SCRS/2007/147 Collect. Vol. Sci. Pap. ICCAT, 62(4): 1271-1279 (2008)

AN ATTEMPT TO EVALUATE THE RECENT MANAGEMENT REGULATIONS OF THE EAST ATLANTIC AND MEDITERRANEAN BLUEFIN TUNA STOCK THROUGH A SIMPLE SIMULATION MODEL

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SUMMARY

This manuscript proposes a simple simulation model to investigate the implications to the resources of the recent management regulations adopted for the East Atlantic and Mediterranean bluefin tuna stock. If perfectly implemented, the new regulations on minimum size and closed fishing areas mostly lead to a change in the selectivity pattern which moves towards older fish, so decreasing growth-overfishing. The potential sustainable yields therefore considerably increase (almost double in comparison to those that would be obtained without the new regulations) while the SSB can rapidly reach 20% of the virgin SSB. An error of 20% in the implementation of these new regulations affects their efficiencies and does not seem to allow the rebuilding of the SSB at a safe level. A significant increase in fishing mortality on older fish (ages 5+), due to the partial redeployment of the fisheries, affect even more strongly the rebuilding of the SSB. In conclusion, the new regulations may appear sufficient to rebuild the SSB to a level > 20% of the virgin SSB, if (and only if) they are perfectly implemented and don't generate any increase in the fishing effort on older fish. In other words, control over all the fisheries that target BFT in the East Atlantic and the Mediterranean is probably the key of the edifice.

RÉSUMÉ

Ce manuscrit examine, au travers d'un modèle de simulation élémentaire, les implications pour la ressource des récentes mesures de gestion adoptées pour le stock de thon rouge de l'Atlantique-est et de la Méditerranée. Les nouvelles mesures de gestion sur la taille limite et les zones et périodes de fermeture de la pêche génèrent, si parfaitement mises en place, une modification du patron d'exploitation, qui se décale vers les poissons plus âgés, diminuant ainsi la surpêche de croissance. De ce fait, les captures potentielles soutenables augmentent fortement (doublant par rapport au scenario qui ne considère pas ces nouvelles régulations) et la biomasse reproductrice peut rapidement atteindre 20% de la biomasse vierge. Une erreur de 20% dans la mise en place de ces mesures affectent leur efficacité et ne semble pas permettre la reconstitution de la biomasse reproductrice à un niveau suffisant. Une augmentation significative de la mortalité par pêche sur les ages 5+, résultant du redéploiement partiel des pêcheries, affecte plus encore la reconstitution de la biomasse reproductrice. En conclusion, les nouvelles mesures de gestion semblent permettre une reconstitution de la biomasse reproductrice à un niveau > 20% de la biomasse vierge si (et seulement si) elles sont parfaitement mises en place (sans erreur) et si elles ne génèrent pas une augmentation de l'effort de pêche sur les gros reproducteurs. En d'autres termes, le contrôle de toutes les pêcheries visant le thon rouge dans l'Atlantique-est et la Méditerranée est probablement la clé de tout le système.

RESUMEN

Este documento examina mediante un modelo de simulación simple las implicaciones para el recurso de las recientes medidas de ordenación adoptadas para stock de atún rojo del Atlántico este y Mediterráneo. Si se implementan perfectamente, las nuevas medidas de ordenación sobre talla mínima y vedas de zona y temporada generan, una modificación en el patrón de selectividad que se desplaza hacia los peces mayores, disminuyendo así la sobrepesca de crecimiento. Por tanto, aumentan considerablemente los potenciales rendimientos sostenibles (casi el doble en comparación con los que obtendrían sin las nuevas medidas), mientras que la SSB puede alcanzar rápidamente el 20% de la SSB virgen. Un error del 20% en la implementación de las nuevas regulaciones afecta a su eficacia y no permite la recuperación de la SSB hasta un nivel seguro. Un aumento significativo de la mortalidad por pesca sobre los peces mayores (edades 5+), debido al redespliegue parcial de las pesquerías, afecta incluso más todavía a la recuperación de la SSB. En conclusión, las nuevas medidas pueden parecer suficientes para recuperar la SSB hasta un nivel >20% de la SSB virgen si (y sólo si) son perfectamente implementadas y no generan un aumento significativo del esfuerzo pesquero en los peces de más edad. Dicho de otro modo, el control de todas las pesquerías que se dirigen al BFT en el Atlántico este y Mediterráneo es probablemente la clave del asunto.

