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A bio-economic evaluation of the potential for establishing a commercial fishery on two newly developed stocks: The Ionian red shrimp fishery

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Abstract:

It has recently been shown that two deep-water red shrimp species (*Aristeus antennatus* and *Aristaeomorpha foliacea*) have the potential to support a viable fishery in the Greek Ionian Sea (eastern Mediterranean). In this article, we investigate (i) the evolution that this newly developed trawl shrimp fishery may undergo when subjected to different management measures, and (ii) the most suitable extraction rates considering the uncertainties about the resource. We further analyse the effects that potential future fuel price increases and changes in the market may have on the fishery. Forecasting the biological and economic consequences of management actions, as well as the effects of market changes on inputs and outputs before they are applied, may help managers select the most suitable management options. We approach the problem by means of bio-economic simulation analysis. The results of this study show that fishing effort can increase by 50-100%, increasing the fleet's profitability without jeopardizing the sustainability of the fishery.

Keywords: bio-economic modelling ; market development ; fuel price ; newly developed stocks ; Ionian Sea ; red shrimps

Resumen :

Evaluación bio-económica del potencial para establecer una pesquería comercial sobredos nuevos stocks: la pesquería degambas rojas del Jónico – Recientemente se ha demostrado que dos especies de gambas rojas de profundidad (*Aristeus antennatus* and *Aristaeomorpha foliacea*) tienen el potencial de sostener una pesquería viable en el mar Jónico griego (Mediterráneo oriental). En este trabajo investigamos i) la evolución que esta nueva pesquería de gambas puede tener ante distintas medidas de gestión, y ii) cuáles serían las tasas de extracción del recurso más adecuadas teniendo en cuenta la incertidumbre sobre el recurso. Además analizamos los efectos que puedan tener sobre la pesquería el aumento del precio del combustible y cambios en el precio de mercado. La proyección de las consecuencias biológicas y económicas de las acciones de gestión, así como los efectos de cambios en el mercado sobre las entradas y salidas antes de ser aplicadas puede ayudar a los gestores a seleccionar las opciones de gestión más adecuadas. Proporcionamos una aproximación al modelo mediante análisis bio-económico de simulación. Los resultados de este estudio muestran que el esfuerzo de pesca puede aumentar en un 50 a 100%, aumentando la rentabilidad de la flota, sin comprometer negativamente la sostenibilidad de la pesquería.

Palabras clave: modelización bioeconómica ; desarrollo de mercados ; precio del combustible ; stocks nuevos ; mar Jónico ; gambas rojas

1. Introduction

Stocks of the two species of deep-water shrimps, the blue-and-red shrimp and the giant red shrimp (*Aristeus antennatus* and *Aristaeomorpha foliacea*, family Aristeidae), comprise valuable resources of Mediterranean fisheries (Carlucci *et al.* 2006; Mytilineou *et al.* 2006). Red shrimp stocks have been exploited commercially since the 1930s in the western Mediterranean basin (Relini and Orsi-Relini 1987, Bas 2006), while new deep fishing grounds have been discovered in recent decades, especially in the eastern Mediterranean (Bas 2006). Declared landings of red shrimps in the entire Mediterranean amounted to 5000 t in 2008 (FAO 2000), but their economic importance is comparatively higher, due to the high market prices for red shrimps (from 10 €/kg in North African countries to 50 €/kg in Spanish markets, Maynou *et al.* 2006).

The two red shrimps constitute the main target species for the demersal deep-water fishery in the western and central Mediterranean, captured exclusively by trawlers on muddy bottoms, especially near submarine trenches and canyons, from 400 to 800 m depth. Both species are the most economically and ecologically important deep-water crustacean resource in the Mediterranean basin, together with *Nephrops norvegicus* (Sardà *et al.* 1994, Sardà *et al.* 2004). The distribution of *Aristaeomorpha foliacea* covers tropical and subtropical areas of the eastern Atlantic (including the Mediterranean) and the Indian ocean, while the geographical distribution of *Aristeus antennatus* is restricted to the Mediterranean and the eastern-central Atlantic. Nevertheless, *A. antennatus* is eurybathic with a documented depth of occurrence ranging from 80 to 3300 m (Sardà *et al.* 2004, and references therein), while *A. foliacea* has been recorded at depths from 123 to 1100 m (Politou *et al.* 2004, and references therein). Another important feature is the longitudinal segregation of the two species along the Mediterranean: *A. foliacea* increases in abundance from the western to the eastern Mediterranean, while the opposite is true for *A. antennatus*. In Spanish Mediterranean waters, the Gulf of Lions and the Ligurian Sea *A. foliacea* is scarce or absent and a dominance of *A. antennatus* is observed (Cau *et al.* 2002). The abundance of *A. foliacea* increases gradually eastwards, from the Tyrrhenian Sea to the Straits of Sicily and the waters around Greece, where it becomes more abundant than *A. antennatus* (Cau *et al.* 2002). In the Western Ionian Sea, *A. foliacea* is found in low concentrations and *A. antennatus* is dominant (D'Onghia *et al.* 1998), while in the Eastern Ionian Sea the converse is true (Politou *et al.* 2004).

