Fisheries Research 96 (2009) 160–166

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

A bio-economic evaluation of different management measures for the Mediterranean swordfish

George Tserpes [a,*], Evangelos Tzanatos [a], Panagiota Peristeraki [a], Vincenzo Placenti [b], Laurence Kell [c]

[a] Hellenic Centre for Marine Research, P.O. Box 2214, GR 71003 Iraklion, Greece
[b] ARGO SRL, Via S. Leonardo (Trav. Migliaro), 84131 Salerno, Italy
[c] CEFAS, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK

ARTICLE INFO

Article history:
Received 5 June 2008
Received in revised form 23 October 2008
Accepted 23 October 2008

Keywords:
Swordfish
Management
Yield prediction
Mediterranean
Season regulations

ABSTRACT

The biological and economic implications of different management measures concerning the Mediterranean swordfish stock were evaluated by means of simulations performed under the Fisheries Language in R (FLR) framework. Six different scenarios were examined including Mediterranean-wide seasonal closures of different duration and an effort reduction scheme. Recruitment was assumed to vary in levels either predicted by a Beverton–Holt stock–recruitment relationship or around an average value estimated from the latest assessment accomplished by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Simulations projected the levels of landings, spawning stock biomass (SSB), gross and net revenue for a period of twenty years. Considering the estimated statistical uncertainty, gains in terms of landings and SSB from short fishery closures (e.g. one month) will be negligible. On the contrary, seasonal closures of at least four months would result in important long-term gains, which are more profound in the case of SSB and net revenue. The ICCAT convention objectives concerning SSB, can only be met with drastic closures (i.e. six months). However, drastic closures would result in short-term decreases in landings and revenues, which should be taken into account before such measures are adopted.

1. Introduction

Swordfish, *Xiphias gladius* (Linnaeus, 1758), is a commercially important highly migratory fish, globally distributed between the latitudes 45°N to 45°S (Palko et al., 1981). Swordfish in the Mediterranean is considered a unique stock based on genetic analyses (Kotoulas et al., 1995, 2003) having different growth and maturity characteristics from the adjacent Atlantic stocks (Cavallaro et al., 1991; Ehrhardt, 1992; Tserpes and Tsimenides, 1995). Mediterranean swordfish was described to spawn from May to July (Rey, 1988; Cavallaro et al., 1991; Tserpes et al., 2001) and recruitment to the fishery extends from September to February having its peak from October to January (Anon., 2008a).

In the Mediterranean Sea, fishing for swordfish is carried out throughout the year, but it is most intensive from late spring to middle autumn and is heavily exploited by several countries which target swordfish using surface drifting longlines and/or gillnets. Overall catch levels have been relatively stable during the last decade. While the most recent assessment carried out by the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated that recruitment showed little variation (CV ≈ 12%) with no trend over the past twenty years (Anon., 2008a) in the same period spawning stock biomass (SSB) has shown a decline between 24% and 38%, depending on the assessment model used. In addition, the main catch is of juveniles that have not yet spawned and assessment results clearly indicate growth overfishing and that at current levels of fishing mortality drastic stock declines could be seen within a generation (seven to ten years).

Management of Mediterranean swordfish is within the Convention area of the International Commission for the Conservation of Atlantic Tunas (ICCAT), whose Convention states that "*The Commission may, on the basis of scientific evidence, make recommendations designed to maintain the populations of tuna and tuna-like fishes that may be taken in the Convention area at levels which will permit the maximum sustainable catch*". Until recently there were no Mediterranean-wide management measures for swordfish although various technical measures have been imposed at a national level in attempts to reduce fishing pressure on the stock and juvenile catches. Measures include, among others, fishery closures during the recruitment period (middle autumn–early winter), minimum landing size (MLS) regulations and fishing license control systems. A MLS of 120 cm at a European level (i.e. within the

* Corresponding author. Tel.: +30 2810 337851; fax: +30 2810 337822.
E-mail address: gtserpes@her.hcmr.gr (G. Tserpes).

0165-7836/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2008.10.008

EU countries) resulted in under-reporting of juvenile catches and proved to be impractical due to the low size-selectivity of the fishing gears used and the traditional high availability of juvenile swordfish in the surface gears used in the Mediterranean (Goode, 1883). Recently, the ICCAT commission has decided to implement a one-month fishery closure during the recruitment period of 2008 and asked for the evaluation of the impact of the measure. However, before any action is taken to implement such technical measures, the potential effect on the stock and the fisheries should be evaluated (Di Natale et al., 2002).

In a previous study, Tserpes and Peristeraki (2007) evaluated the medium-term effect of a four-month Mediterranean-wide fishing closure on the volume of landings. In addition, during the latest ICCAT assessment the effects of certain seasonal closures on landings and stock levels were evaluated, assuming an empirically estimated stock–recruitment relationship (Anon., 2008a). Although it has been pointed out that seasonal closures would also result in a greater economic return for the fishery, such economic benefits have not been quantified.

Therefore in the present work we undertake a comparative bio-economic evaluation of the medium-term effect of a series of Mediterranean-wide management measures, including seasonal closures and effort reduction schemes. Our analysis includes the impact on economic aspects, such as the value of landings and the net revenue from fishing as well as on stock size and landings. Our analysis also evaluates the robustness of the conclusions to alternative assumptions about future recruitment, i.e. (i) independent of stock size or (ii) an empirical stock–recruitment relationship and are based on stock estimates derived from the latest ICCAT assessment. Economic data were obtained from the Greek and Italian longline swordfish fisheries, which account for about 50% of the total Mediterranean swordfish fishery production (Anon., 2008a).