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KEYWORDS

Bluefin tuna, management regulations, stock rebuilding, simulation model

1. Introduction

Following the pessimistic advice given by the SCRS on BFT stock status (Anon. 2007), a 15 years recovery plan for the East Atlantic and Mediterranean bluefin tuna stock has been adopted in 2006 during the last Commission meeting that was held in Dubrovnik. The recovery plan contains multiple elements related to monitoring, control and surveillance, such as the ban of airplanes or helicopters for searching purposes, associated measures to the TAC, observers on board or on cages, etc. (For more details see [Rec. 06-05]). In terms of conservation, the plan is built around three major rules:

1) A Total Allowable Catch (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 bait boat 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 major step towards the regulation of BFT fisheries in the East Atlantic and Mediterranean, but it differs substantially from the SCRS advice. To avoid potential fisheries and stock collapse, the SCRS indeed advocated for substantial reductions in fishing mortality and catch, closure of the Mediterranean to fishing during the spawning season, enforcement of the minimum size and substantial decrease in the fishing capacity (ICCAT, 2007).

Therefore, it might be of interest to investigate more deeply and, in a quantitative manner, the potential consequences to the stock of this recovery plan. A first option might be to evaluate the Dubrovnik regulations within the framework of the YPR scenario elaborated by the BFT Working Group in 2006 (ICCAT, 2007). However, YPR implies equilibrium assumptions that are rather limiting to investigate the likelihood of a dynamic process, i.e. the rebuilding of the population within the next 15 years (i.e. until 2022). However, the low quality of the catch and catch-at-age or the lack of CPUE indices do not allow us to run classic dynamic models, such as VPA or surplus production models, with confidence (Anon., 2005; Anon. 2007). Therefore, this manuscript proposes a simple simulation model to investigate the recent management regulations of the East Atlantic and Mediterranean bluefin tuna stock.

2. The simulation model

The simulation model is based on a framework previously developed and published by Fromentin and Fonteneau (2001) to compare fishing effects on tuna displaying contrasting life histories. It is based on the fundamental equation of fish population dynamics:

$$N_{a,t} = N_{a-1,,t-1}\, e^{-Zt},$$

where, $N_{a,t}$ is the number of fish of age (a) at time (t), and Z the total mortality from age (a-1) to age (a). Z = M+F, with M being the natural mortality and, F the fishing mortality.

The main life history traits of BFT are stated as follows: yearly spawning (1 cohort per year), life span of 20 years, 50% maturity at 4 years (100% at 5+). As the natural mortality of East Atlantic BFT is poorly known, the model has been run considering different M vectors, i.e. equal to 0.14 (i.e. age and time invariant) and age-specific and time invariant. Age-length and weight relationships are based on equations retained by the SCRS BFT Working Group, mean weights spread from 4kg at age 1 to 400kg at age 20.

To close the life cycle, a Beverton and Holt stock/recruitment relationship was assumed because it is currently used within the ICCAT BFT Working Group. Besides this deterministic approach, a stochastic recruitment (resulting from varying and unpredictable environmental conditions) has been also implemented by multiplying the deterministic component of the recruitment by a random noise coefficient (being Gamma distributed with mean and standard error equal to 1).

Simulations were run over 122 years, after a transition period of 50 years without any fishing mortality to reach a steady state (i.e. a virgin spawning biomass set arbitrarily at 1 million tonnes). To reflect the long lasting BFT fishing that has taken place, the model has been then run over 70 years, assuming an F vector equal to the mean of the Fs during the 1970s (i.e. being time invariant but age specific; F estimates come from ADAPT VPA run 2 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) assuming the following scenarios:

1. Fs equal to those of the 2001-2004 period, i.e. no implementation of the recent management rules
2. Perfect implementation of the recent regulations on minimum size (see point 3 of the introduction) and time-area closures (see point 2 of the introduction), without any report of fishing effort.
3. Implementation of the recent regulations on minimum size and time-area closures with 20% of error and without any report of fishing effort.
4. Perfect implementation of the recent regulations on minimum size and time-area closures with a 50% increase in fishing mortality on ages 5+ (that would be due to a partial redeployment of the fisheries on older fish, i.e. 5+).
5. Perfect implementation of the recent regulations on minimum size and time-area closures with a 75% increase in fishing mortality on ages 5+.
6. Implementation of the recent regulations on minimum size and time-area clossures 20% of error, with a 50% increase in fishing mortality on ages 5+.
7. Implementation of the recent regulations on minimum size and time-area closures with 20% of error, with a 75% increase in fishing mortality on ages 5+.

