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THE KEY IMPORTANCE OF THE UNDERLYING STOCK-RECRUITMENT ASSUMPTION WHEN EVALUATING THE POTENTIAL OF MANAGEMENT REGULATIONS OF ATLANTIC BLUEFIN TUNA

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SUMMARY

The aim of this study is to investigate the implications of different stock-recruitment assumptions when examining the potential of Dubrovnik's bluefin tuna recovery plan. To do so, some Beverton and Holt relationships displaying contrasting steepness of 0.99, 0.90, 0.75 and 0.50 were applied within a simulation model. In addition to these four stock-recruitment scenarios, parental effects and stochastic variations were also considered. The main conclusion is that our ability to evaluate the consequences of the Dubrovnik agreement (as any set of management measures) relies on our capacity to predict future recruitment levels in an accurate way. Assuming a Beverton and Holt relationship with different steepness, with or without parental effects and with or without stochastic variations led to contrasting outputs, i.e. from a significant rebuilding of the simulated population within 15 years to the crash of this same simulated population. This outcome is somewhat problematic, as we are unable to properly estimate the stock-recruitment relationship for the East Atlantic and Mediterranean bluefin tuna stock. Consequently, it is crucial to clearly state recruitment assumptions when an advice is given and to consider a significant range of contrasting and realistic stock-recruitment relationships.

RÉSUMÉ

L'objectif de ce manuscrit est d'étudier les implications de différents scénarios de recrutement lors de l'analyse du potentiel du plan de rétablissement du thon rouge de Dubrovnik. Pour ce faire, des relations de Beverton et Holt présentant des pentes différentes de 0,99, 0,90, 0,75 et 0,50 ont été utilisées au sein d'un modèle de simulation. A coté des quatre relations stock-recrutement, des effets parentaux et des variations stochastiques ont été également considérés. La principale conclusion est que notre faculté à évaluer les conséquences des accords de Dubrovnik (comme de toutes mesures de gestion) dépend étroitement de notre capacité à prédire les futurs niveaux de recrutement de manière fiable. En effet, considérer une relation de Beverton et Holt avec différentes pentes, avec ou sans effets parentaux, et, avec ou sans variations stochastiques, conduit à des résultats très différents, c'est-à-dire d'un rétablissement significatif de la biomasse féconde simulée en 15 ans à l'effondrement de cette même biomasse simulée. Ce résultat est quelque peu problématique du fait que nous sommes incapables d'estimer proprement la relation stock-recrutement pour le stock de thon rouge de l'Atlantique Est et de la Méditerranée. Il est donc crucial d'énoncer clairement le postulat fait sur le recrutement lorsque qu'un avis est donné et de considérer une large palette de relations stock-recrutement.

RESUMEN

El objetivo de este documento es estudiar las implicaciones de los diferentes escenarios de reclutamiento al examinar el potencial del plan de recuperación de atún rojo de Dubrovnik. Para ello, se utilizaron relaciones de Beverton y Holt con inclinaciones diferentes de 0,99; 0,90; 0,75 y 0,50 en un modelo de simulación. Además de estas cuatro relaciones stock-reclutamiento, se consideraron efectos parentales y variaciones estocásticas. La conclusión principal es que nuestra capacidad para evaluar las consecuencias de los acuerdos de Dubrovnik (así como cualquier medida de ordenación) depende en gran medida de nuestra

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capacidad de predecir los niveles futuros de reclutamiento de un modo fiable. En efecto, considerar una relación de Beverton y Holt con diferentes inclinaciones, con o sin efectos parentales y con o sin variaciones estocásticas, da lugar a resultados muy diferentes, a saber, desde una recuperación significativa de la biomasa fecunda simulada en quince años hasta el colapso de esta misma biomasa simulada. Este resultado es en cierto modo problemático, ya que somos incapaces de estimar adecuadamente la relación stock –reclutamiento para el stock de atún rojo del Atlántico este y Mediterráneo. Por lo tanto, a la hora de facilitar asesoramiento es crucial que se formulen adecuadamente los supuestos sobre reclutamiento y que se considere una amplia gama de relaciones stock-reclutamiento diferentes y realistas.

