vessels of small dimension, indicating that they are not able to cover the costs. This can produce an exit from the fleet on the part of some vessels for which the activity would not be economically sustainable anymore (Fig. 4).

The catch and biomass values are not significantly affected as a consequence of the change in the price fuel (Scenario 1), even if the biomass would tend to be preserved in correspondence to the high prices (Fig. 3). In general there is an inverse relationship between the fuel price and the profit: when the first increases, the second decreases. Within fleets there are not homogeneous behaviour, this means that there exist different levels of fuel price tolerance. In particular smaller vessels are more sensitive to changes and for this fleet a price increase of 10 % would determine in the long run situations of negative profits. Removal of the fuel subsidy to the fleet after year 3, increasing the price of 40 %, has a negative impact on the economy of the full fleet, and would determine negative profits. The profit sensitivity is weaker with the increase in the fuel price (Fig. 4).

The current fuel price is exempted from excise tax, and the fishermen buy it at a subsidized price. In spite of this, fishermen indicate fuel price among the costs that affect the activity. For this reason we evaluate the possible change on the profits linked to the reduction in the fuel price. From a biological point of view (Scenario 2), the biomass would decrease and the catches would increase, but not in significant way (Fig. 3). Profits would show a significant increase for the entire fleet (Fig. 4).

In the short run the anchovies biomass would derive a benefit from the reduction of the number of days at sea (Scenario 3). In the long run this value would recover at levels similar to those without this measure. The action would allow the biomass to recover only in the case in which the number of days is equal to 185. For the sardine stock only a sharp reduction in the number of days can bring a benefit. This means that sardines are overexploited. As the number of days is reduced the volume of catches would decrease (Fig. 3). Smaller profits would be generated, in correspondence to the smaller number of days at sea, and consequently, this management measures is not recommended, especially for smaller vessels. For *vessels* groups 2 and 3 profit remains positive also in under the effort regime of 185 days/year. For *vessels* of group 4 profit increases in all events, but 185 days/year in the short run can produce negative profits (Fig. 4).

Due to the strong relation between fishing effort and fishing mortality the evolution of catches follows biomass in function of the fishing effort. In this way when the fishing effort increases (Scenario 4), the fishing mortality also increases determining a considerable pressure on the total biomass. After some time the total biomass decreases progressively producing reduced catches. The weak increase of the catches observed can be explained by the rise in efficiency derived from investments. For the two stocks considered, extending the fishing period would have a negative impact on the biomass (Fig. 3). At the same time this action is not a guarantee of larger profits: more days at sea contribute to increase variable costs. Profits for smaller vessel with this measure would increase but would maintain a negative trend. For vessel groups 2, 3 and 4 profits show a not relevant increase, and, in all cases, inferior to that corresponding to the actual effort level (Fig. 4).

CONCLUSION AND DISCUSSION

The MEFISTO bioeconomic model was successfully applied to the small pelagic fishery in the Northern Adriatic Sea. The model employed does not provide an equilibrium point, because it is not an optimization model but a simulation model. Therefore it allows to quantify the effects deriving from the application of management measures and simulate different scenarios providing a risk assessment associated to different levels of exploitation of the resources. In these terms this is a cause-effect model that can support the policy maker on the decision process. With this aim, for example, it shows that the adjustment should be done by segmenting the fleet. The impact of each measure produces different results depending on the size of the vessels to which it is applied.

The MEFISTO model has been previously applied to a case study of hake in Catalonia (western Mediterranean) as shown in Lleonart *et al*. (2003), but it was later applied to red shrimp (*Aristeus antennatus*) fisheries in the Catalan sea (Maynou *et al*., 2006) and to carry out an analysis of hand-line and gillnet coastal fisheries of Pernambuco State (Mattos *et al*., 2006).

This work represents one of the first applications of bioeconomic simulation tools to small pelagic fisheries in the Northern Adriatic Sea. Other bioeconomic models developed at national level, such as the model BIRDMOD (IREPA, 2005; Accadia and Spagnolo, 2006) which, however, was applied to study demersal resources, are optimization models. The choice of different scenarios is based on the observation of catch trends and research conducted on the sector, that highlight from one part an overexploitation of the fish resources, in particular of sardines, and from the other part a reduction in the number of vessels and operators. This means that the effort is excessive or the size of the individuals caught is too low, or both; from an economic point of view there is an increasing incapacity from the part of the operators to support the management costs of the activity. For this reason, our simulations mainly regard management aspects based on effort control whose regulation allows to reduce pressure on the overexploited stocks so as to guarantee their conservation and jobs, safeguarding the investment done in the sector. To answer these objectives we studied the effects of different fuel price and number of days alternatives.