Different hypotheses have been put forward to explain the distribution pattern of the giant red shrimp *A. foliacea* along the Mediterranean. Different hydrological conditions (i.e. temperature and salinity) between the westernmost and the easternmost areas have been reported to affect the species distribution (Murenu *et al.* 1994). *A. foliacea* is considered to be linked to warmer and more saline water masses, such as those of the Eastern Mediterranean, compared with *A. antennatus* (Ghidalia and Bourgois 1961, Cartes *et al.* 2011). Another major factor, which may explain its distribution pattern, is the vulnerability of the giant red shrimp to over-fishing, especially in the case of the high fishing pressure exercised on the deep waters of north-western Mediterranean fishing grounds (D'Onghia *et al.* 1998). The deep waters of the Western and Central Mediterranean are intensively exploited down to a depth of 800-1000 m, whereas they are almost unexploited in the Eastern Mediterranean (waters around Greece), since commercial fishing has traditionally been carried out in waters shallower than 500 m. In this area, *A. foliacea* is present in shallower waters than *A. antennatus,* and its main distribution range was found in the zone exploited by commercial fisheries (<1000 m). Also, being relatively stenobathic it has a lower resilience to changes in environmental conditions (Cartes *et al.* 2011). The recruitment of *A. foliacea* takes place on bottoms that can be reached by commercial trawl fleets (around 600 m), which makes juveniles available to fishing. In contrast, the recruitment of *A. antennatus* takes place at unexploited depths, 1500 m or deeper (Sardà *et al.* 1994). Additionally, *A. foliacea* matures later than *A. antennatus*, with the smallest mature females larger and older. Consequently, the former species has a lower probability of reproduction before being caught in the nets and is in general more susceptible to fishing pressure (Politou *et al.* 2004).

Recently, it has been shown that these species have the potential to support a viable fishery in the Greek Ionian Sea (Eastern Mediterranean) (Papaconstantinou and Kapiris 2001, 2003), where *Aristaeomorpha foliacea* is more prevalent than *Aristeus antennatus*. This higher abundance seems to be related to the particular ecological conditions of this area, which satisfy better the ecological demands of the giant red shrimp (Papaconstantinou and Kapiris 2003).

Red shrimps fisheries have not been historically exploited until recently in the Greek Ionian Sea because: (a) fishing at these depths yields a relatively low economic return; (b) knowledge and gear technology for fishing red shrimps is limited; and (c) red shrimps have a relative low local value, because demand for them is still limited since they have not been traditionally available in Greek fish markets, and Greek consumers are not familiar with them.

From an economic point of view, the development of the red shrimp fishery in Greek waters also offers an unusual opportunity to study the market evolution of a product hardly commercialized and not familiar to the consumers, with still relatively low prices (5-6 € / kg for the small fresh shrimp and 15-17 € / kg for the larger sizes). With a larger and more stable supply, it is expected that red shrimps will either create their niche in the local Greek market or will be exported to other countries where they are more appreciated, resulting in an increase in *ex-vessel* prices.

Considering that nearly two-thirds of assessed fish stocks worldwide may be in need of rebuilding (Worm et al. 2009), the development of sustainable new fisheries (and their markets) could become an important source of wealth generation and help to divert effort from stocks under excessive pressure. However, this may only be possible in a restricted number of cases due to the need of applying the precautionary principle to newly developed stocks and that only 15% of worldwide marine stocks were estimated to be underexploited or moderately exploited in 2008 (FAO 2010).

