INCLUSION OF STOCK REPRODUCTIVE POTENTIAL IN THE EVALUATION OF MANAGEMENT SCENARIOS FOR MEDITERRANEAN SWORDFISH

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SUMMARY

In the present work a series of management strategy evaluations for the Mediterranean swordfish were examined considering two different approaches regarding recruitment dependency. The management scenarios that were evaluated (including seasonal closures, capacity reduction and selectivity modification) assumed either a Beverton-Holt stock recruitment relationship or a TEP-recruitment formulated relationship. The TEP approach results were relatively similar to those obtained through the use of the conventional stock-recruitment model, with the greater differences (the Beverton-Holt stock-recruitment model providing estimates higher by 6.5%) appearing in the selectivity modification scenario. The latter suggest that the TEP approach should not be ignored in case that the age structure of the stock is altered due to changes in the selection pattern of a fishery.

RÉSUMÉ

Dans ce document, plusieurs évaluations de stratégie de gestion s'appliquant à l'espadon de la Méditerranée ont été examinées en prenant en considération deux différentes approches relatives à la dépendance du recrutement. Les scénarios de gestion qui ont été évalués (dont les fermetures saisonnières, la réduction de la capacité et la modification de la sélectivité) postulaient une relation stock-recrutement de Beverton-Holt ou une relation stock-recrutement TEP. Les résultats de l'approche TEP étaient relativement semblables à ceux obtenus par le biais de l'utilisation du modèle conventionnel de stock-recrutement, avec des différences plus importantes (le modèle stock-recrutement de Beverton-Holt fournissait des estimations supérieures de 6,5 %) apparaissant dans le scénario de modification de la sélectivité. Ce scénario donne à penser que l'approche TEP ne devrait pas être ignorée si la structure des âges du stock est altérée en raison de changements dans le schéma de sélection d'une pêcherie.

RESUMEN

En este documento se examina una serie de evaluaciones de estrategias de ordenación para el pez espada del Mediterráneo considerando dos enfoques diferentes respecto a la dependencia del reclutamiento. Los escenarios de ordenación que fueron evaluados (lo que incluye vedas estacionales, reducción de capacidad y modificación de la selectividad) asumían una relación de stock reclutamiento de Beverton-Holt o una relación de reclutamiento TEP. Los resultados del enfoque TEP eran relativamente similares a los obtenidos mediante el uso del modelo stock-reclutamiento convencional, y las mayores diferencias (el modelo stock-reclutamiento de Beverton-Holt proporciona estimaciones superiores en un 6,5%) aparecen en el escenario de modificación de la selectividad. Este último sugiere que el enfoque TEP no debería ser ignorado en el caso de que la estructura de edad del stock se vea alterada debido a cambios en el patrón de selección de una pesquería.

KEYWORDS

Swordfish, Simulation, Spawning, Gear selectivity, Season regulations

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1. Introduction

The establishment of a relationship between stock and recruitment is of outmost importance for the assessment of fisheries resources (Hilborn and Walters 1992). The relationships of Ricker (1954) and Beverton and Holt (1957) are those with the widest acceptance for that purpose. One of the simplifying assumptions of the stock-recruitment relationship is the proportionality between spawning stock biomass and total egg production-TEP (Ricker 1954, Beverton and Holt 1957). However, a number of authors have questioned the validity of this proportionality (e.g. Trippel et al. 1997, Marshall et al. 1998, Cardinale and Arrhenius 2000, Marshall 2009).

Instead of the usage of the classic stock-recruitment relationship, the direct inclusion of TEP in assessments could provide significant benefits. Those benefits range from the improvement/reformulation of the stock-recruitment relationship, the accounting for maternal effects, the incorporation in the model of the importance of the big individuals for the stock (Birkeland and Dayton 2005) as well as the possibility to reduce uncertainty in the estimates of recruitment (Marshall 2009).

In the present study we use a TEP-recruitment relationship in management strategy evaluation for the Mediterranean swordfish and compare findings with those coming by the use of a classical Beverton-Holt stock-recruitment relationship.