KEYWORDS

Thunnus thynnus, management regulations, stock-recruitment, parental effects, stock rebuilding, simulation model

1. Introduction

The 15 years recovery plan for the East Atlantic and Mediterranean bluefin tuna stock adopted in 2006 in Dubrovnik includes multiple elements related to monitoring, control and surveillance (see Rec. [06-05]). In terms of conservation, the plan is built around three major rules:

1) A Total Allowable Catches (TAC) of 29,500; 28,500; 27,500 and 25,500 tonnes/year for 2007, 2008, 2009 and 2010, respectively.

2) An extended closed fishing season: (i) from the 01 June to 31 December for large longliners over the whole area except the area delimited by West of 10°W and North of 42°N, (ii) from the 01 July to 31 December for purse seiners over the whole area and (iii) from 15 November to 15 May for baitboat and pelagic trawlers over the whole area.

3) A minimum size being extended to 30 kg (with a tolerance of 8 % on the by-catch of fish less than 30 kg and no less than 10 kg), with the exception of baitboat and pelagic trawlers catches in the East Atlantic and catches for farming purposes in the Adriatic Sea for which the minimum size is set at 8kg.

This plan is obviously a significant step towards the regulation of bluefin tuna fisheries in the East Atlantic and Mediterranean, but it differs substantially from the SCRS advice given in 2006 (Anon., 2007). Therefore, the potential of the 2006 recovery plan has been investigated in 2007 through simulation modelling (see Fromentin 2008; Anon., 2008). The former study concluded that the new regulations adopted in Dubrovnik in 2006 may be sufficient to rebuild the SSB to a level > 20% of the virgin SSB, if and only if they are perfectly implemented and without any increase in fishing effort on older fish. However, any significant increase in fishing mortality on older fish due to a partial redeployment of the fishing fleets as well as any implementation errors (as those recorded in 2007 which led to higher total catches than the TAC) would seriously impair the rebuilding. The latter study concluded to even more pessimistic conclusions and indicated that the current measures are unlikely to fully fulfill the objective of the plan to rebuild to the MSY level in 15 years with 50% probability. Differences between both studies and between scenarios within the bluefin tuna species group's study actually mostly rely on the stock-recruitment assumption made in the different simulation models.

The aim of this study is thus to investigate more deeply the implications of different stock-recruitment assumptions when examining the potential of Dubrovnik's recovery plan, including new features such as the parental effects.

2. The simulation model

The simulation model is based on a framework previously developed by Fromentin (2008). The main life history traits of bluefin tuna are stated as follows: yearly spawning (1 cohort per year), life span of 20 years, 50%

maturity at 4 years (100% at 5+). The natural mortality vector, the age-length and weight relationships are based on values/equations adopted by the SCRS Bluefin Tuna Working Group (Anon., 1999, Anon., 2003, Anon., 2007).

The outputs of SSB and recruitment (number of fish at age 1) from the ADAPT-VPA runs made by the SCRS in 2006 (Anon., 2007) led to an unclear (fuzzy) pattern (as it was already the case in the past, see Figure 1). A Beverton and Holt relationship (BHR) cannot be fitted to such data unless a parameter is fixed by the operator. Consequently, to close the life cycle of the simulated population, four "theoretical" BHRs displaying contrasting steepness, i.e. a steepness of 0.99, 0.90, 0.75 and 0.50, respectively, have been considered (**Figure 1**). Doing so, the model included a rather large spectrum of resistance of the stock to exploitation (i.e. to recruitment overfishing), from low resistance (i.e. steepness about 0.50) to very high (steepness of 0.99, note that in this case recruitment is almost independent from SSB). However, the intermediate values of 0.75 and 0.90 probably make greater biological sense than these two extremes (Fromentin and Kell, 2007).