Assessing the long-term, sustainable potential of newly developed deep-water fisheries resources is difficult, due to the paucity of data coupled with the uncertainty in ecological and economic processes. Nonetheless, there exists a need for scientific advice to managers on the likely evolution of the fisheries resource under alternative management strategies, even when the best scientific information is simply inadequate for determining the state of the exploitation (or the stock status against pre-agreed reference points: Richards and Maguire 1998, Restrepo and Powers 1999). In this context, bio-economic simulation models are a useful tool. By capturing the essential aspects of the biological and economic dynamics of a fishery, a simple bio-economic model such as the one used in this work allows the provision of scientific advice to guide the decision-making process of local fisheries managers (Larkin *et al.* 2011).

Here, we investigate the scope for expanding the newly developed deep shrimp trawl fishery in the eastern Ionian Sea under different management scenarios with the application of a bio-economic model. The bio-economic simulation model allows also to analyse the effects that uncertainty in the form of future fuel price increases and changes in fish market prices may have on the profitability of the exploitation of the red shrimp fishery. Forecasting the biological and economic consequences of management actions before they are applied and the effects in fuel prices and market developments may help managers to select the more appropriate management options.

Management options in Mediterranean fisheries are characterised by the use of restrictions on effort and technical measures. Most Mediterranean fisheries are based on effort control (i.e. limitations in the number of vessels, fishing days and hours, close seasons), and no TACs are implemented (except for bluefin tuna). In the Mediterranean regulations have especially focused on the trawl segments since it is the main gear contributing to demersal catches and it also presents a worst selectivity pattern than more traditional artisanal gears (Lleonart and Maynou 2003).

2. Material and methods

2.1. The economic data on the deep-water shrimp fishery

Economic data were obtained by questionnaires under the Data Collection Regulation. In particular, it is collected data on capacity (number of vessels, gross tonnage, engine power and average age), landings in weight and value, effort (in fishing days, Kwdays and GTdays), employment (total employment, full-time employment, part-time employment and full time equivalents), revenues, costs and fuel consumption (income, crew cost, fuel cost, operational cost, capital cost, fixed cost, repair and maintenance and fuel volume consumed) and the financial position.

Deep-water shrimp fishing in Greece is mainly practiced in the west of the country (Ionian Sea) by the local trawling fleet. According the Ministry of the Mercantile Marine, the number of the trawlers in Western Greece is 35 and they are distributed on the ports illustrated in Fig. 1: Gytheio, Itea, Kalamata, Katakolo, Lefkada, Neapolis (Lakonia), Patra and Zakynthos. The main fishing grounds for red shrimps are the strait between Zakynthos and Cephalonia, the waters around the island of Zakynthos, Western Messinia and Western Lefkada (Fig. 1).

2.2. The bio-economic model MEFISTO

The bio-economic analysis was carried out using the MEFISTO 3.0 bio-economic simulation model (Lleonart *et al.* 1999, 2003, Maynou *et al.* 2006). The bio-economic model comprises a biological submodel (or stock module) and an economic submodel. The stock module simulates biological dynamics of the resource, from reproduction to growth and death and considers two kinds of species: the main species, whose dynamics are completely known (and modelled through an age-structure biological model, such as the 2 red shrimp species here; see Lleonart *et al.* 2003 for the biological equations), and the secondary species, whose dynamics are not known but their contribution to total revenues is important in Mediterranean fisheries (Lleonart *et al.* 2003) and their catch is empirically related to the catch of the main species. Model inputs are maximum fishing effort and catchability (which are in turn the output of the economic submodel) whose product represents the fishing mortality applied to the stock. Outputs are fish catches that are converted to revenues by means of species-specific price equations.

The fish catches of each species generated by the stock model are converted into revenues, through price functions. The mean price for deep water shrimps in the local market is about 9 € / kg. Small fresh shrimp (age ≤ 2 approximately) can fetch 5-6 € / kg (50 specimens/kg) and for the larger sizes (age > 2 approximately) price can be higher (10-12 specimens/kg), reaching 15-17 € / kg. The price function used assumed that price is independent of the amount of catches and imports, and only the effect of size (age) was modelled: log P = β1+ β2 log(age), where β1 and β2 are coefficients of a linear regression between shrimp categories (small, large) and price P.

The simulations were carried out under steady state conditions with stochastic recruitment for a projection horizon of 15 years (from 2007 onwards) using 10,000 iterations. Because the simulations were carried under biological steady state and the dynamics of effort did not change over time, the trajectory of each indicator in time was very similar and only the mean and the 95% confidence interval are shown for selected indicators to facilitate comparisons across scenarios.