2. Materials and methods

For the analysis, stock number at age estimates for the Mediterranean swordfish were used. The data were obtained from the latest ICCAT assessment (Anonymous 2008). In order to calculate the number of females at age a relationship between sex ratio and age was needed. An exponential relationship was estimated between sex-ratio and age, assuming that the sex ratio at age 3 is 0.5 and that sex-ratio at age 10 is 0.9 (unpublished data). Thus the parameters of the relationship: sex ratio=a_1*e^(age*b_1) were estimated to be: a_1=0.3887, b_1=0.084. Consequently the number of females at age for the years 1985-2005 was estimated. At a subsequent step, a fecundity of 0 was assumed for females of ages 0 to 2, a fecundity of 0.5 was assumed for females of age 3 and females of 4-years or higher ages were assumed to be fully fecund (fecundity=1) in order to calculate the number of fecund females at age (unpublished data).

The equation: Fecundity=7.01218E-03*LJFL^3.994 that relates fecundity, expressed in terms of number of eggs, to lower jaw fork length for the western Mediterranean swordfish was used (de la Serna et al. 1996). Based on the above equation and the length-at-age estimates deriving from the swordfish growth model adopted in ICCAT (Tserpes and Tsimenides 1995) values for the mean fecundity at age were calculated. As a consequence, the number of eggs produced by each age-group of females per year was estimated and its yearly sum provided the TEP by year.

The parameters a and b of the relationship between recruitment and TEP of the type r=a*TEP/(b+TEP) were estimated empirically (Hilborn and Walters 1992) making the following assumptions: (a) half of the 2005 TEP will produce about half of the maximum recruitment and (b) the 2005 recruitment is 70% of the maximum, similar to the estimation of a typical Beverton-Holt stock-recruitment relationship from the same dataset (Tserpes et al. 2009). The parameters were estimated to be: a= 1530823.456, b= 5.07447E+11.

The simulations included management scenario evaluations similar to those presented in (Tserpes et al. 2009): they included (a) a current exploitation scenario with no Mediterranean-scale fisheries closures, (b) a one-month closure of the fishery in the peak of the swordfish recruitment period, a similar (c) two-month and (d) four month closure and a (e) six months closure including the entire recruitment period, (f) a gradual reduction of the global capacity by 5% yearly in the first four years of the simulation combined with a one-month closure, (g) a new scenario of modification of the gear selectivity (e.g. by an increase in hook size). In the scenario of selectivity modification (g), the old selectivity pattern of the ages 0 to 5 (full selection at age-3) was transferred to the ages 1 to 6 (the selectivity of age 0 was kept constant) and a gradual decrease from age 7 to age 10 by 2% was employed (**Figure 1**). Details on the parameters and calculations of the scenarios (a-f) can be found in Tserpes et al. (2009). For each scenario 100 simulations were performed using a classic Beverton-Holt stock-recruitment model and another 100 simulations were carried out using the Total Egg Production-recruitment model developed in order to compare the results of the two approaches. The simulations projected for 20 years. Similarly to the previous study, the simulations included estimations on landings, spawning stock biomass, gross and net revenue.

3. Results

The results of the different management scenarios concerning landings, spawning stock biomass, gross and net revenue were in general similar, either using the Beverton-Holt stock-recruitment or the Total Egg Production-recruitment models (**Figure 2**-only the spawning stock biomass is presented). The confidence intervals (not presented in the figure for clarity) indicate no significant differences between the two ("classic" stock-recruitment relationship and TEP-formulated relationship) approaches. At most, the estimation medians differed by 6.5% (in the selectivity modification simulations) in the 10 final years of stabilization.

While in the fishery closure scenarios at the last years of the simulation the medians of the estimations are relatively higher in the TEP models, the contrary is found for the effort reduction and selectivity modification models.

4. Discussion

The results of the present work were in agreement with the findings of a previous study (Tserpes et al. 2009). The similar results of the two studies were not surprising: The TEP showed a strong linear relationship to the spawning stock number-SSN (**Figure 3**). This indicates proportionality between TEP and SSN as is the case in the relationship formulated by Beverton and Holt (1957). This finding indicated that the construction of a TEP-recruitment relationship would give similar results to that of a classic stock-recruitment relationship. However the case could have been that in ranges of SSN other than those for which data on the Mediterranean swordfish exist, the relationship between the two parameters is different. The same could be valid for a different age structure than that currently existing. Consequently it was considered necessary to carry out the simulations using instead of a stock-recruitment relationship a TEP-recruitment relationship in order to see the response of the stock related variables to the metric of egg production instead of stock size.