Simulations were operated using Matlab R2006a.

3. Results

This simulation is thus simple and rather similar to a forward cohort analysis. All the model outputs depend on model specifications, especially regarding M and the stock-recruitment relationship (note, however, that the model cannot give any indication about the level of simulated F against F_{MSY}). Therefore the results must be interpreted with caution and in a relative manner (i.e. by comparing the outputs of one scenario to those of another).

Without fishing, the virgin spawning biomass is thus equal to 1 while Fs catches, yields are equal to 0 (**Figure 1**, position -20 to 0 on the x-axis). 70 years of fishing set at the 1970s level lead to a simulated SSB of about 30% of the virgin SSB. Additional 36 years of Fs similar to those estimated by ADAPT VPA between 1970 and 2006 further decrease the SSB to 8% of the virgin one, with a rapid decline during the last 15 years (corresponding to the 1990s and 2000s, i.e. between the position 90 and 106 on the x-axis, **Figure 1**). Simulated catches exceed one million of fish while the simulated yields reach about 40,000 tonnes during this period of low SSB.

Scenario 1: Assuming a fishing pressure over the next 15 years similar to this of the early 2000s does not allow any recovery. On the contrary, the simulated SSB continues to decrease (to about 7% of the virgin SSB) in 2022 **(Figure 1)**. The catches are around one million fish while the yields fit perfectly (by chance) between the 29,500 and 25,500 tonnes limits. These results indicate that relatively high yields are possible even if the SSB is rather depleted (depending on the M values) and that a unique TAC measure could not be sufficient to reverse the decreasing trend in SSB if it is set at a relatively high level (which is in agreement with the YPR outputs of the last assesment).

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) leads to a contrasting picture **(Figure 2)**. F for age 2 (i.e. fish < 8 kg) equal to zero over the last 15 years and there is also a 72% decrease in F for ages 3 and 4 (8 kg<fish<30 kg). The simulated SSB exceeds the 20% of the virgin SSB limit 8 years after the beginning of the recovery plan. It tends towards 24% of the virgin SSB (but remains slightly lower than in 1970, **Figure 2**). The simulated catches decrease a lot, firstly at around 300,000 fish and then at around 500,000 fish (i.e. <50% of the number of fish in scenario 1). Consequently, after a short transition period of low yields (of about 17,500 tonnes), the simulated yields sharply increase up to historic levels, i.e.

45,000 tonnes, if not regulated **(Figure 2)**. So, if perfectly implemented, the new regulations mostly act a change in the selectivity pattern (moving towards older fish) which thus strongly decreases growth-overfishing (as expected under YPR analyses; see Anon. 2007). Doing so, the potential sustainable yields considerably increase, almost double in comparison to scenario 1.

Scenario 3: If the implementation error of the recent regulations is about 20%, Fs for ages 2, 3 and 4 increase significantly, leading to higher simulated catches (about 680,000 fish, **Figure 3**). The simulated yields are lower than in scenario 2, but remain at a high level (about 38,000 tonnes) because Fs on juveniles still remain much lower than in scenario 1. However, the simulated SSB does reach 20% of the virgin SSB, but tends towards a value of 17% after 15 years, so that the rebuilding of SSB is a bit less efficient than in scenario 2.

***Scenarios 4 and 5**:* Assuming a perfect implementation of the recent regulations on minimum size and time-area closures with a 50% (scenario 4) or 75% (scenario 5) increase in fishing mortality on ages 5+ affect even more strongly the rebuilding of the SSB **(Figure 4)**. In these two cases (results being very close), Fs at age 2 remain null and these at ages 3 or 4 low, but Fs for older ages strongly increase. Yields are at about the same level as those in scenario 2, but SSB doesn't exceed 15% of the virgin SSB after 15 years.