2.3. Management strategies and simulation conditions

With the objective of assessing the potential of the Greek fishery for red shrimp in the Ionian Sea, we established alternative scenarios based on current knowledge of this fishery and the options that fisheries managers are considering for the near future, complemented with the constraints imposed by the likely increase of fuel price in the near future. We compare the performance of selected indicators (SSB, catches, profits) in 3 alternative scenarios against the current exploitation strategy (18 trawlers fishing for 2 months in the area).

- Scenario 1: **50% increase in the number of days** (effort) devoted to this fishery, increasing the fishing period from 2 to 3 months, for the 18 trawlers already targeting shrimps.

- Scenario 2: all **35 trawler vessels** in the area enter the red shrimp fishery in the current open season of 2 months (corresponding to a 94% increase in capacity).

- Scenario 3: Remove the seasonal restriction and allow the current fleet of 18 trawlers to fish shrimp **during the whole year** (estimated to be 267 fishing days).

- Scenario 4: Further, we investigate the effects of **changes in market conditions**, derived from a development of the Greek market for shrimp may have on the economic performance of this trawler fleet. Development of the Greek market for shrimps would be translated into shrimp price increases, because the product in other European markets fetch higher prices, for instance in Spain ex-vessel price for *A. antennatus* is around 50 €/kg (Maynou *et al.* 2006). We compared current profitability with the scenarios of shrimp price 2x and 4x current price, in line with ex-vessel prices paid in Italy or Spain (Scenarios 4.1 and 4.2).

- Scenario 5: Finally, we analysed the effects of **changes in fuel costs**, in particular a fuel price increase may have on the economic performance of this trawler fleet by simulating fuel price increases of 20%, 50% and 100% and comparing the results with the current situation (Scenarios 5.1, 5.2 and 5.3).

3. Results

3.1. Fleet description

From the questionnaires collected it was determined that vessels engaged in red shrimp fishing have an average length of 24.33 m, average engine power of 352.72

HP, and average capacity of 59.93 GRT. They belong to the middle to high category of the Greek fleet. This would be expected because red shrimp fishing requires advanced tools and equipment (wires, gates, winches), as well as engine power (to be able to pull the net at the depths of shrimp habitat), making this fishery unsuitable for small trawlers (Maynou *et al.* 2006). Only 18 of the potential 35 local trawler vessels are actively engaged in red shrimps fishing at present (Table 1).

From the data collected, and presented in Anderson and Guillen (2009), it can be seen that Greek trawlers are making high profits, but revenues from red shrimps comprise a small portion of overall revenues (just 1% of the total revenues of the fleet), hence the fleet is not dependent exclusively on this resource, and the shrimp fishery is just an extra source of income for the trawlers that practise it.

Based on the revenues generated in the market module and the costs incurred (fuel, operational and fixed costs), the profitability of the fleet was calculated. The current economic parameters and profitability of the Greek trawl fleet operating in the Ionian Sea are shown in Table 2.

3.2. Assessment of the two red shrimp stocks

The necessary information on the population structure at the start of the simulations regarding the number of individuals, fishing mortality (*F*) and number of recruits (*R*) was estimated by means of a steady-state version of Virtual Population Analysis (VPA) using the VIT program (Lleonart *et al.* 1999), with the biological parameters shown in Table 3 and length frequency data derived from field sampling EU's Data Collection Framework. The initial biological conditions and fishing mortality vectors, obtained through VPA analysis, and used as parameters in the bio-economic model are shown in Table 4.

We carried out the analysis of alternative scenarios under the assumption of biological equilibrium, with stochastic variation of recruitment around the mean recruitment estimated through steady-state VPA. Despite extensive biological research carried out on other stocks of red shrimps in the Mediterranean in recent decades, knowledge on stock-recruitment relationships is very scarce and only very short (10 years or less) series on spawning stock and recruitment exist. This data poor situation precludes computing stock/recruitment relationships, but the existing data on variation of recruitment in other Mediterranean stocks has been used to establish a coefficient of variation (CV) of recruitment. We used data from Cardinale *et al.* (2010, p. 852 and ff) to calculate CV = 0.62 for *A. foliacea* and CV = 0.29 for *A. antennatus*. In the biological model this recruitment variation was introduced as a lognormal distribution function with a mean corresponding to N_1 in Table 3 for each species and a standard deviation corresponding to sd = mean * CV. Although the assumption of mean constant recruitment is very strong (because it implies that recruitment behaves independently of the stock level), this assumption is often used when limited data are available to calculate the stock-recruitment relationship (Silvestri and Maynou, 2009).