As previously indicated fishermen buy fuel at a subsidized price and thus fiscal burden cannot be further reduced. In addition, total production costs also are high, while producer’s prices are maintained stable.

Increase in fuel price, Scenario 1, simulating the partial or total payment of removed taxes, shows that if fishers are constrained to buy fuel at a not subsidized price, this can have a negative impact on the fleet that can produce an abandonment of the sector above all from the part of the smaller vessels. Considering the current worldwide increase in fuel price, the economic losses sustained by smaller vessels will probably worsen in the near future.

Government subsidies, as simulated in Scenario 2, showed that profits increase in a significant way. As indicated in Mackinson *et al*. (1997), conducting a bioeconomic analysis that consider a constant CPUE model, when fishers fail to cooperate or there are subsidies, profits accrue so quickly for fishers that they continue to invest in fishing even when a stock collapse is imminent. As consequence of this, greater catches of fish despite the decline abundance and stock collapse are probable. The cause of this, as highlighted in Pereiro (1995), is that moderate increases in fishing mortality would lead to a small reduction in biomass and CPUE, but this fact is not detectable in the short term with the tools available to measure them, especially when these reductions can 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. Profit shows an inverse relation with the price of fuel (when it increases the profit decreases in a proportional way). On the other hand, generally, the more the price of fuel increases, the worse the catch decreases, according to the higher costs that the fishermen could support. From a biological point of view a minor cost of the fuel leads to an increase of the fishing effort and to reduction of the biomass. The price of fuel cannot be reduced excessively from the current price that is about 0.50 €/l.

Biological fishing closure (Scenario 3) seems quite effective only from a biological point of view, according to the obtained results, because it allows biomass to recover and range to high levels, but, simultaneously might produce some problems due to low profit levels generated. In particular, reducing the number of days to 185 cannot be suggested for the smaller vessels. The better purpose ranks at the actual levels of fishing effort in term of number of days at sea. Also the hypothesis assessing 205 days might be applied without damaging biomass, but, in the long term, can determine negative profits for the smaller vessels. If we decrease the number of days to 215 the profit decreases by about 20 %, but, on the other hand if the number of days increases to 245, Scenario 4, the profit would decrease anyway, although by about 6 % only. The profit is regarded to lower level in correspondence to 185 days/year, it do not reach his maximum value at 245, but rather at 225. An effort beyond actual levels, and equal to 235 and 245, represent an unfavourable situation for the stocks.

On the basis of the obtained results, the proposal for management is articulated around a combination of measures: i) apply targeted support policy in defence of smaller vessels, in particular introducing compensatory policy; ii) guarantee greater profits for the sector, by means of cost reduction or/and product valorisation policies (promotion, label, etc); iii) promote sector reconversion (commerce, aquaculture, tourism, etc); iv) place fishing effort in terms of number of day at sea to between 205 and 215 days / year.

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Parameters	Sardines	Anchovies
$L\infty$	21.19	15.30
k (year $^{-1}$)	0.35	2.440
t_0 (year)	- 2.42	0
A	0.069	0.0116
B	3.050	2.782
Natural mortality (M)	0.890	0.600
SSB (x 10^9 t)	3.75	30.95
Bmean (x 10^9 t)	7.07	60.54
Recruitment (x 10^6 ind.)	298.56	3281.52

TABLE 1. – Biological parameters of *Sardina pilchardus* and *Engraulis encrasicolus* exploited on Northern Adriatic sea. Parameters of the: von Bertalanffy growth function: $L\infty$, k and t_0; length-weight relationship: a, b; natural mortality (M), spawning stock biomass (SSB), mean stock biomass (Bmean) and initial recruitment.