In addition to these four stock-recruitment scenarios, we also considered that bluefin tuna population may, as most longlive species, exhibit parental effects, i.e the fact that older females older females produce larvae and offsprings that have much higher survival and growth than do younger adults (see e.g. Berkeley *et al.*, 2004b, Birkeland and Dayton, 2005, Cardinale and Arrhenius, 2000, Fromentin, 2006). To quantify such a process in a simple manner, the SSB has been computed as such:

$$SSB= 0.2*sum(ages\ 4\text{-}8)+0.8*sum(ages\ 9\text{-}14)+1.6*sum(ages\ 15+)$$

In other words, the SSB is a weighted sum depending on the age (while the standard SSB is simply the sum over all the ages), assuming that bluefin tuna of age 15+ contribute two times more to the SSB than bluefin tuna of ages 9 to 14 and 8 times more than a young adult of ages 4 to 8. This quantification remains highly speculative, but is partially based on the ranges given by Berkeley *et al.* (2004a). The SSB-recruitment form remains, however, similar as above, i.e. BHRs with 4 contrasting steepness.

The simulations were run over 122 years. At time t_0, the population is at a steady state, with a virgin spawning biomass (with or without parental effects) set arbitrarily at around 1 million tonnes. To reflect the long lasting bluefin tuna fishing that has taken place, the model has been then run over 70 years, assuming an *F* vector equal to the *Fs* of 1970 (the *F* estimates come from ADAPT VPA run 3 of the last stock assessment), then over 37 years that correspond to the 1970-2006 period (*F* estimates coming from the same ADAPT-VPA run to which two years have been added, i.e. 2005 and 2006, and set equal to the mean of the Fs over the 2001-2004 years). Finally, simulations were run over 15 years (that would represent 2007-2022 years) assuming the following scenarios:

1. *Fs* from 2007 to 2022 are equal to the mean of *Fs* of the 2001-2004 period, i.e. no implementation of the recent management rules.
2. Perfect implementation of the Dubrovnik agreement, without any report of fishing effort.

Simulations were operated using Matlab R2006a.

3. Results

Results over the historical period 1900-1970

The results of the simulated population are relative to the assumptions made on the choice of *F* in the historical period, M, growth, weight-at-age, etc. Other choices will have led to other absolute values. Therefore, the results must be interpreted in a relative manner. Given the growth equation, the weight-at-age matrix and M vector being used, 70 years of fishing set at the 1970 level led to a simulated SSB of about 33% of the virgin SSB in 1970.

Results over the recent past period 1971-2006

Additional 36 years of *Fs* similar to those estimated by ADAPT VPA between 1970 and 2006 drove the SSB to a very low level, about 1.5% to 4% of the virgin one, depending on the BHR being used. In all the simulations, the SSB remains at around 20% of the virgin biomass until the mid-1990s and then linearly decreased to low levels over the last decade (**Figure 2**). Simulated catches varied but stayed constant until 2005 while simulated yields reach a peak during the 1990s and then decreased regardless of higher Fs because of severe recruitment overfishing over the last decade (**Figure 2**). Implementing parental effects does not change the whole picture, but tends to accentuate the decline over the last years (because higher fishing pressure led to lower number of older fish).

Scenario 1: Assuming *Fs* equal to those from the early 2000s over the next 15 years (i.e. no implementation of the Dubrovnik agreement) led to the crash of the simulated population within a delay that depends on the stock recruitment relationship (**Figure 2**, note that this crash will have occurred later and even after 2022 if we would have assumed lower historical *Fs* or higher growth or different M). Using a BHR with a steepness of 0.99 led to a less pessimistic view and if the simulated population did not crash, the SSB is at a very low level by 2022 (**Figure 3**). Implementing parental effects did not change this whole picture.