2. Materials and methods

A swordfish-like population was generated based on the latest ICCAT assessment of the Mediterranean swordfish stock, and a series of management scenarios were simulated using the FLR framework (the Fisheries Library in R, Kell et al., 2007) using an operating model that consisted of three components: the population, fleet and observation models.

2.1. Population model

The model was based on the estimates of numbers and fishing mortalities-at-age obtained from Extended Survivors Analysis (XSA, Shepherd, 1999) during the most recent ICCAT assessment (Anon., 2008a). The assessment covered the years 1985–2005. Annual recruitment was assumed either to be independent of stock size (constant recruitment, CR) and equal to the mean from the assessment period, or derived from an empirically estimated Beverton–Holt stock–recruitment (BH) model. As assessment results do not allow estimation of recruitment model parameters due to low contrast, these were estimated empirically (Hilborn and Walters, 1992) assuming that (a) half of the 2005 stock size will produce about half of the maximum recruitment and (b) 2005 recruitment is 70% of the maximum.

Population numbers at age and year ($N_{a,y}$; α > age at recruitment, y: year) for the projection years were derived from the standard exponential decay function.

$$N_{a,y} = N_{a-1,y-1}e^{-(F_{a-1,y-1}+M_{a-1,y-1})}$$

where F is fisheries mortality and M is natural mortality considered constant for all ages. Based on the catch-at-age data used in the latest ICCAT assessment, a lifespan of ten years was assumed.

Natural mortality, mean weight in the catch and in the stock, and maturity-at-age were all taken from the ICCAT stock assessment (Anon., 2008a).

2.2. Fleet model

Two fleet components were considered: (a) the Greek–Italian longliners (LL) and (b) all other fleets combined (OTH).

For each fleet component:

Fishing mortality by age and year ($F_{a,y}$) was determined by a separable model:

$$F_{a,y} = S_a F_y, \tag{1}$$

where S_a is the fisheries selection pattern.

The relationship between F_y and fishing effort (F_y), expressed in terms of days at sea was modeled as:

$$F_y = q_y f_y,$$

where q_y is the catchability. Hence Eq. (1) becomes: $F_{a,y} = S_a q_y f_y$.

Annual catches by age and year ($C_{a,y}$) were generated using the standard Baranov equation:

$$C_{a,y} = \frac{F_{a,y}}{Z_{a,y}} N_{a,y}(1 - e^{-(F_{a,y}+M_{a,y})}),$$

For the longline fleet component the annual value of landings (gross revenue, GR_y) was estimated from:

$$GR_y = \sum_a (C_{a,y} P_{a,y}),$$

where $P_{a,y}$ is the price per kilo at age and year.

Total variable (operational) costs by year (VC_y) were estimated from:

$$VC_y = \overline{D_y} f_y,$$

where $\overline{D_y}$ are the mean daily operational costs by year.

Total fixed costs (FC_y) were estimated from:

$$FC_y = \overline{V_y} n_y,$$

where $\overline{V_y}$ is the mean annual fixed vessel costs by year and n_y the number of vessels.

Finally, net revenue (NR) was estimated from:

$$NR_y = GR_y - (VC_y + FC_y).$$

Due to lack of data, economic parameters were not considered for the "other" fleet component.

2.3. Observation model

Log–normal errors with coefficients of variation equal to 15% and 30% were assumed for abundance-at-age in the first year of the simulation (2005) and the annual recruitment estimates respectively. Therefore, abundance and recruitment values were drawn randomly from the assumed distributions.

2.4. Scenarios

Six Mediterranean-wide management scenarios were examined, details are given below. Each scenario projection was simulated 100 times for a period of twenty years and the following statistics were estimated by year: the total volume of landings, the spawning stock biomass (SSB) levels, the value of landings (gross revenue) and the net revenue from the longline fishing activity.

The reference (base case) estimates of S_a were derived from the mean F_a assessment estimates for the period 2003–2005:

$$S_a = \frac{\overline{F_a}}{\overline{F}}.$$

As the two fleet components have equal production in the latest years (Anon., 2008a), it was assumed that:

$$F_{a,LL} = F_{a,OTH} = \frac{F_a}{2}.$$

Based on 2005 data, the reference fishing effort for the longline fleet component was assumed equal to 58,800 days. As data on fishing effort and economic parameters were not available for the “others” fleet component, this component was not included in the economic analysis and its reference fishing effort was assumed equal to 1. The economic data used (operational costs by day, fixed costs by vessel, fish price by kilo and size) refer to the mean 2005 values and were collected within the frames of the National Fisheries Data Collection Programmes accomplished in accordance with the 1539/2003 EU Regulation.

The first, the base case scenario, assumes an open fishery throughout the year (with the exception of the existing national regulations), i.e. the situation until the end of 2007. Scenarios 2–4 examine the effects of fishery closures during the peak recruitment period (October–January) and scenario 5 for the entire recruitment period (September–February). The growth pattern of the Mediterranean swordfish (Tserpes and Tsimenides, 1995) suggests that the fish reach a Lower Jaw Fork Length (LJFL) of up to 70 cm by the end of the recruitment period, it has been assumed that such closures would affect the selectivity of zero-age fish (up to 71 cm of LJFL in the catch-at-age table used in the latest ICCAT assessment). A 6th scenario examines a progressive reduction of fishing effort. In all cases, full implementation of the examined measure is assumed.