Cost structure of the fleet	Volante1	Volante 2	Volante 3	Volante 4
Capital in €/vessel	156848	449085	761291	1211304
Annual costs in €/vessel	17376	25881	37090	45270
Commercial costs in %	9	9	9	9
Owner's share in %	50	50	50	50
Daily fuel consumption in liters/vessel	269	617	733	1.071
Daily ice expenses in €/day	17	34	41	48
Demolition, sale, transfer €/GRT	4228	3011	2732	2732
Technical structure of the fleets				
GRT/vessel	10	59	112	178
HP/vessel	178.3	419.0	533.8	681.0
Crew/vessel	3	5	6	7
Daily fishing hours	13	13	13	13
Annual fishing days	225	225	225	225
Number of vessels	6	18	12	6
Market				
Sardines price in €/kg	1.727	1.727	1.727	1.727
Anchovies price in €/kg	0.952	0.952	0.952	0.952
Other economic factors				
Opportunity cost in %	2	2	2	2
Financial cost in %	5	5	5	5
Fuel price in €/liter	0.510	0.510	0.510	0.510

TABLE 2. – Initial conditions for the economic, technical and market parameters of *volante* fishing vessels operating in the Veneto region, north-eastern Italy, (average values per class).

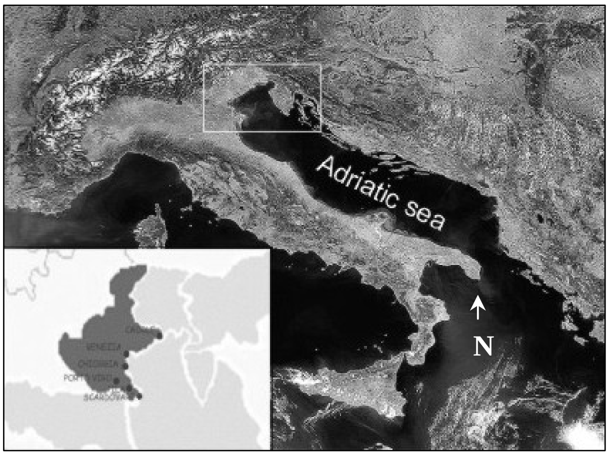

FIG. 1 - Map of the study area, showing the location of the markets analysed in the Veneto region, North-eastern Italy.

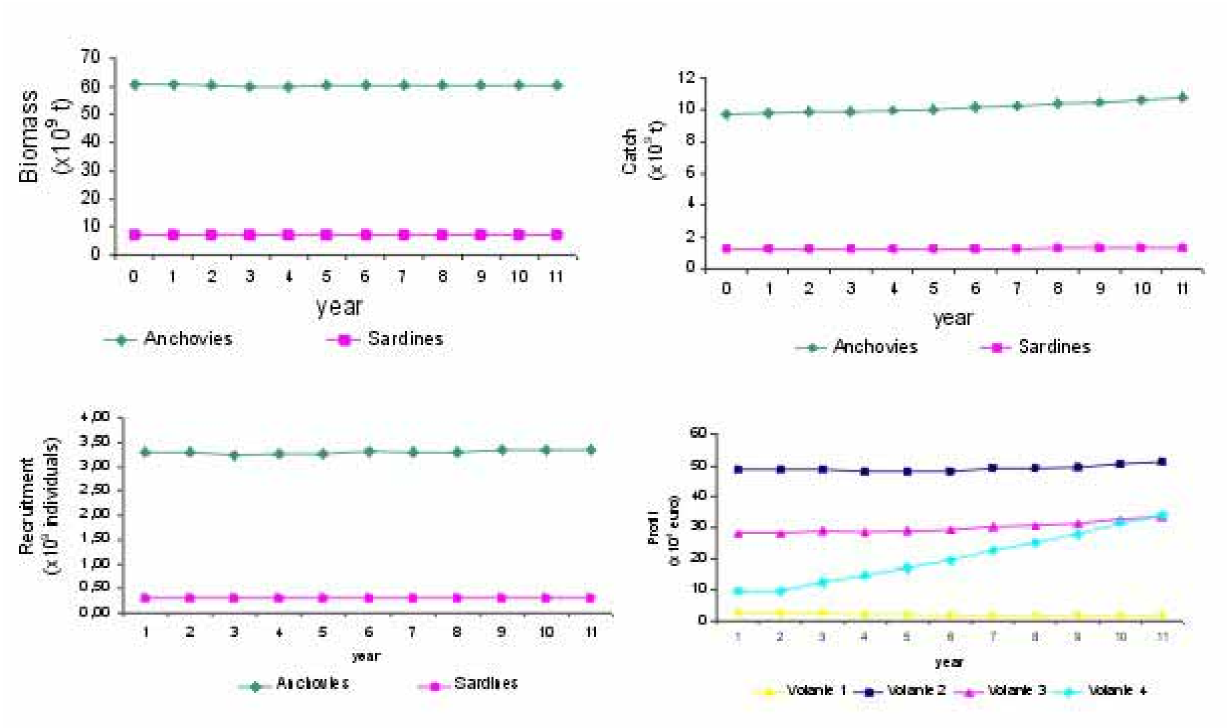

Fig. 2 – Bioeconomic simulations for *volante* vessels in a 10 - years projection.