Scenarios 6 and 7: If the implementation error is about 20% together with a 50% (scenario 6) or 75% (scenario 7) increase in fishing mortality on ages 5+, all the Fs increase (including those on juvenile fish). Yields are lower than those of scenario 2, 3, 5, 6 (i.e. about 36,000 tonnes at the end of the series). More importantly, the SSB remains at a low level (about 10% of the virgin SSB after 15 years).

Considering stochastic runs don't change the whole picture, but generate long-term cycles (see Fromentin, 2002) which can significantly affect (positively or negatively) the yields and the SSB levels at the end of the recovery plan. To illustrate this, let's take two contrasting stochastic runs from scenario 7. If stochastic variations in the recruitment lead to high values in some recent years, both yields and SSB will be much higher than under its deterministic counterpart: the SSB can even reach about 20% of the virgin SSB and the yields can exceed 45,000 tonnes **(Figure 6)**.

In contrast, if stochastic recruitment leads to low values in some recent years, both the yields and the SSB can be strongly depleted: in this case the SSB can even not exceed 5% of the virgin SSB, whereas the yields are about 2.5 times less than in the deterministic run of scenario 7 **(Figure 7)**.

4. Discussion and conclusion

Such a simple model is not fully adequate to investigate the potential of recovery of the BFT population because key processes such as population structure, migration patterns or recruitment dynamics, are not (or roughly) considered (but these will remain difficult to implement regarding the limitations of our knowledge and data on these issues). Consequently, this model must be seen as very optimistic (possibly the most optimistic case) because it considers that if fishing is totally banned, then the SSB will be rebuilt to its virgin level within one generation (i.e. 20 years, see **Figure 8**). The recent example of Atlantic cod (see e.g., Hutchings, 2000) has taught us that the situation is always much more complicated than this because fishing does only result in an arithmetic operation (i.e. removing fish from the population) but can also severely alter the population dynamics and structure, sometimes in an irreversible way (e.g. Hilborn *et al.* 2003; Berkeley *et al.* 2004; Birkeland and Dayton 2005; Ottersen, *et al.* 2006).

Another limitation of this simulation model is that it assumes that current Fs are not very different than those estimated by the ADAPT VPA during the last stock assessment which are, however, impaired by a large amount of uncertainty (see ICCAT 2007). Furthermore, we did not fit the model to the data, so that the outputs are mostly interesting from a comparative perspective (i.e. from one scenario to another). Doing so, a few points emerge:

- The 2006 regulations on minimum size and closed fishing areas mostly lead to a change in the selectivity pattern which moves towards older fish, i.e., decreasing growth-overfishing. Doing so, the potential sustainable yields considerably increase, almost double in comparison to those of scenario 1 (i.e. without new regulations), as this has been already noticed in the 2002 and 2006 BFT stock assessment reports (ICCAT, 2003; Anon. 2007). SSB can rapidly reach 20% of the virgin SSB (within 8 years), but this must be interpreted with caution because of the simplicity of the model (see previous paragraph).

- The simulations also indicate that relatively high yields are possible even if the SSB is rather depleted (i.e., scenarios 1, 6 and 7). However, this situation increases the risk of fisheries and stock collapse in a stochastic regime if successive years of low recruitment happen **(Figure 7)**. This indicates that a unique TAC regulation is probably not sufficient to reverse the decreasing trend in SSB if it is set at a relatively high level.
- An error of 20% in the implementation of the new regulations affects their efficiencies and does not seem to allow the rebuilding of the SSB at a safe level.
- A significant increase in fishing mortality on older fish (ages 5+), due to a jpartial redeployment of the fisheries, impairs the rebuilding of the SSB.

In conclusion, new regulations may appear sufficient to rebuild the SSB to a level > 20% of the virgin SSB, if they are perfectly implemented and without any increase in fishing effort on older fish (an hypothesis that remains probable regarding the current overcapacity; see Anon. 2007). In other words, control over all the fisheries that target BFT in the East Atlantic and the Mediterranean is probably the key of the edifice.