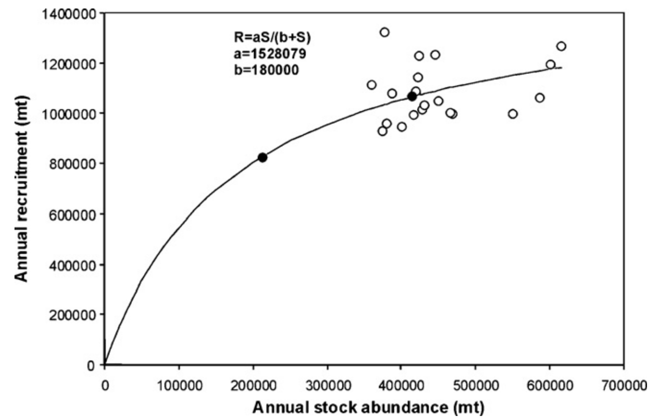

Fig. 1. Fitting of the Beverton–Holt stock–recruitment model to the ICCAT assessment estimates for the years 1985–2005. Black circles indicate the coordinates the model was forced to fit according to the assumptions.

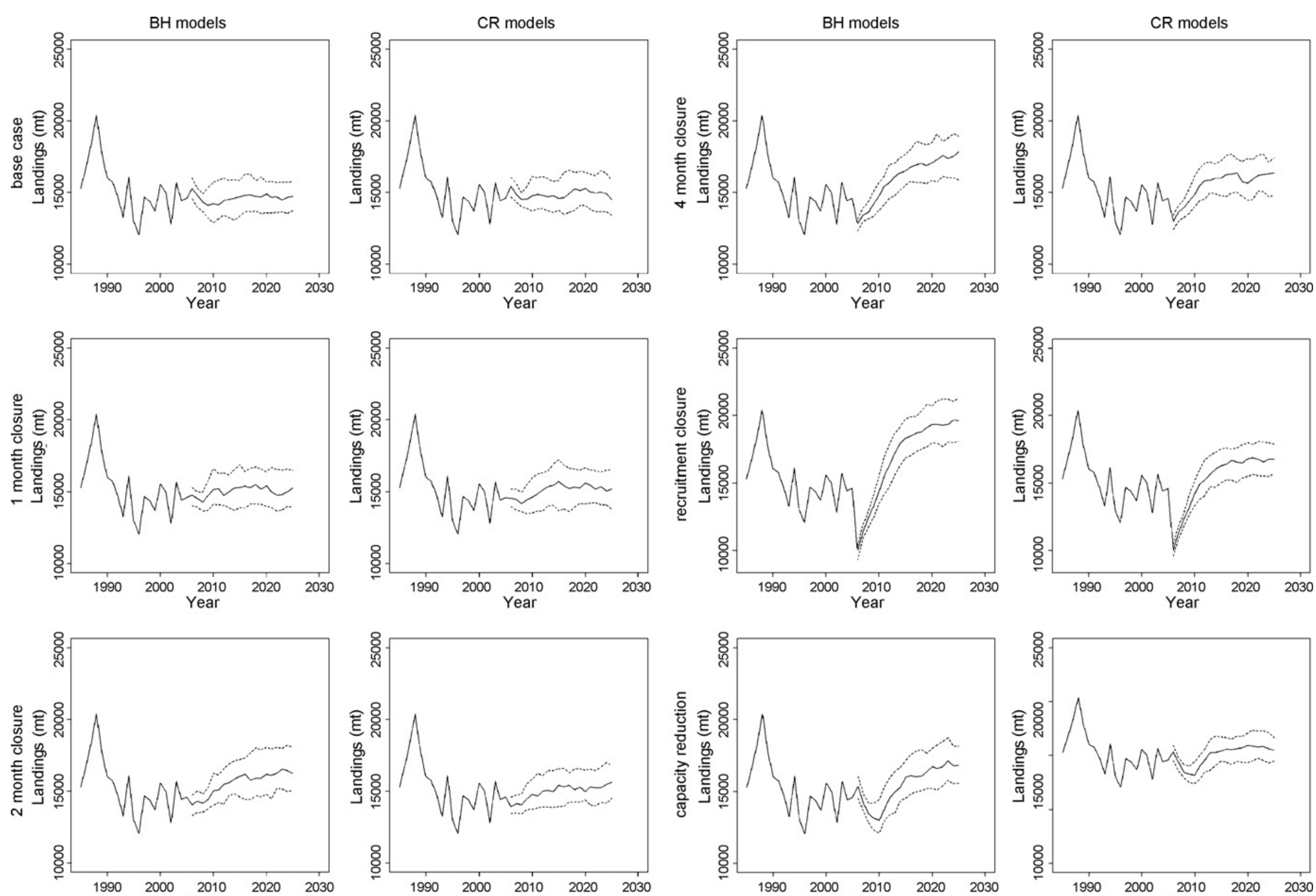

Fig. 2. Median estimates of landings for the projection period (2006–2025). Broken lines correspond to the lower and upper quartiles. BH = Beverton–Holt, CR = constant recruitment. Values prior to 2006 are taken from the ICCAT database.

2.4.1. Scenario 1 (base case): open fishery throughout the year

It was assumed that S_a and global f will be equal to the corresponding reference estimates for the entire projection period.

2.4.2. Scenario 2: a one-month fishery closure during the peak of the recruitment period

Based on the observed fish growth pattern, it was assumed that such a closure would reduce S of zero-ages by 25%. Taking into account that over the Mediterranean much more fishing pressure is exerted on the stock from late spring to middle autumn (Anon., 2008a), it was considered that this one-month closure during the peak recruitment season will reduce global f only by 5%. This scenario is an extension of the recent temporal closure recommended by ICCAT for the Mediterranean swordfish fishery in 2008.