3.3. The scenarios

3.3.1. Scenario 0: Initial situation

The initial scenario reflects the current situation, where 18 trawler vessels are licensed for deep shrimp fishing during 2 months each year (corresponding to 1008 fishing-days-vessel). The summary indicators of the current situation are given in Table 5. Figs 2-4 show the values of selected indicators in the alternative scenarios compared against the current situation (Scenario 0)

3.3.2. Scenario 1: Increase in the number of days by 50%

An increase of 50% in the number of days (effort) from 2 to 3 months for the 18 trawler vessels already participating in the fishery would correspond to 1512 fishing-days-vessel and was simulated by increasing the fishing mortality of each age class by 50%. The simulation results show a decrease of SSB by 15% and 11% for *A. foliacea* and *A. antennatus* respectively, while catches of the two species would increase by 20% and 31% respectively, with no appreciable increase in the profits of the fleet (Figs 2-4).

3.3.3. Scenario 2: Increase to 35 trawlers

An increase in the number of trawlers (capacity) from the 18 trawler vessels already participating in the fishery to the 35 vessels that operate in the area would correspond to an increase of 1960 fishing-days-vessel. This management scenario was simulated by increasing the fishing mortality of each age class by 94%. The simulation results show a decrease of SSB by 27% and 17% for *A. foliacea* and *A. antennatus* respectively, while catches of the two species would increase by 30% and 55% respectively, with a very small increase (1%) in the profits of the fleet (Figs 2-4).

3.3.4. Scenario 3: Fishing during the whole year

Opening the fishery to the whole year for the 18 trawler vessels participating in the fishery corresponds to an increase of 4816 fishing-days-vessel, assuming 267 effective fishing days each year. This management scenario was simulated by increasing the fishing mortality of each age class by 477%. This large increase in fishing pressure would drive the stocks of both species to very low levels: a reduction of 74% of SSB for *A. foliacea* and a reduction of 65% for *A. antennatus*. Under these conditions catches of *A. foliacea* would increase by 45%, while catches of *A. antennatus* would increase by 170%. Still, this large increase in catches (additional 5800 kg) would represent only an increase in revenues of 58,000 Euro, a small fraction of the revenues of the fleet. For this reason, despite the increase in catches, profits would increase only by 1% (Figs 2-4).

3.3.5. Scenario 4: Market development

We analyzed the effects of the development of a market for Greek red shrimps, either based on an increase of internal demand or an export market. We have done that by comparing the current situation alternative scenarios of increase by 2x and 4x times the current price (average of 18 € / kg and 36 € / kg, Scenarios 4.1 and 4.2). Because these Scenarios do not change the base fishing mortality (because effort is held constant), no significant effect can be expected on SSB or catches (Figs 2 and 3), but profits would increase by 2% and 6% respectively (Fig. 4). The development of the Greek red shrimp market would allow a moderate increase of revenues and profitability of the trawler fleet in a low amount, due to the small share of red shrimps in the overall annual catches.

3.3.6. Scenario 5: Fuel price increases

Fuel costs are the main cost in many fishing fleets, especially fleets using active gears, like trawlers. In 2007, the fuel price for commercial fishers was 0.45 Euro / l in Greece, but since 2008 global oil prices have increased and they are likely to increase in the near future. Forecasts predict the oil price to reach 113 US$ per barrel (in year 2009 dollars) in 2035, while short term price volatility is likely to remain high (IEA, 2010). In Scenarios 5.1, 5.2 and 5.3 fuel price increases of 20%, 50% and 100% relative to current prices were compared. Because these Scenarios do not change the base fishing mortality, no significant effect can be expected on SSB or catches (Figs 2 and 3), but profits of the fleet would decrease by 2%, 5% and 11% respectively (Fig. 4)