References

ANON. 2003. Report of the 2002 Atlantic Bluefin Tuna Stock Assessment Session. Collect. Vol. Sci. Pap. ICCAT, 55(3): 710-937.

ANON. 2005. Report of the 2004 Data Exploratory Meeting for the East Atlantic and Mediterranean Bluefin Tuna. Collect. Vol. Sci. Pap. ICCAT, 58(2): 662-699.

ANON. 2007. Report of the 2006 Atlantic Bluefin Tuna Stock Assessment Session (Madrid, June 12 to 18, 2006). Collect. Vol. Sci. Pap. ICCAT, 60(3): 652-880.

BERKELEY, S.A, C. Chapman, S.M. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, Sebastes melanops. Ecology 85: 1258-1264.

BIRKELAND, C., P.K. Dayton. 2005. The importance in fishery management of leaving the big ones. Trends in Ecology & Evolution 20: 356-358.

FROMENTIN, J-M. 2002. Can stochastic variations in recruitment induce long-term fluctuations in the carrying capacity? Collect. Vol. Sci. Pap. ICCAT, 54: 985-991.

FROMENTIN, J-M., A. Fonteneau. 2001. Fishing effects and life history traits: a case-study comparing tropical *versus* temperate tunas. Fisheries Research 53: 133-150

HILBORN, R., T.P. Quinn, D.E. Schindler, D.E. Rogers.2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Science US 100: 6564-6568.

HUTCHINGS, J.A. 2000. Collapse and recovery of marine fishes. Nature 406: 882-885.

ICCAT. 2007. Species Executive Summary: Bluefin Tuna. ICCAT *In* Report for Biennial Period, 2006-07, Vol. 2-SCRS: 98-114.

OTTERSEN, G., D.O. Hjermann, N.C. Stenseth. 2006. Changes in spawning stock structure strengthen the link between climate and recruitment in a heavily fished cod (*Gadus morhua*) stock. Fisheries Oceanography 15: 230-243.

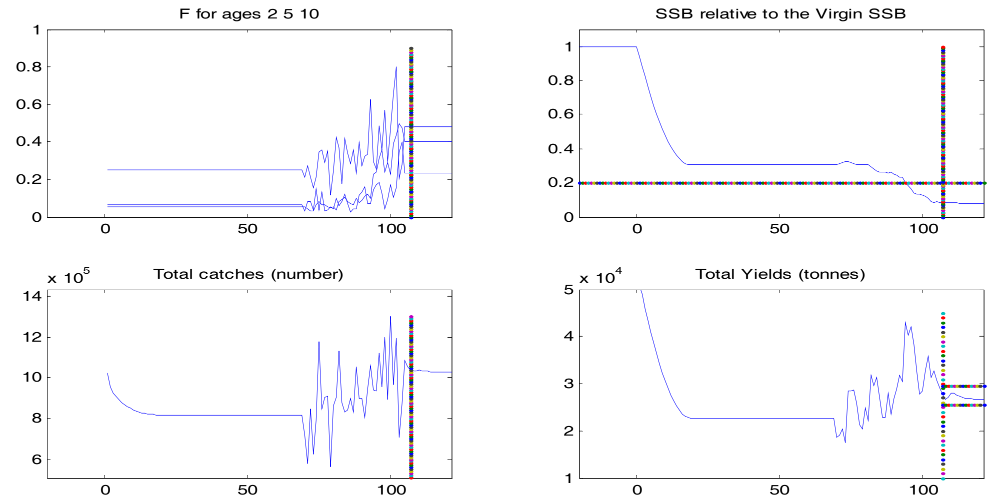

Figure 1. Outputs of the simulation model for scenario 1 (see text). Top-left: Values of the Fs for the ages 2, 5 and 10 over the 122 years. Top-right: Simulated SSB values relative to the virgin biomass, horizontal line corresponds to the value of 20%. Bottom-left: Simulated total catches (in number of fish). Bottom-right: Simulated total yields, horizontal lines correspond to the values of 29,500 and 25,500 tonnes (i.e. TACs for 2007 and 2009). Vertical lines in the four plots correspond to the starting year of the recovery plan.