2.4.3. Scenario 3: a two-month fishery closure during the peak of the recruitment period

It was assumed that a two-month closure would reduce S of zero-ages by 50%. Similarly to the previous scenario, taking into account the seasonal pattern of the fishing activity it was considered that this two-month closure out of the peak fishing season will reduce global f by 10%.

2.4.4. Scenario 4: a four-month fishery closure during the peak of the recruitment period

It was assumed that such a closure would reduce S of zero-ages by 90% and global f by 20%.

2.4.5. Scenario 5: fishery closure for the entire recruitment period (six-month closure)

According to this scenario S of zero-age fish would be completely eliminated and global f would be reduced by 40%.

2.4.6. Scenario 6: gradual reduction of the fishing effort

It was assumed that global f will be reduced by 5% annually for the first four years (overall reduction equals 20%).

3. Results

The empirically estimated BH S/R model is shown in Fig. 1. In all scenarios, apart from the base case, decreases in landings are expected in the short-term, which are more profound in the case of the entire recruitment period closure (Fig. 2). Gains in SSB are mainly expected from the four- and six-month closures. The four-month closure will bring SSB levels up to those estimated for the late 80s, while the corresponding levels from the six-month closure would be 1.7–2 times higher than those of the 80s (Fig. 3). Both, the one- and two-month closures will not result in any substantial gains in terms of landings and SSB. The effort reduction scheme will result to landings and SSB levels between those estimated for the two- and four-month closure scenarios.

The expected median yearly estimates of the examined parameters have been standardized by subtracting the corresponding base case estimates and then dividing by them, in order to allow direct scenario comparisons (Figs. 4–7). Responses of CR models are more conservative than those of the BH models since no

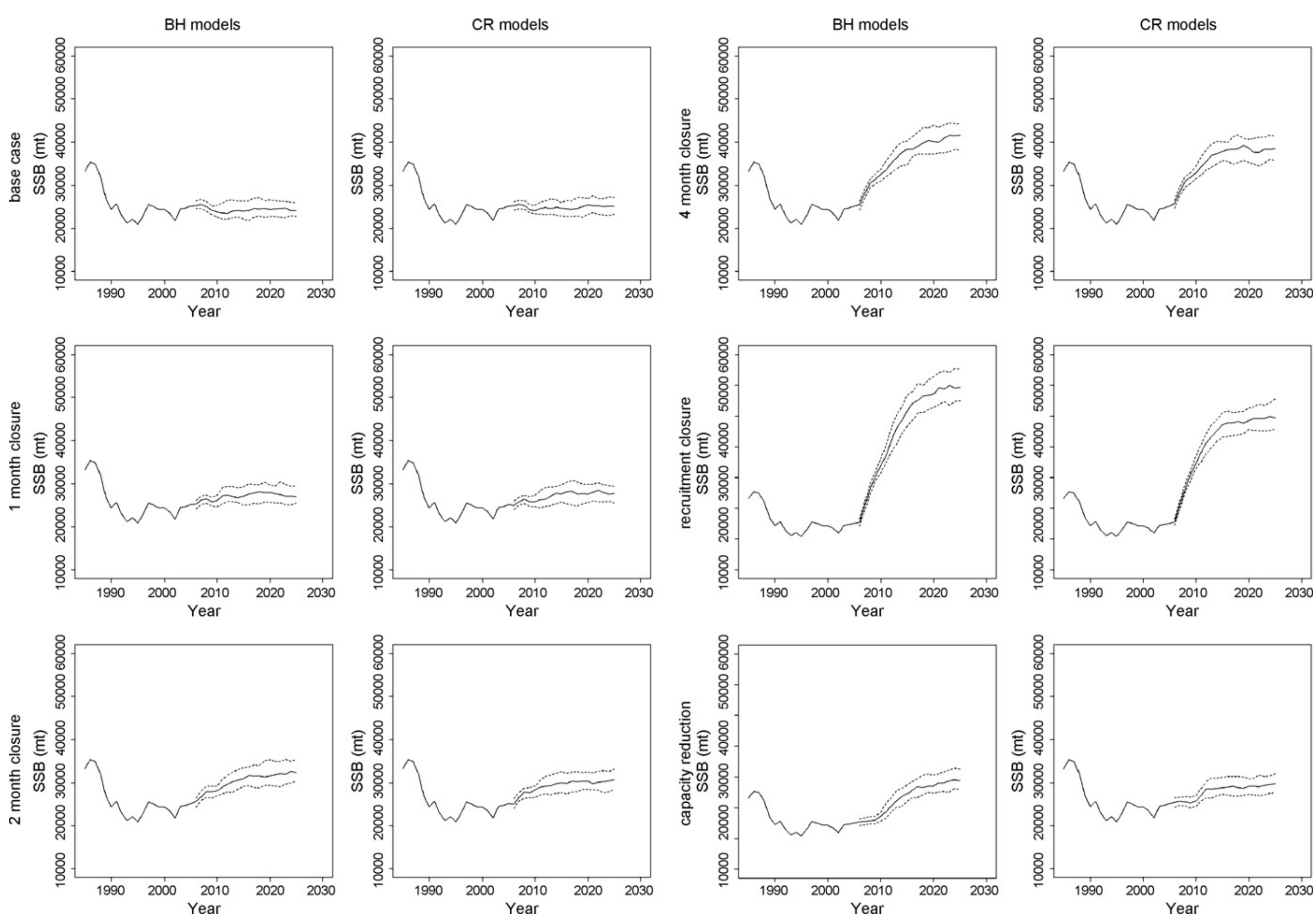

Fig. 3. Median estimates of spawning stock biomass (SSB) for the projection period (2006–2025). Broken lines correspond to the lower and upper quartiles. BH = Beverton–Holt, CR = constant recruitment. Values prior to 2006 refer to the latest ICCAT assessment results.