4. Discussion

Managing a newly developed fishery is a difficult issue because of lack of information in many biological and economic parameters, as newly developed fisheries are typically data-poor. There are many sources of uncertainty in fisheries, but in newly developed fisheries recruitment dynamics and how the stock will respond to continued fishing pressure are particularly significant (Beddington and Cooke 1983). Here we examined alternative scenarios of the evolution of a newly developed deepwater red shrimp fishery targeting two shrimp species (*Aristaeomorpha foliacea* and *Aristeus antennatus*) in the eastern Ionian Sea, that are important deepwater resources elsewhere in the Mediterranean (Sardà *et al.* 2004, Carlucci *et al*. 2006). In the absence of agreed biological reference points, it is difficult to provide managers with sound scientific advice, and providing the results of bio-economic simulation exercises (founded on realistic alternative scenarios with assumptions clearly underlined) is a way of communicating to fisheries managers the possibilities of expansion of new fisheries (Richards and Maguire 1998, Restrepo and Powers 1999). In our case, moderate increases in fishing effort (either by extending the open season by 1 month, Scenario 1, or allowing the entire local fleet entry in this fishery, Scenario 2) would allow for moderate increase in catches (25-35%) without jeopardizing the sustainability of the stocks (decrease of SSB from 11% to 27% on average from the base scenario). Instead, opening the fishery to the entire year (Scenario 3) would put the stocks at risk, with a reduction of 74% of SSB in *Aristaeomorpha foliacea* and 65% in *Aristeus antennatus*. These figures show that this level of fishing pressure would be far from sustainable, even in the absence sufficient information to compute reference points. Furthermore, due to the relatively low price of red shrimps in the local market, a large increase in fishing effort would not increase the profits of the trawl fleet in a significant amount. Our results show that fishing effort can slightly increase without negatively compromising the sustainability of the fishery, but would not produce significant changes in the profitability of the fleet.

The development of a red shrimp internal or export market in Greece would allow to increase the revenues and the profitability of the trawler fleet, by a moderate amount (2-6%). An increase in the demand for Greek red shrimp in the current price range analysed should not threaten the resource, since the expected benefits from targeting these species are not significant higher, and so there should be no significant pressure to enter in the fishery. However, this would be an incentive to increase fishing effort of the trawler fleet on deep sea resources if shallow water resources become scarce in the future, as happened elsewhere in the western Mediterranean (Maynou *et al.* 2006). If effort is increased above the thresholds previously analysed, the sustainability of the resource would be threatened.

Conversely, potential future fuel price increases (or reductions in the fuel subsidies -tax exemptions, which would have the same effect since they are equivalent), by increasing the exploitation costs, may reduce the profitability of this fleet segment by 2 to 11% in the scenarios tested. Unlike fleet segments in other countries that have been very sensitive to fuel prices changes (see for example Silvestri and Maynou 2009), this segment presents positive profits despite significant fuel price increases. This is because the data for this Greek trawler fleet show a very high profitability, in accordance with the 2009 Annual Economic Report (Anderson and Guillen, 2009), where Greek fleets economic performances are not dramatically affected by fuel prices. Increases in subsidies would have the opposite effect, reducing exploitation costs, and so increasing the profitability, as happened with the price increases.

Thus, the uncertainty coming from the evolution of economic parameters does not affect significantly the economic performance of this fleet, as we can see from the simulations on the shrimp income and the main costs. However, more important in this fishery is the uncertainty coming from the biological characteristics of the resource, specially the stock-recruitment dynamics and the response of the stock to fishing effort. Even if we have modelled uncertainty on the analysis and reported confidence intervals, the results should be taken as approximations.

Thus, it can be concluded from the simulations that it seems viable for the shrimp fishery to increase its effort (either by letting the 18 vessels that are currently in the fishery fish during 3 months, or by letting the other 17 trawlers in the area enter the shrimp fishery during the 2 month period). This would result in a 35% increase on the revenues from shrimps (more than 50,000 Euro annually for the fleet) and potentially more if a market is established. However, this effort increase should be accompanied with biological surveys to obtain precise indicators of the biomass evolution and provide an accurate monitoring of fishing effects on particularly vulnerable deep sea habitats.

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Tables

Table 1: Characteristics of Greek trawler vessels fishing for red shrimps. The total number of trawlers in the area is 35.

Number of vessels	18
Average Length (m)	24.33
Average Engine power (HP)	352.72
Average Capacity (GRT)	59.93
Crew (persons/vessel)	6.25
Fishing days per vessel (days/year)	267

Table 2: Economic performance and main cost items of Greek trawler vessels fishing for red shrimps.