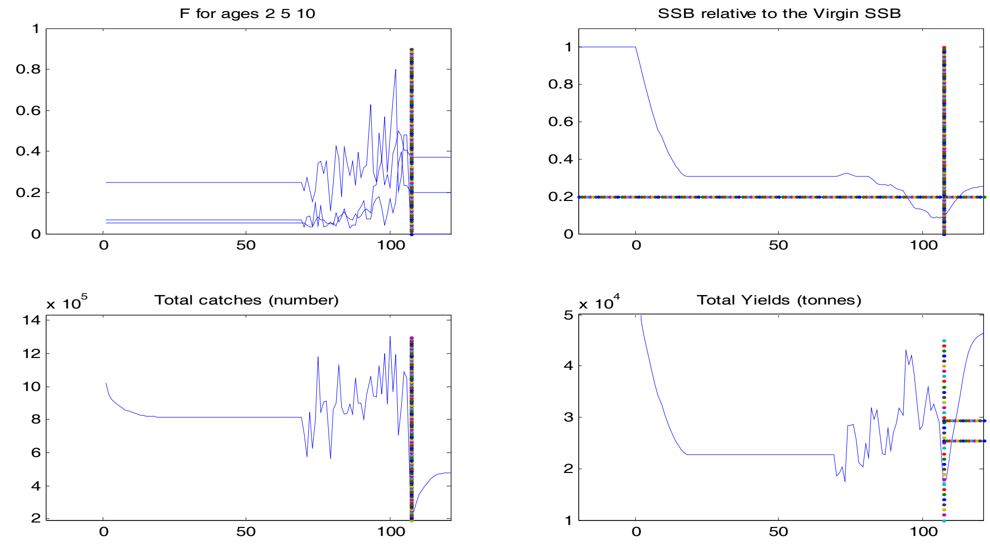

Figure 2. Same simulation model outputs as Figure 1 for scenario 2 (see text).

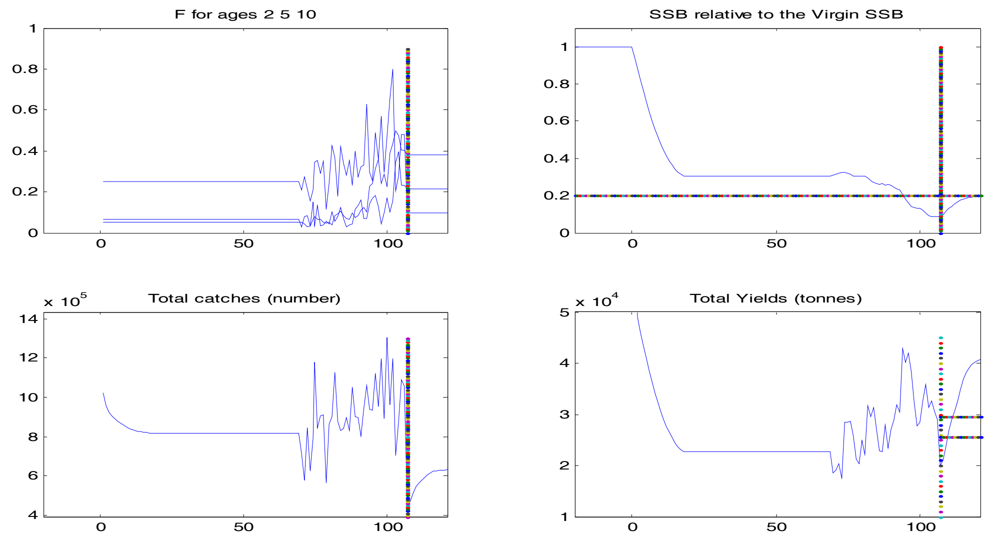

Figure 3. Same simulation model outputs as Figure 1 for scenario 3 (see text).