Scenario 2: Assuming a perfect implementation of the recent regulations on minimum size (including 8% of by-catch between 10 and 30 kg fish) and time-area closures (without any report of the fishing effort) from the Dubrovnik agreement led to contrasting results depending on the stock-recruitment assumptions made. Assuming a BHR with a steepness of 0.75 and no parental effects led a slow rebuilding of the SSB, which remains however at very low level after 15 years (i.e. about 4% in 2022 against 2% in 2006, **Figure 4).** Assuming a BHR with a steepness of 0.50 did not lead to any rebuilding but simply maintained the SSB at around 1% of the virgin biomass. In contrast, assuming a BHR with a steepness of 0.99 led a significant rebuilding within 15 years (**Figure 5**). In that case, the SSB exceeded 17% of the virgin biomass and the yields even sharply increased after a drop of a few years.

However, if parental effects are implemented, the consequences of the Dubrovnik agreement can be significantly different. For instance, the rebuilding of the SSB can be seriously impaired. When an optimistic BHR (with a steepness of 0.99) is assumed, there is a rebuilding up to 13.5% of the virgin biomass, but when a BHR with a steepness of 0.50 is assumed, the Dubrovnik agreement is unable to reverse the decline of the SSB and to avoid the crash of the simulated population (**Figure 6**).

All the previous treatments have been performed within a deterministic approach (i.e. the recruitment was only determined by the level of the SSB). Adding stochastic variations in the recruitment (being Gamma distributed with mean and standard error equal to 1) to simulate varying environmental conditions can here again change considerably the outputs.

For instance, assuming a BHR with a steepness of 0.99 and no parental effects can lead to a strong and rapid rebuilding of the SSB within 15 years in some case (**Figure 7**) as well as to slower and weaker rebuilding (**Figure 8**).

4. Discussion and conclusion

The results of such a simple model must obviously be interpreted with great care as the absolute outputs are intrinsically related to the various assumptions made about the historical *F*, *M*, growth etc… Therefore, the results must be analyzed in a relative way, i.e. by comparing the different scenarios between each other and focusing on the trends.

However, this simulation study highlights one point very clearly: our ability to evaluate the consequences of the Dubrovnik agreement (as any set of management measures) relies on our capacity to predict future recruitment levels in an accurate way (in other words to have a trustworthy stock-recruitment relationship). Indeed, assuming a BHR with different steepness, with or without parental effects and with or without stochastic variations led to contrasting (and sometimes divergent) results. A perfect implementation of the Dubrovnik agreement applied on a simulated population displaying a recruitment +/- independent from its SSB (i.e. a BHR with a high steepness) and no parental effects can lead, in most cases, to satisfactory results (i.e. a significant rebuilding of the SSB within 15 years). In contrast, the same set of management rules perfectly implemented on a simulated population displaying a BHR with a low steepness and parental effects did not prevent the decline of the SSB and even the crash of the simulated population.

This (expected) outcome is somewhat problematic as we are unable to properly estimate the stock-recruitment relationship for the East Atlantic and Mediterranean bluefin tuna stock (see **Figure 1**). Consequently, we have to make some assumptions about this relationship in order to compute projections and/or to evaluate the potential of new management measures, such as the Dubrovnik agreement. It is thus important that these assumptions be clearly stated when an advice is given. Furthermore, it would be better to consider a significant range of contrasting (but realistic) stock-recruitment relationships (e.g. from low steepness to high steepness) and to finally quantify the probability of each scenario (which will be the most difficult/debated part).