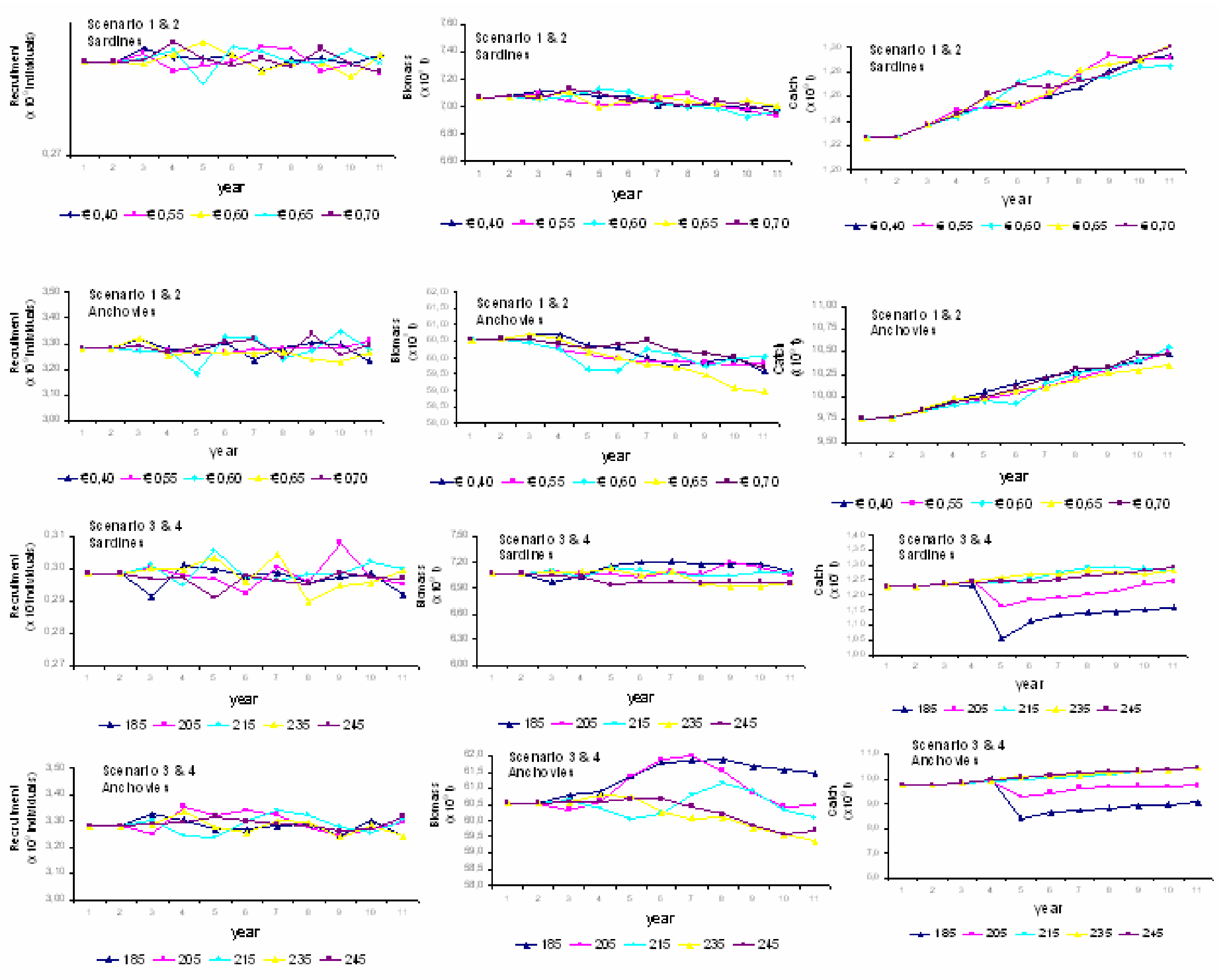

Fig. 3 – Bioeconomic simulations for sardines and anchovies stocks in a 10 - years projection.