Poisson and Fauvel (2009) working on the reproductive biology of swordfish in the Indian Ocean underline the importance of older/larger females in the reproductive capacity of the stock. In our study, the selectivity modification scenario simulates a management leading to the fishing of larger individuals. In this scenario the TEP model, that incorporates reproductive stock size/age structure, provided lower median estimations than the classic model, being in agreement with the above finding, however the estimations did not differ spectacularly. If the TEP approach is correct, this finding could indicate that the Mediterranean swordfish fishery is luckily a juvenile-targeting one, since the removal of the terminal-sizes/ages could significantly have reduced the reproductive capacity of the stock.

The relatively lower estimations of the TEP model in the selectivity modification scenario could be attributed to the relatively increased selection of the oldest (and more fecund) ages. Nevertheless, even in the selectivity modification scenario, the fishery remains far from being in "longevity overfishing" (Marshall 2009) that could have provided spectacular differences among the two models due to a significant decrease in the stock reproductive potential. In such cases where the selection pattern of the fishery has substantially changed, thus modifying the stock age structure, the use of a TEP-oriented approach could be beneficial.

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References

Anon. 2008, 2007 Mediterranean Swordfish Stock Assessment Session. Collect. Vol. Sci. Pap. ICCAT, 62(4): 951-1038.

Beverton, R.J.H. and Holt, S.J. 1957, On the dynamics of exploited fish populations. Fisheries Investigation Series II, Marine Fisheries. Ministry of Agriculture, Fisheries and Food, UK. 19.

Birkeland, C. and Dayton, P.K. 2005, The importance in fishery management of leaving the big ones. Trends in Ecology and Evolution 20 (7): 356-358.

Cardinale, M. and Arrhenius, F. 2000, The relationship between stock and recruitment: are the assumptions valid? Marine Ecology Progress Series, 196: 305-309.

De la Serna, J.M., Ortiz de Urbina, J.M. and Macias, D. 1996, Observations on sex-ratio, maturity and fecundity by length-class for swordfish (*Xiphias gladius*) captured with surface longline in the western Mediterranean. Collect. Vol. Sci. Pap. ICCAT, 45(1): 115-139.

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

Marshall, C.T. 2009, Implementing Information on Stock Reproductive Potential in Fisheries Management: The Motivation, Challenges and Opportunities. *In* Jakobsen, T., Fogarty, M., Megrey, B.A., Moksnes, E. (Eds) Fish Reproductive Biology, implications for assessment and management, Wiley-Blackwell, pp. 395-422.

Marshall, C.T., Kjesbu, O.S., Yaragina, N.A., Solemdal, P. and Ulltang, Ø. 1998, Is spawner biomass a sensitive measure of the reproduction and recruitment potential of Northeast Arctic cod? Can. J. Fish. Aquat. Sci. 55: 1766-1783.

Poisson, F. and Fauvel, C. 2009, Reproductive dynamics of swordfish (*Xiphias gladius*) in the southwestern Indian Ocean (Reunion Island). Part 2: fecundity and spawning pattern. Aquat. Living Resour. 22: 59-68.

Ricker, W.E., 1954, Stock and recruitment. J. Fish. Res. Board Can. 11: 559-623.

Trippel, E.A., Kjesbu, O.S. and Solemdal, P. 1997, Effects of adult age and size structure on reproductive output in marine fishes. *In* Chambers, R.C., Trippel, E.A. (Eds) Early Life History and Recruitment in Fish Populations, Chapman and Hall. pp. 31-62.

Tserpes, G. and 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., Tzanatos, E., Peristeraki, P., Placenti, V. and Kell, L. 2009, A bio-economic evaluation of different management measures for the Mediterranean swordfish. Fish. Res. 96: 160-166.