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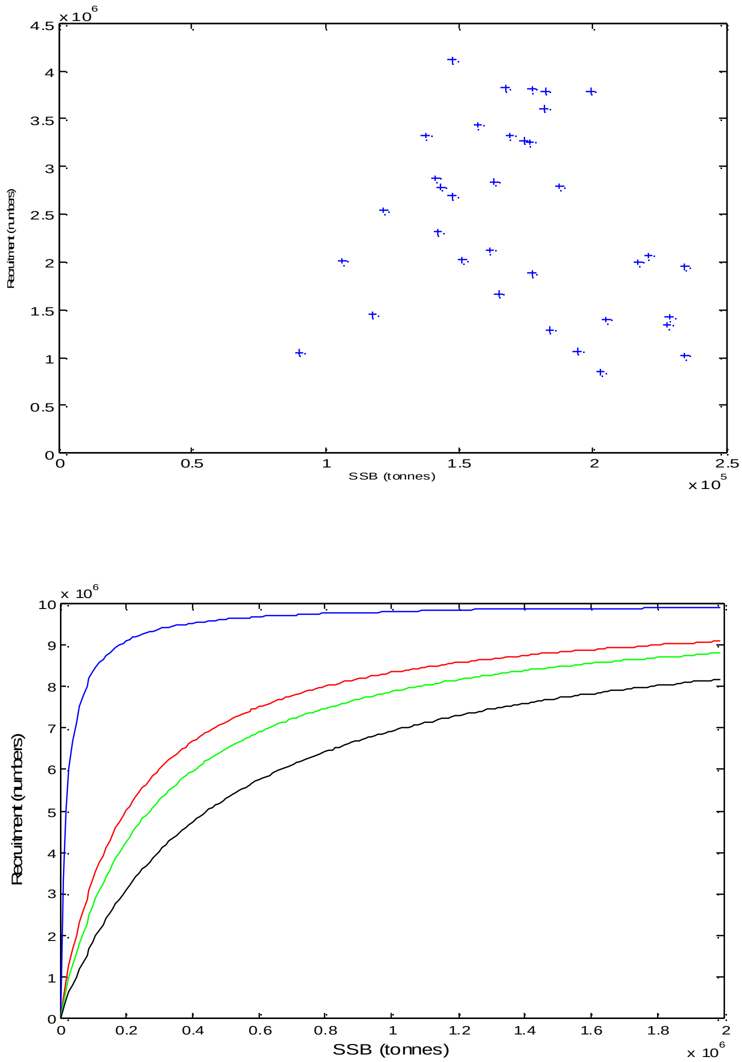

Figure 1. Top: Scatter plot of the SSB *versus* recruitment (both time series coming from ADAPT-VPA run 3 performed by ICCAT 2007). Bottom: Plots of the four Beverton and Hold stock-recruitment relationships used in the simulation model, i.e. steepness of 0.99 (blue), 0.90 (red), 0.75 (green) and 0.50 (black).