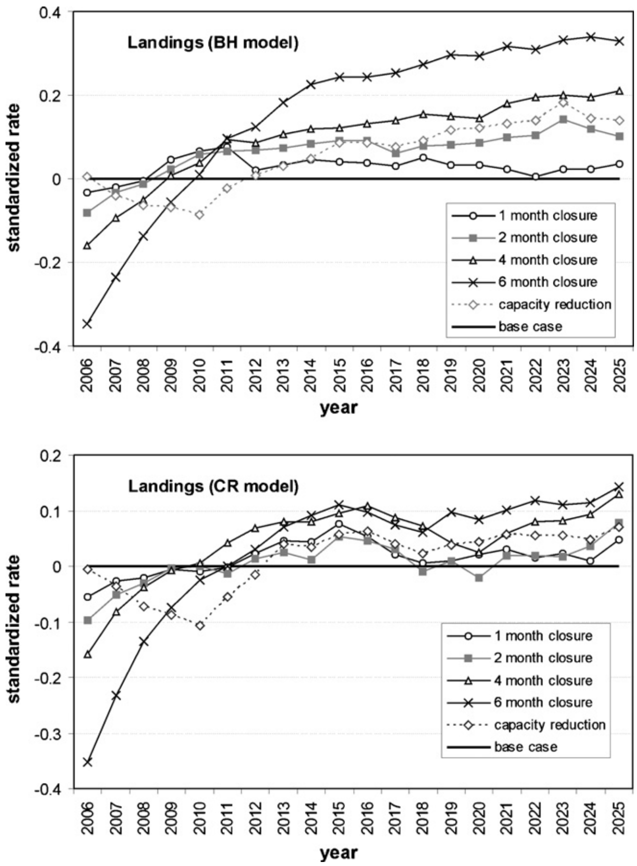

Fig. 4. Standardized estimates of landings by year and management scenario. BH = Beverton–Holt, CR = constant recruitment.

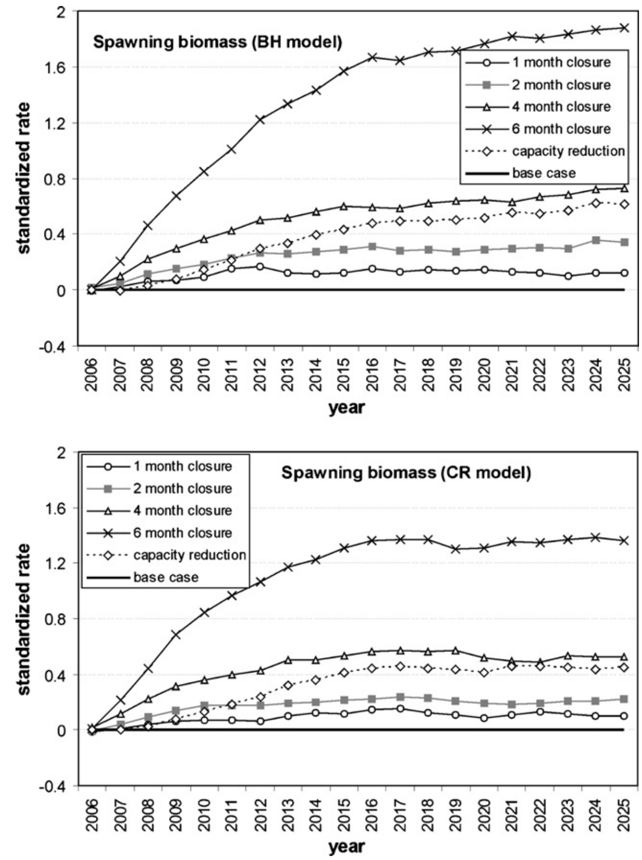

Fig. 5. Standardized estimates of spawning stock biomass (SSB) by year and management scenario. BH = Beverton–Holt, CR = constant recruitment.

benefit in increased recruitment is seen as the population size increases.

Regarding SSB, it is clear that the longer the closure the more beneficial it is in the long-term, with the six-month closure resulting in 140–180% (depending on the recruitment assumption) higher SSB in relation to the base case (Fig. 5). Significant increases (over 40%) are also expected from the four-month closure and the capacity reduction scenarios.

Initially all closure scenarios result in landings, gross and net revenues lower than those of the base case (Figs. 4, 6 and 7). The biggest initial reduction is seen for landings while for net revenues after about a year revenues are greater than the base case. Base case values are surpassed after some years (earlier in scenarios of smaller closure) and reach higher relative values, especially in the four- and six-month closure scenarios. Predicted gross revenue from the effort reduction scenario is similar to the two-month closure scenario, while net revenue is relatively higher but still lower than the four month one (Figs. 6 and 7).

Extended closures, such as the six month one, result in important initial losses in annual landings, with reference to the base case. In the first year, in particular, such losses reach up to 4500 t (Fig. 8). The respective net revenues, however, show less significant decreases and approach the base case rates within a year.