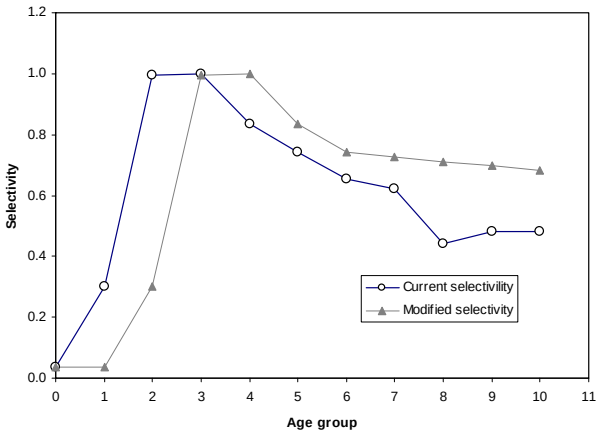


Figure 1. The selectivity pattern (by swordfish age) used in the simulation scenarios. Current selectivity is the pattern used in the scenarios of fishery closures and capacity reduction, i.e. scenarios (a-f) (see text). Modified selectivity is the selectivity pattern used in the scenario (g).

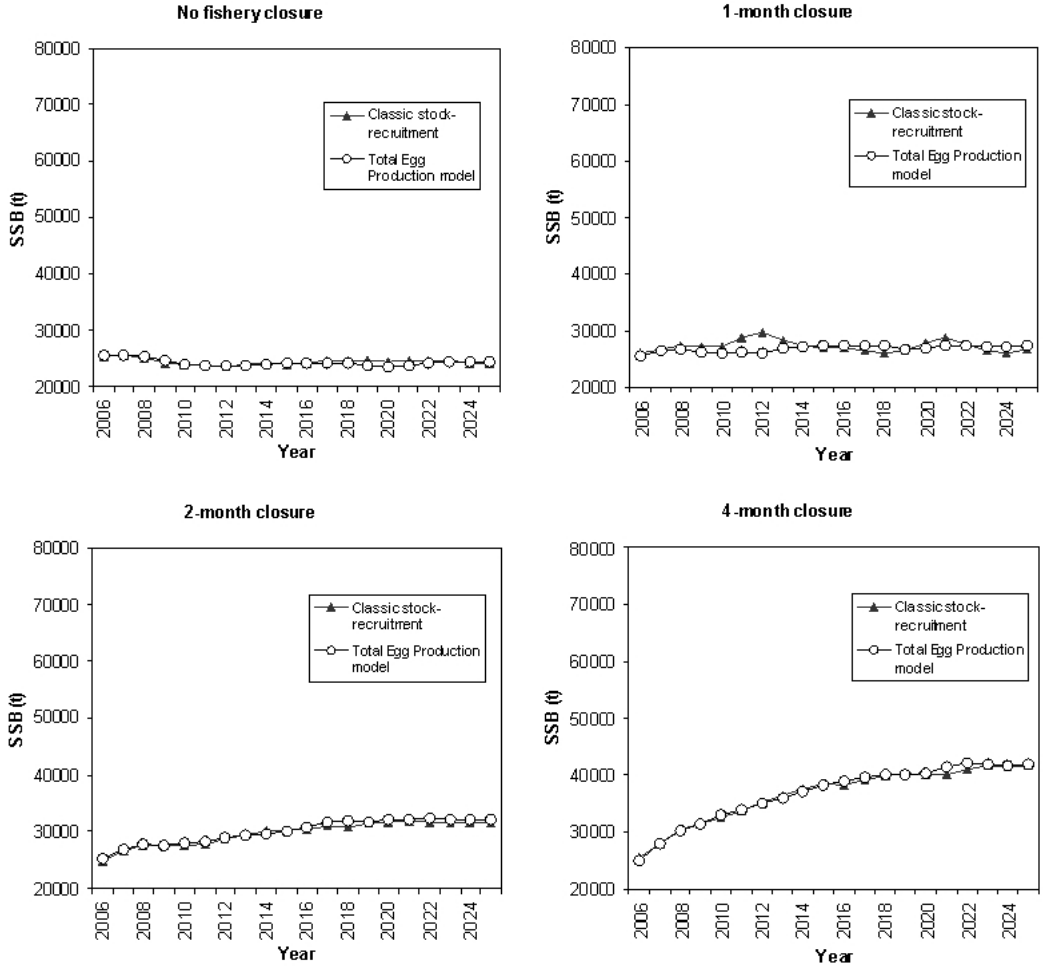
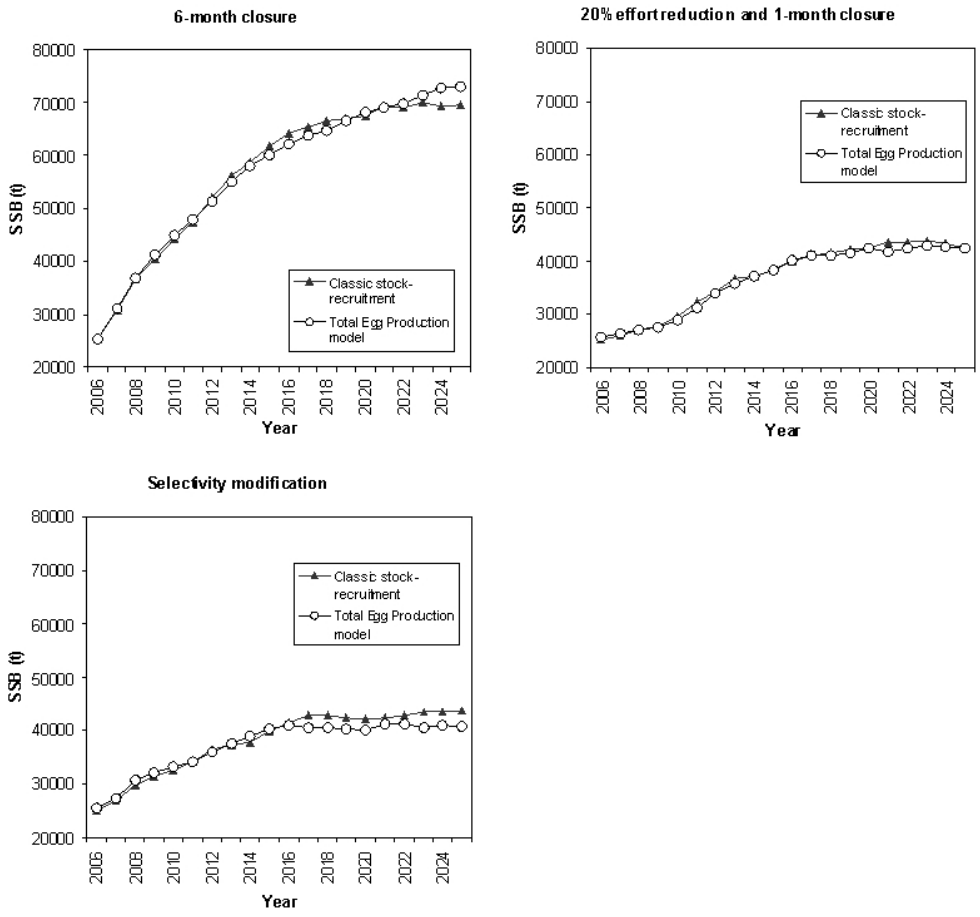