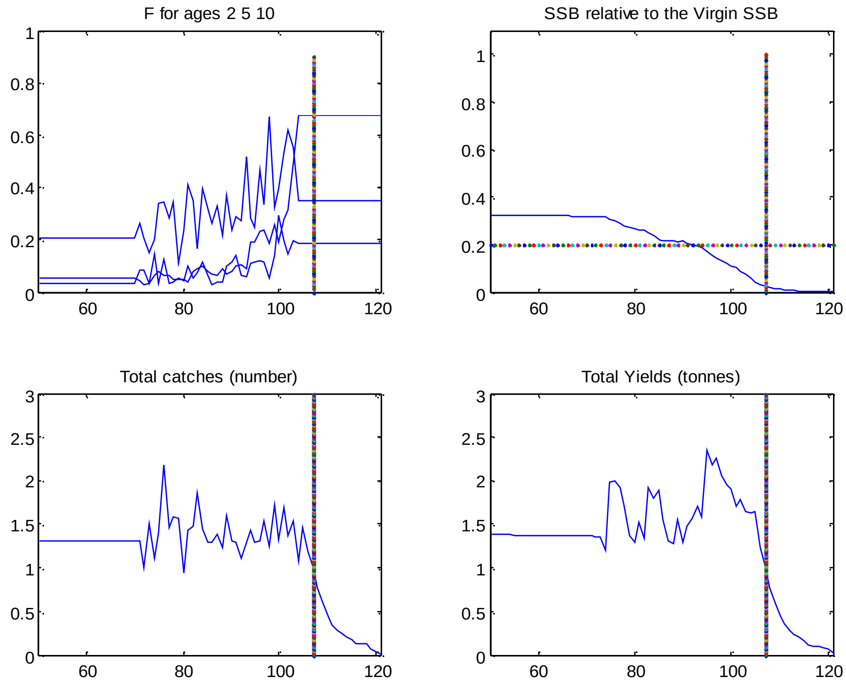

Figure 2. Outputs of the simulation model without the implementation of the Dubrovnik agreement (*Fs* from 2007 to 2022 being equal to those of the early 2000) and assuming a BHR with a steepness of 0.75 and without parental effects. Top-left: Values of the *Fs* for the ages 2, 5 and 10 from 1950 to 2022. Top-right: Simulated SSB values relative to the virgin biomass, horizontal line corresponds to the value of 20%. Bottom-left: Simulated total catches (in number of fish) relative the 2006 catches. Bottom-right: Simulated total yields relative the 2006 yields. Vertical lines in the four plots correspond to the starting year of the recovery plan, i.e. 2007.

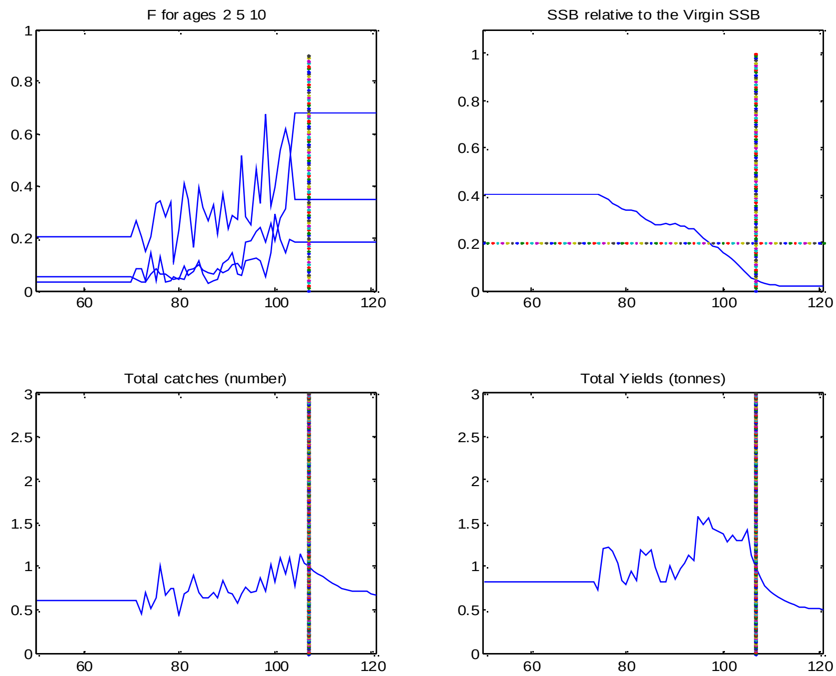

Figure 3. Outputs of the simulation model without the implementation of the Dubrovnik agreement and assuming a BHR with a steepness of 0.99 and without parental effects.