Capital value of the vessel (thousand Euro/vessel)	160
Annual revenues (thousand Euro/vessel)	522
Annual cost (thousand Euro/vessel)	314
• Fuel cost (thousand Euro/vessel)	102
• Labour cost (thousand Euro/vessel)	63
• Daily cost (thousand Euro/vessel)	55
• Maintenance cost (thousand Euro/vessel)	35
Profits (thousand Euro/vessel)	208
Return On Investment (%)	130

Table 3: Biological parameters for *Aristeus antennatus* and *Aristeus antennatus* for the stocks exploited by the Greek trawling fleet in the eastern Ionian sea. Parameters of the von Bertalanffy growth function: $L\infty$, k and t_0. Parameters of the length-weight relationship: a, b. Natural mortality (M).

	Aristaeomorpha foliacea	*Aristeus antennatus*
$L\infty$ (mm CL)	59.5	58.0
k ($year^{-1}$)	0.48	0.42
t_0 (year)	-0.5	-0.42
a	0.0034	0.0083
b	2.38	2.23
Natural Mortality (M)	0.52	0.48

Table 4: Population parameters for *Aristeus antennatus* and *Aristeus antennatus* based on steady-state VPA: number of individuals at age in the reconstructed population (N_a), proportion of mature individuals at age ($MAT_a a$), fishing mortality at age (F_a).

Aristaeomorpha foliacea			
Age (a)	N_a	MAT_a	F_a
1	1242860	0.121	0.126
2	651274	0.382	0.599
3	212728	0.735	0.554
4	72687	0.926	0.1

Aristeus antennatus			
Age (a)	N_a	MAT_a	F_a
1	906376	0.226	0.045
2	536424	0.567	0.151
3	285495	0.854	0.163
4	150137	0.963	0.211
5	75255	0.992	0.1

Table 5: Summary indicators of the base scenario (current situation)

	Aristaeomorpha foliacea	*Aristeus antennatus*	Eastern trawl fleet	Ionian
SSB (kg)	21 426	12 774		
catch (kg)	7 161	1 609		8 770
Profits (000 €)				3 630

Figures

Figure 1. Map of the research area with the locations of the main local fishing harbours for trawlers

Figure 2. Spawning Stock Biomass at equilibrium under different simulation scenarios. Mean value with 95% confidence interval of 10,000 simulation runs with stochastic recruitment. Values on top of the charts represent changes in percentage with relation to the current situation (2007, Scenario 0).