Figure 2. (continues to next page/…) Medians of the 100 simulations for the classic stock-recruitment model simulations (filled triangles) and the Total Egg Production model simulations (open circles) for the 20 years simulated for each management strategy evaluation scenario.



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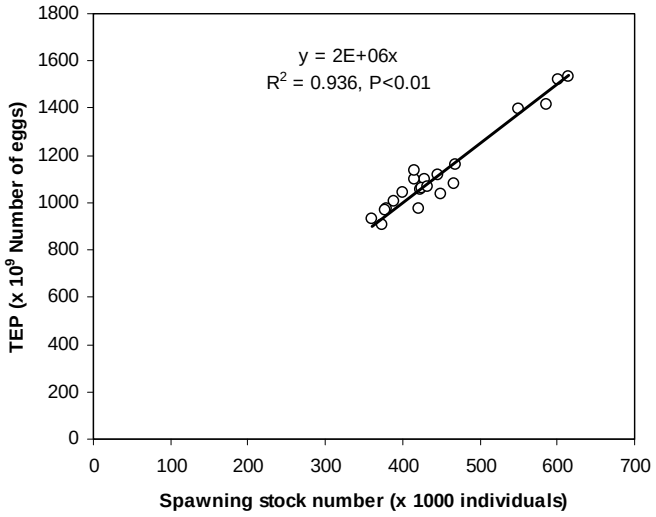

Figure 3. Regression of Total Egg Production (number of eggs) on stock number (number of individuals).