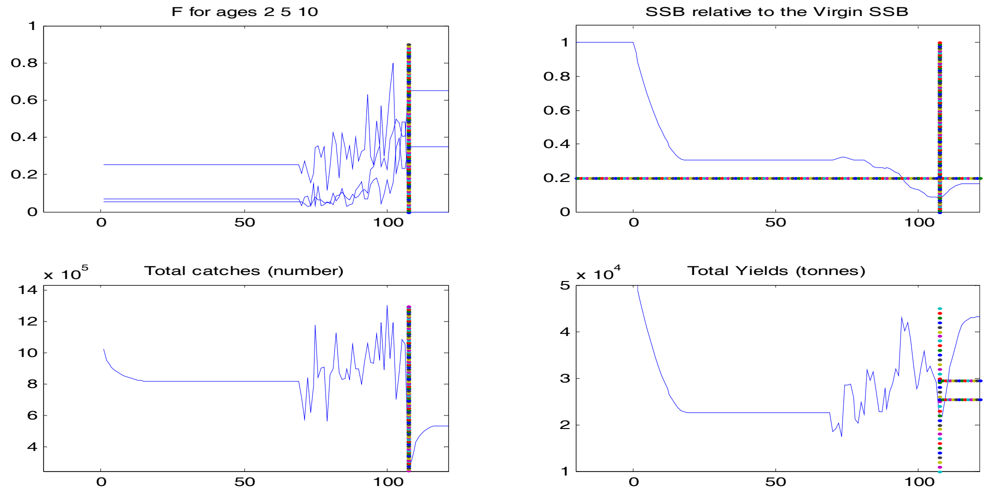

Figure 4. Same simulation model outputs as Figure 1 for scenario 5 (see text).

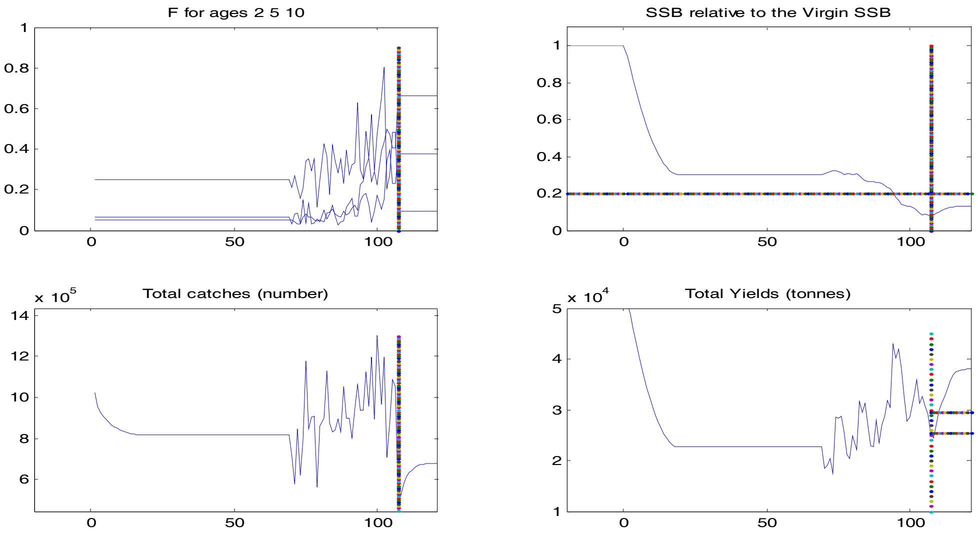

Figure 5. Same simulation model outputs as Figure 1 for scenario 7 (see text).