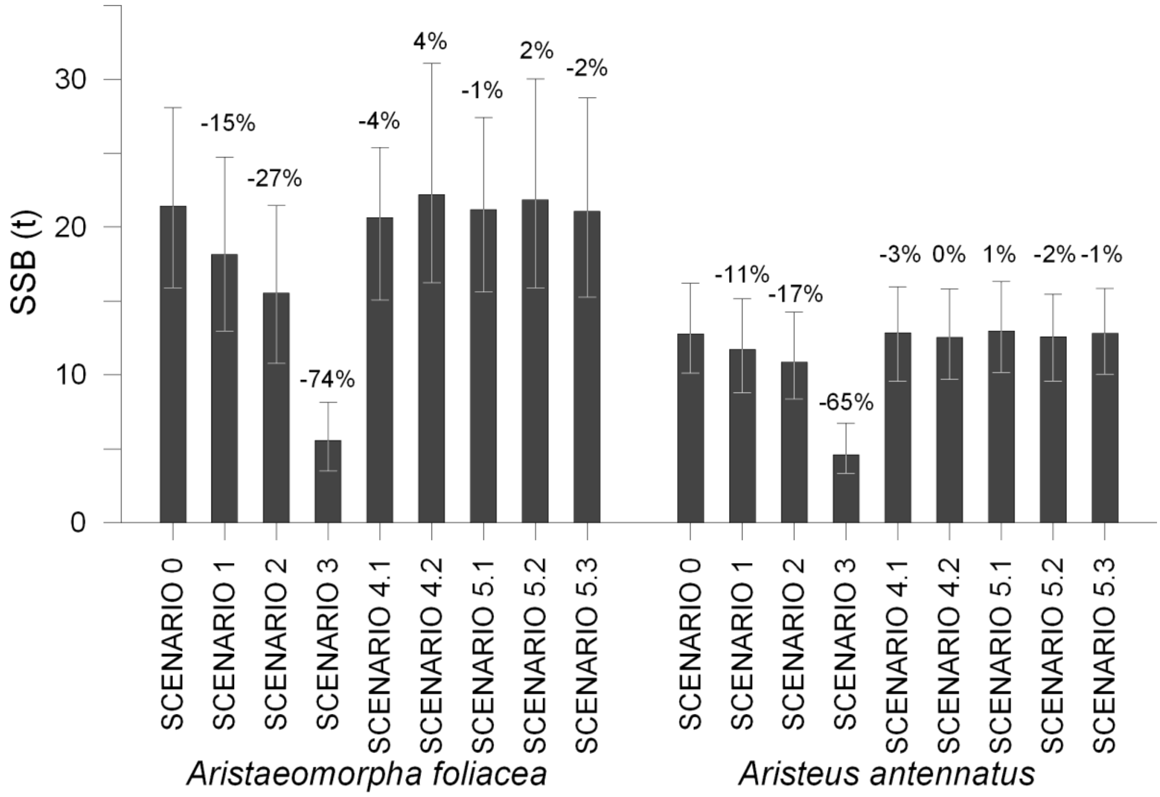

Figure 3. Catches at equilibrium under different simulation scenarios. Mean value with 95% confidence interval of 10,000 simulation runs with stochastic recruitment. Values on top of the charts represent changes in percentage with relation to the current situation (2007, Scenario 0).

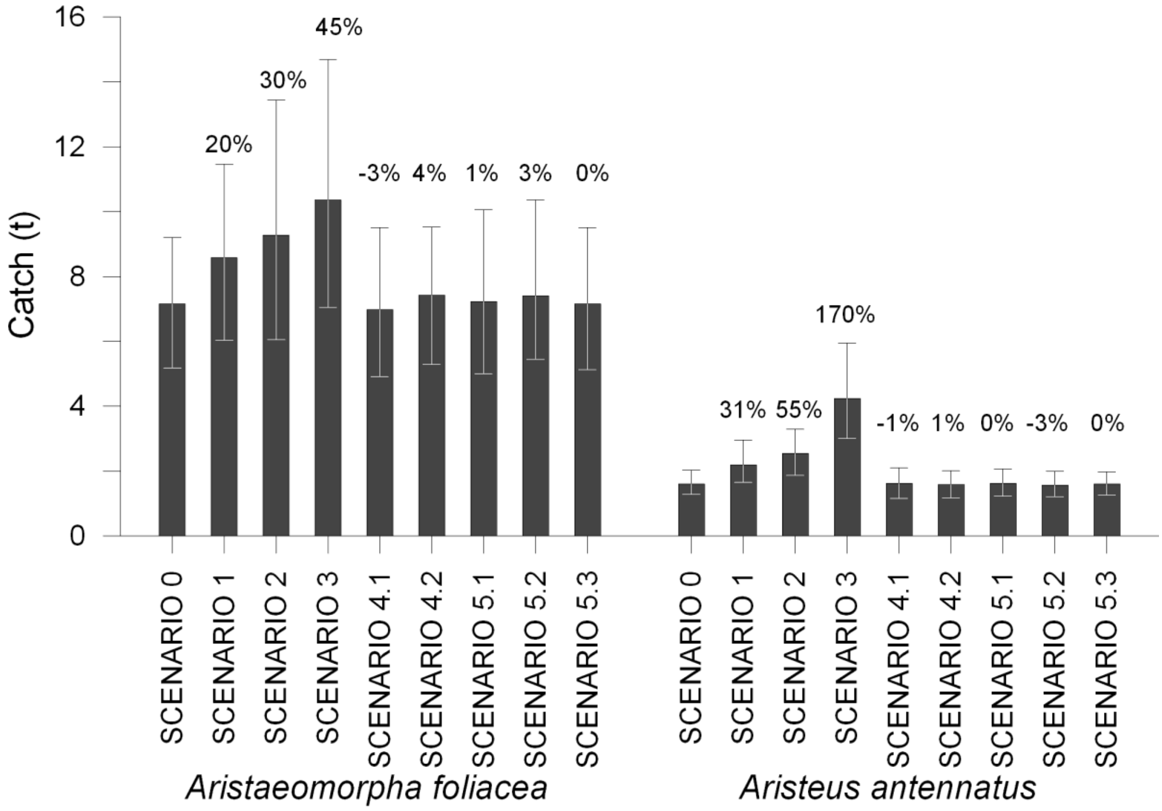

Figure 4. Profits at equilibrium under different simulation scenarios. Mean value with 95% confidence interval of 10,000 simulation runs with stochastic recruitment. Values on top of the charts represent changes in percentage with relation to the current situation (2007, Scenario 0).