4. Discussion

The use of the open-source FLR framework to conduct a bio-economic analysis allowed us to simulate the effects of a series of management measures that have been repeatedly discussed in various management bodies but never fully evaluated nor implemented. Apart from the biological implications it was also possible to evaluate for the first time the economic implications of the different measures. The FLR framework offers great flexibility and could be easily adapted to simulate other management actions, if desirable. It has already been used for assessing stocks and evaluating management plans for various stocks in the Atlantic (Michielsens et al., 2006; Catchpole et al., 2007; Ulrich et al., 2007; Pilling et al., 2008), but, to the best of our knowledge, it is the first time it is used for the evaluation of technical measures in the Mediterranean.

In the present work we focused on the evaluation of temporal fishery closures, a technical measure that has been already applied in certain national fisheries and its potential applicability on a Mediterranean-wide level has been repeatedly discussed within ICCAT (Di Natale et al., 2002; Anon., 2008a). Taking into account the low size selectivity of the fishing gears used, application of other technical measures, such as MLS regulations, has proved to be impractical in most situations (Anon., 2008b). Additionally, area closures cannot be justified, as information on swordfish essential habitats (e.g. spawning areas) is limited to a few studies (Rey, 1988; Cavallaro et al., 1991; Tserpes et al., 2001) that do not permit evaluation of such a measure.

Management of the Mediterranean swordfish stock through temporal fishery closures is in line with the general practice followed in the Mediterranean, whereas marine stocks are traditionally managed through technical measures and/or control effort regimes. Quota systems, with the exception of the bluefin tuna fisheries, are not adopted as their successful enforcement is questionable due to the multispecies nature of most fisheries and the lack of sufficient infrastructure for monitoring and control (Caddy, 1993; Papaconstantinou and Farrugio, 2000). The high amount of bluefin tuna catch misreporting (Anon., 2008c) confirms the problems regarding quota implementation.

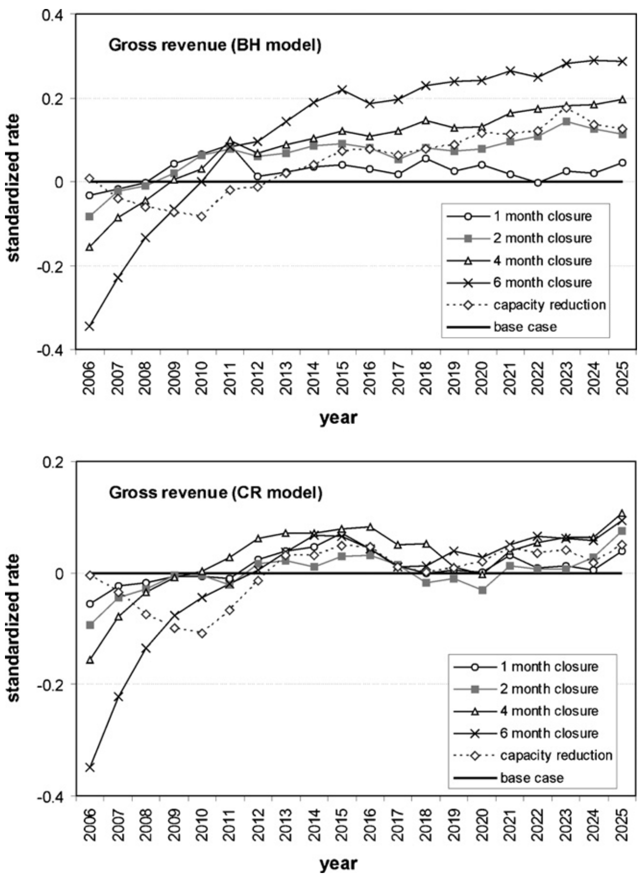

Fig. 6. Standardized estimates of gross revenue by year and management scenario. BH = Beverton–Holt, CR = constant recruitment.

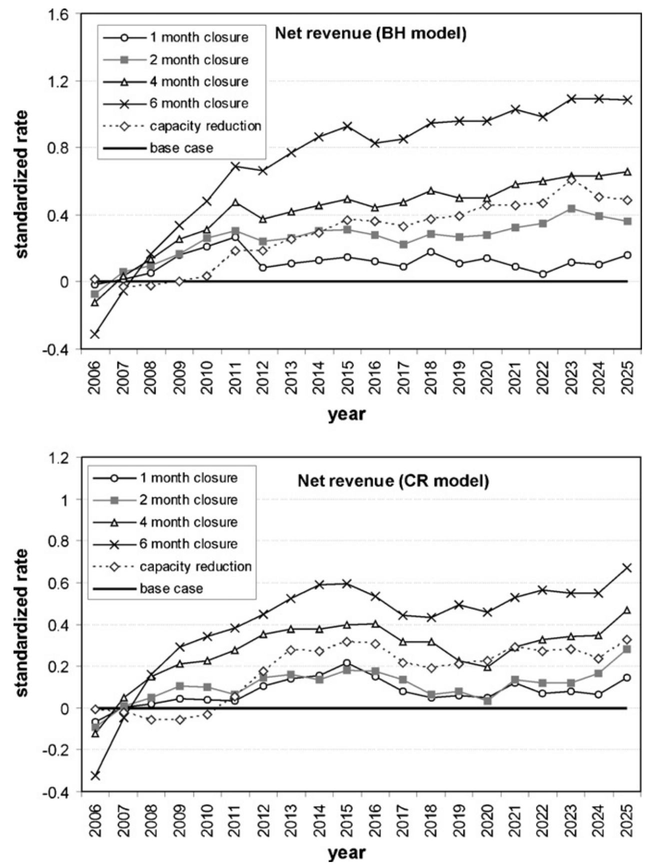

Fig. 7. Standardized estimates of net revenue by year and management scenario. BH = Beverton–Holt, CR = constant recruitment.