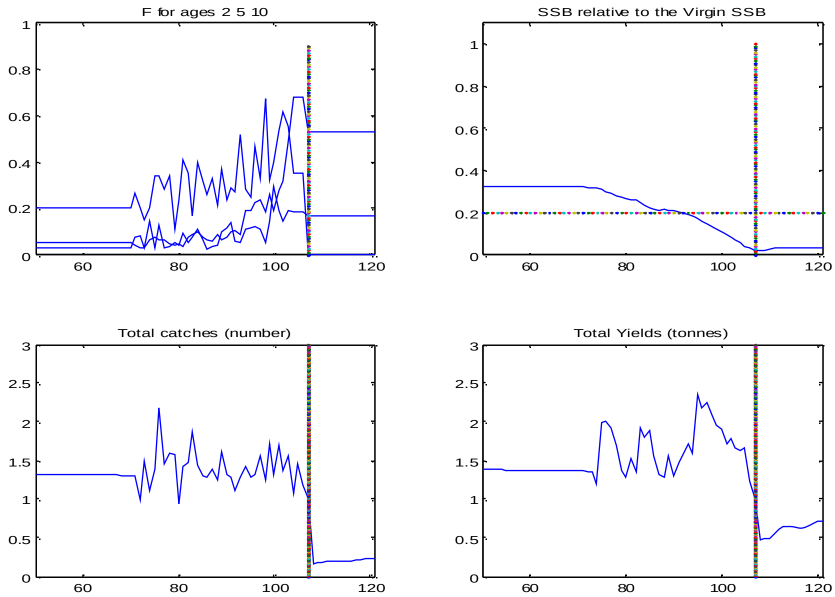

Figure 4. Outputs of the simulation model considering a perfect implementation of the Dubrovnik agreement and assuming a BHR with a steepness of 0.75 and without parental effects.

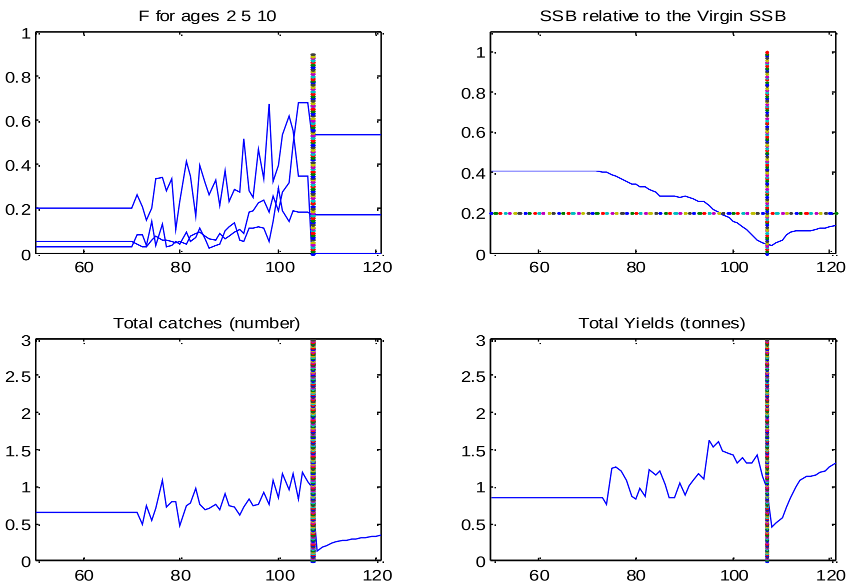

Figure 5. Outputs of the simulation model considering a perfect implementation of the Dubrovnik agreement and assuming a BHR with a steepness of 0.99 and without parental effects.

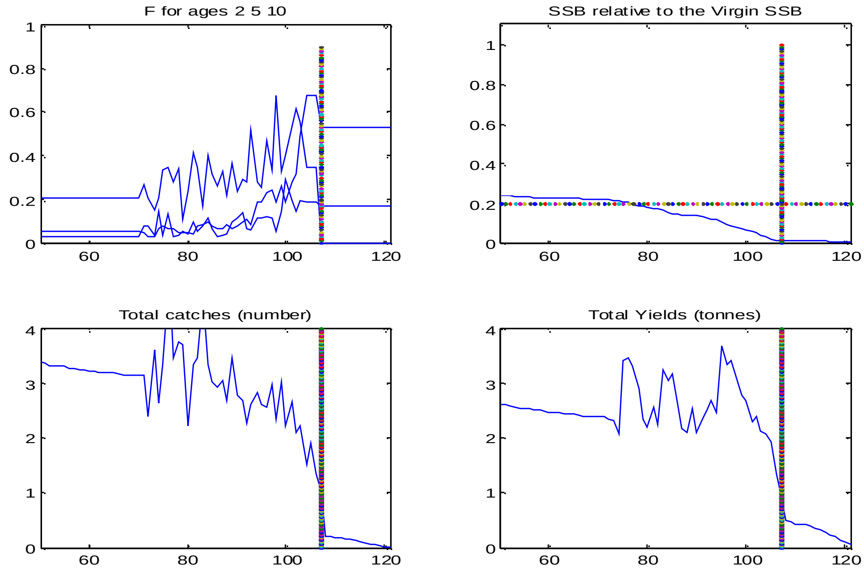

Figure 6. Outputs of the simulation model considering a perfect implementation of the Dubrovnik agreement and assuming a BHR with a steepness of 0.50 and with parental effects.