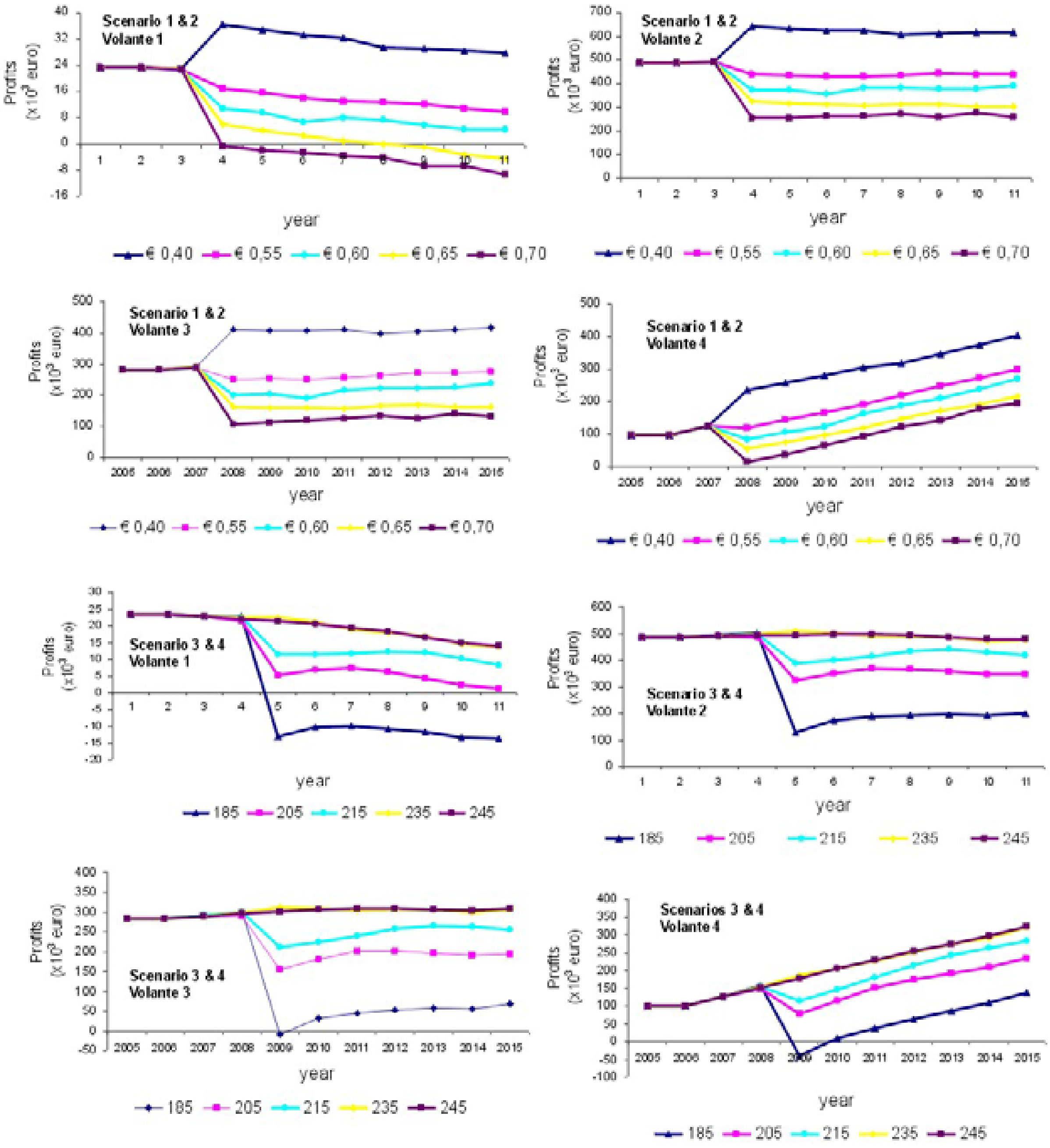

Fig. 4 – Bioeconomic simulations of profits for *volante* vessels in a 10 - years projection.