Our results suggested that seasonal closures of at least four months would result in significant (>40%) long-term increases in SSB. In the case of the six-month closure in particular, SSB will attain by the end of the examined period levels corresponding to maximum sustainable yield (MSY) as estimated from the most recent age-based ICCAT assessment. It should be noted that a biomass dynamic model assessment based on a longer time series of data suggested much lower optimum levels regarding SSB. The quality, however, of the longer data series is questionable (Anon., 2008a); hence we based our comments about the success of each management measure on the age-based SSB threshold estimates. Similar findings, regarding SSB have also been reported from previous simulations carried out by ICCAT (Anon., 2008a). Such closures will also result in important (20–100%) long-term increases in the net revenue. Long-term gains in landings and gross revenue will be less profound, ranging from 12 to 20% and 15 to 30% in the case of the four- and six-month closures respectively. Certainly, those estimates on landing gains are based on the assumption that resource availability to the different fishing gears will remain constant, i.e. no changes in gear catchability. Closures that largely cover the recruitment period will improve the exploitation pattern by reducing the proportion of juveniles in the catches. Relatively high catches of juveniles seem, however, to be an old practice in the Mediterranean swordfish fisheries as relevant observations are dated back to the 19th century (Goode, 1883). This indicates an increased availability of juveniles in the surface gears which might imply that recruitment rates, in terms of abundance per surface unit, are higher in the Mediterranean in comparison to other marine regions.

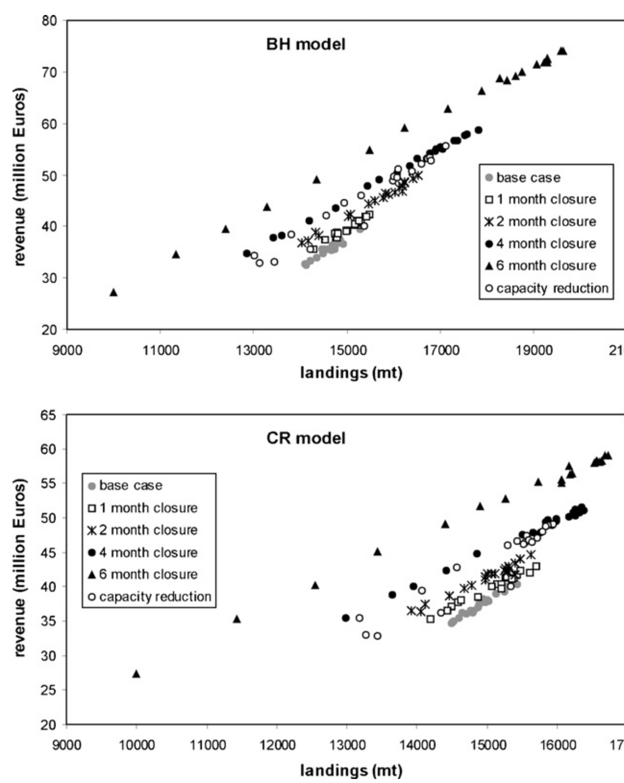

Fig. 8. Plots of median annual estimates of landings versus net revenues for the examined scenarios.

Although fisheries closures will result in short-term decreases in both, landings and net revenues, such decreases do not follow the same pattern over time. For instance, landing decreases from the implementation of a six-month closure will be up to 35% in the first year, with reference to those expected from the base case scenario. They will, however, attain the current levels after five to six years. On the other hand, decreases in net revenue will be equally high in the first year but they will return to the current levels much faster (within one to two years). In any case, taking into account that several swordfish fleets cannot easily switch to other fishing activities, such decreases should be considered before any measure is applied.

Relatively short fishery closures as the one month examined under scenario 2 will result in negligible gains (<10%) in all parameters. Considering the estimated statistical uncertainty (Figs. 2 and 3), it is unlikely that such gains will be observable. Based on this, it can be concluded that the recently established one-month closure for only one year will not produce any traceable results.

Simulations revealed that in the case of the effort reduction scenario landings, SSB, gross and net revenue will attain levels between the two- and the four-month closure scenarios. It is likely that the positive effects of an effort reduction scheme will be enhanced if it is combined with a seasonal fishery closure scheme.

The models assuming CR provided more conservative estimates than the BH S/R, as they do not allow SSB to increase up to the carrying capacity limits. Although, the available data do not allow reliable estimates of any stock–recruitment relationship due to the low variation of the past recruitment rates (Anon., 2008a), the assumption of recruitment completely independent of spawning stock size lacks biological basis and makes impossible to predict any stock collapse due to intensive fishing. In our scenarios we included CR assumptions, similarly to past projections carried out for the North Atlantic swordfish stock (Anon., 2007), but we also considered useful to incorporate additional projections assuming a stock–recruitment model even if it is empirically fitted. Although it is clear that the CR assumption cannot be valid under all circumstances, more data are needed to justify a robust stock–recruitment model.

Economic evaluations were based only on data from the Greek and Italian longline fleets, which, however, account for about 50% of the total Mediterranean production and 60–70% of the corresponding longline one. Taking into account the globalization of the markets and the fact that fishing is carried in the same way throughout the Mediterranean, it can be safely speculated that our findings would be, at least to a certain extent, valid for the remaining longline fleets. Such a conclusion is also supported by the fact that differences in the basic input parameters among the examined fleets were negligible. The current study assumes that costs and market prices will remain constant over the examined period, which is rather unlikely, especially considering the increases in oil price and other associated costs. In that sense, our estimates regarding the absolute value of gross and net revenues are only indicative. In case, however, of stable unitary cost of production (constant cost/fish price ratio) the net revenues will be at the current level.