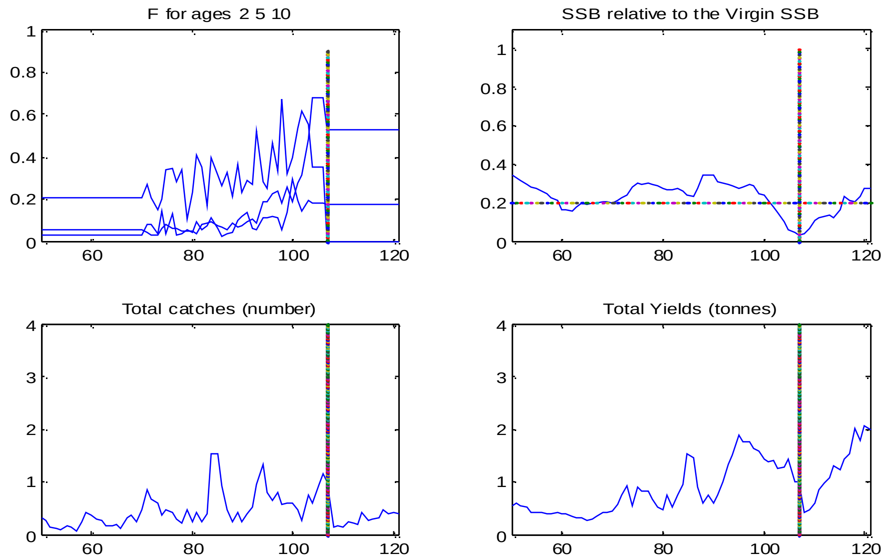

Figure 7. Outputs of the simulation model considering a perfect implementation of the Dubrovnik agreement and assuming a BHR with a steepness of 0.99, without parental effects but stochastic noise around recruitment.

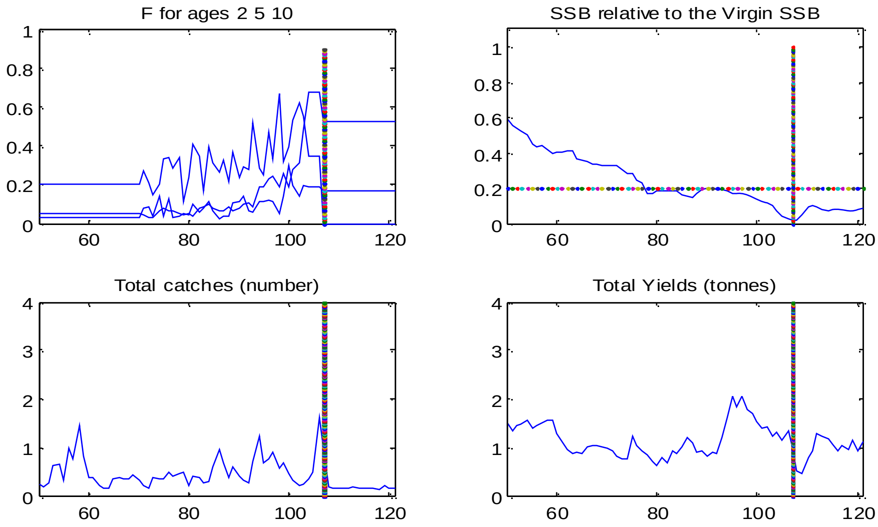

Figure 8. Same as **Figure 7** but for another stochastic run.