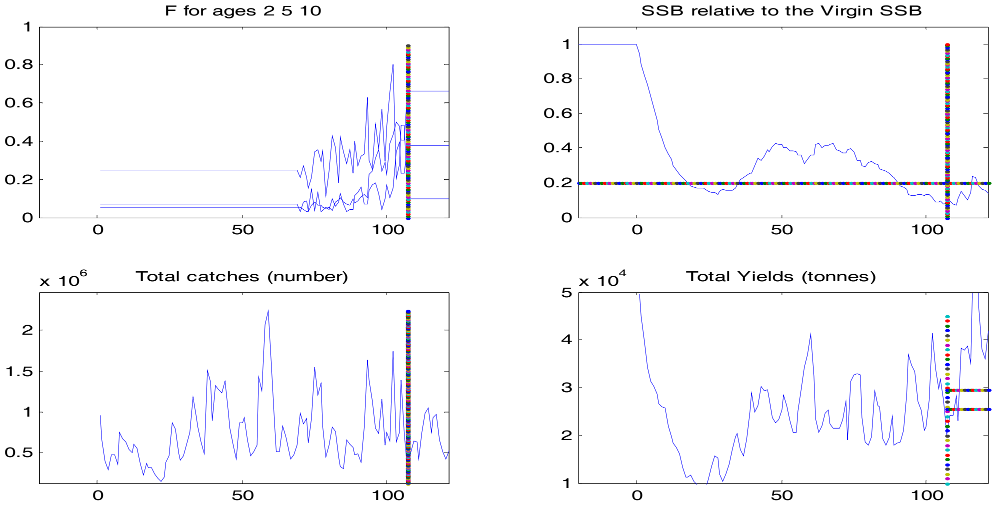

Figure 6. Same simulation model outputs as Figure 1 for scenario 7 with stochastic recruitment (see text).

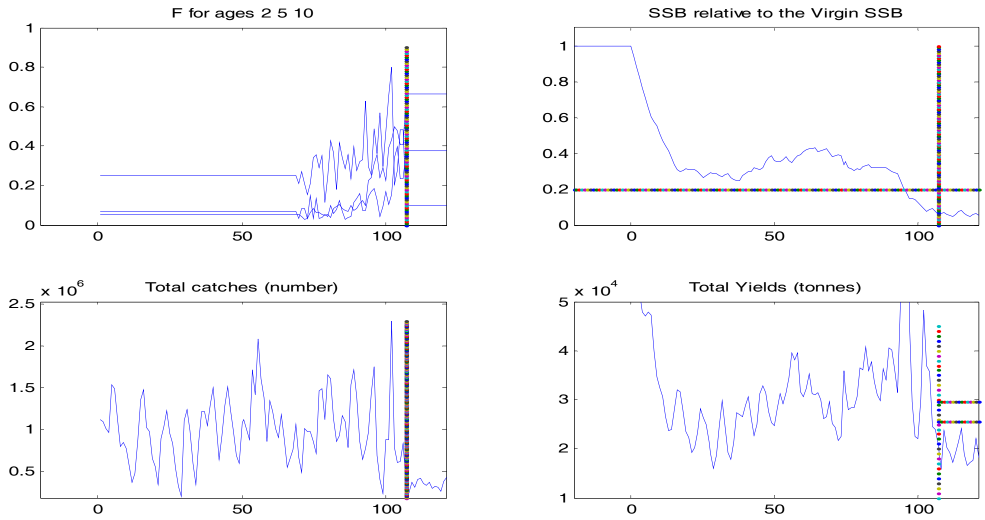

Figure 7. Same simulation model outputs as Figure 1 for scenario 7 with stochastic recruitment (see text).

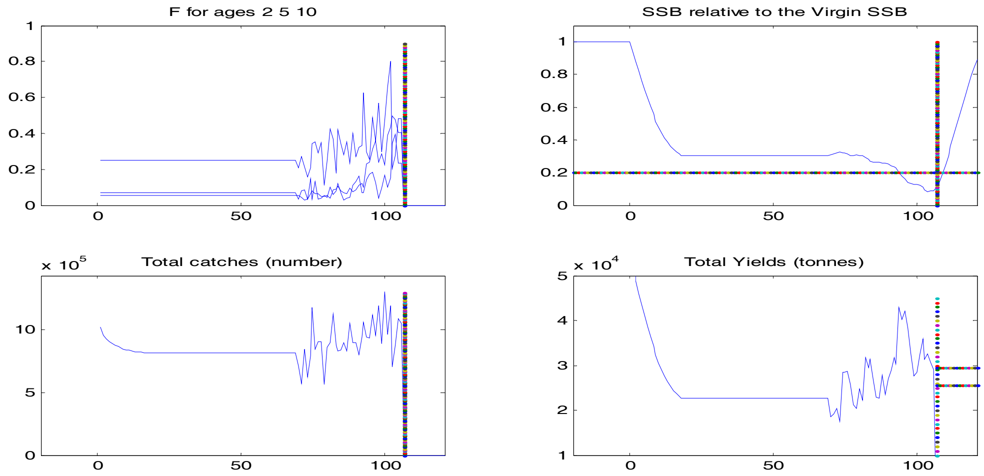

Figure 8. Same simulation model outputs as Figure 1 considering a total fishing ban (see text).