Acknowledgements

This study has been carried out with the financial assistance of the European Commission in the frames of the STREP Project "EFIMAS" (Contract No. SSP8-CT-2003-502516). We wish to thank Paolo Accadia from CEMARE for his help with the preparation of the software routines concerning economic evaluations. We would also like to thank two anonymous reviewers for their valuable comments.

References

Anon., 2007. Report of the 2006 Atlantic swordfish stock assessment session. ICCAT Col. Vol. Sci. Pap. 60, 1787–1896.

Anon., 2008a. 2007 Mediterranean swordfish stock assessment session. ICCAT Col. Vol. Sci. Pap. 62, 951–1038.

Anon., 2008b. Mediterranean swordfish. ICCAT Report for Biennial Period, 2006–07, pp. 147–154.

Anon., 2008c. Bluefin tuna—East. ICCAT Report for Biennial Period, 2006–07, pp. 112–121.

Catchpole, T.L., Tidd, A.N., Kell, L.T., Revill, A.S., Dunlin, G., 2007. The potential for new Nephrops trawl designs to positively effect North Sea stocks of cod, haddock and whiting. Fish. Res. 86, 262–267.

Cavallaro, G., Potoschi, A., Cefali, A., 1991. Fertility gonad-somatic index and catches of eggs and larvae of *Xiphias gladius* L. 1758 in the southern Tyrrhenian Sea. ICCAT Col. Vol. Sci. Pap. 35, 502–507.

Caddy, J., 1993. Some future perspectives for assessment and management of Mediterranean fisheries. Sci. Mar. 57, 121–130.

Di Natale, A., De La Serna, J.M., De Metrio, G., Restrepo, V., Srour, A., Tserpes, G., 2002. On the reduction of juvenile swordfish catches in the Mediterranean. ICCAT Col. Vol. Sci. Pap. 54, 1529–1533.

Ehrhardt, N.M., 1992. Age and growth of swordfish, *Xiphias gladius,* in the northwestern Atlantic. B. Mar. Sci. 50, 292–301.

Goode, G.B., 1883. Report U.S. Commission of Fish and Fisheries (1880), pp. 326–329.

Hilborn, R., Walters, C.J., 1992. Quantitative Fisheries Stock Assessment. Chapman and Hall, London.

Kell, L.T., Mosqueira, L., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., Scott, F., Scott, R.D., 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES J. Mar. Sci. 64, 640–646.

Kotoulas, G., Magoulas, A., Tsimenides, N., Zouros, E., 1995. Marked mitochondrial DNA differences between Mediterranean and Atlantic populations of the swordfish, *Xiphias gladius*. Mol. Ecol. 4, 473–481.

Kotoulas, G., Mejuto, J., Tserpes, G., Garcia-Cortes, B., Peristeraki, P., De la Serna, J.M., Magoulas, A., 2003. DNA microsatellite markers in service of swordfish stock structure analysis in the Atlantic and Mediterranean. ICCAT Col. Vol. Sci. Pap. 55, 1632–1639.

Michielsens, C.G.J., McAllister, M.K., Kuikka, S., Pakarinen, T., Karlsson, L., Romakkaniemi, A., Perä, I., Mäntyniemi, S., 2006. A Bayesian state-space mark-recapture model to estimate exploitation rates in mixed-stock fisheries. Can. J. Fish. Aquat. Sci. 63 (2), 321–334.

Palko, R.J., Beardsley, G.L., Richards, W.J., 1981. Synopsis of the biology of the swordfish *Xiphias gladius* L. NOAA Tech. Rep. NMFS Circ., 441.

Papaconstantinou, C., Farrugio, H., 2000. Fisheries in the Mediterranean. Medit. Mar. Sci. 1, 5–18.

Pilling, G.M., Kell, L.T., Hutton, T., Bromley, P.J., Tidd, A.N., Bolle, L.J., 2008. Can economic and biological management objectives be achieved by the use of MSY-based reference points? A North Sea plaice (*Pleuronectes platessa*) and sole (*Solea solea*) case study. ICES J. Mar. Sci. 65, 1069–1080.

Rey, J.C., 1988. Comentarios sobre las areas de reproduccion del pez espada (*Xiphias gladius*) en el Atlantico y Mediterraneo. ICCAT Col. Vol. Sci. Pap. 27, 180–192.

Shepherd, J.G., 1999. Extended survivors analysis: an improved method for the analysis of catch-at-age data and abundance indices. ICES J. Mar. Sci. 56, 584–591.

Tserpes, G., Peristeraki, P., Somarakis, S., 2001. On the reproduction of swordfish (*Xiphias gladius* L.) in the eastern Mediterranean. ICCAT Col. Vol. Sci. Pap. 52, 740–744.

Tserpes, G., Tsimenides, N., 1995. Determination of age and growth of swordfish *Xiphias gladius* L., 1758, in the eastern Mediterranean using anal-fin spines. Fish. Bull. 93, 594–602.

Tserpes, G., Peristeraki, P., 2007. Effects of a seasonal closure of the Mediterranean swordfish fisheries on the stock production levels. ICCAT Col. Vol. Sci. Pap. 60, 2059–2062.

Ulrich, C., Andersen, B.S., Sparre, P.J., Nielsen, J.R., 2007. TEMAS: fleet-based bio-economic simulation software to evaluate management strategies accounting for fleet behaviour. ICES J. Mar. Sci. 64, 647–651.