SCRS/2010/104 Collect. Vol. Sci. Pap. ICCAT, 66(2): 799-810 (2011)

POTENTIAL IMPACTS OF TAC IMPLEMENTATION ON THE PERCEPTION OF THE EAST ATLANTIC AND MEDITERRANEAN BLUEFIN TUNA STOCK STATUS

S. Bonhommeau[1] and J.-M. Fromentin

SUMMARY

This study aims at examining the potential bias in the VPA estimates by simulating a population, catch and CPUEs over 39 years from 1970 to 2008. In the operational model, two levels of noise were added to catch and CPUEs (50 and 100%), three fishing patterns were explored (F=F_{MSY}, F increases linearly from 0.5 F_{MSY} to 2.5 F_{MSY}, F increases linearly from 0.5 F_{MSY} to 2.5 F_{MSY} over the first 34 years and decreases down to F_{MSY} over the last 5 years). We also tested different hypothesis about the impact of the terminal F-ratios, and the natural mortality used in the current VPA as well as the impact of randomly generated CPUE for long-line and trap CPUE. Results show that the VPA is robust to estimate the SSB whatever the noise level in the catch and the CPUEs. Fs are generally overestimated especially for the last ages and the last year of the run. Randomly generated CPUEs have a strong impact on the estimations for the F at age 8-10+ which is consistent with the fact that the random CPUEs used mainly concern these ages. When fishing mortality decreases during the last years, the SSB estimated by the VPA does not show any sign of recovery while it is the case in the operational model. These results indicate that one of the main bias that could lead to false estimates of SSB and Fs could be the age estimation from the von Bertalanffy curve.

RESUME

Cette étude a pour objectif d'examiner les biais potentiels dans les estimations de la VPA en simulant une population, les captures et les CPUE lors des 39 années de 1970 à 2008. Dans le modèle opérationnel, deux niveaux de bruits ont été ajoutés aux captures et aux CPUE (50 et 100 %), trois patrons d'exploitation ont été explorés (F=F_{PME}, F augmente linéairement de 0,5 F_{PME} à 2,5 F_{PME}, F augment linéairement de 0,5 F_{PME} à 2,5 F_{PME} sur les 34 premières années puis diminue jusqu'à F_{PME} sur les 5 dernières années). Nous testons aussi l'hypothèse de l'impact potentiel des F-ratios terminaux et de la mortalité naturelle utilisés dans la VPA à l'heure actuelle ainsi que l'impact de CPUE générées de manière aléatoire pour les CPUE de palangriers et de madragues. Les résultats montrent que la VPA est robuste aux estimations de SSB quel que soit le niveau de bruit dans les captures et les CPUE. Les F sont généralement surestimés, et ce, principalement pour les âges terminaux et la dernière année évaluée. Les CPUE générées aléatoirement ont un fort impact sur les estimations des F aux âges 8-10+ ce qui est cohérent avec le fait que les CPUE aléatoires utilisées concernent principalement ces âges. Lorsque la mortalité par pêche diminue les dernières années, la SSB estimée par la VPA ne montre aucun signe de rétablissement alors que cela est observé dans le modèle opérationnel. Ces résultats indiquent que l'un des principaux biais qui pourrait mener à des estimations de SSB et F erronées pourrait provenir de l'estimation de l'âge à partir de la courbe de von Bertalanffy.

RESUMEN

Este trabajo tiene el objetivo de examinar el sesgo potencial mediante la simulación de una población, captura y CPUE durante 39 años, desde 1970 a 2008. En el modelo operativo, se añadieron 2 niveles de ruido a la captura y a las CPUE (50 y 100%) y se exploraron tres patrones pesqueros (F=F_{RMS}, F aumenta linealmente desde 0,5 F_{RMS} hasta 2,5 F_{RMS}, F aumenta linealmente desde 0,5 F_{RMS} hasta 2,5 F_{RMS} durante los primeros 34 años y desciende a F_{RMS} durante los cinco últimos años). También se han probado diferentes hipótesis acerca del impacto de las ratios de F terminal y la mortalidad natural utilizada en el VPA actual así como el impacto de la CPUE generada aleatoriamente para el palangre y la almadraba. Los

[1] IFREMER, Centre de Recherche Halieutique Méditerranéenne et Tropicale, avenue Jean Monnet, BP 171, 34203 Sète cedex, France. E-Mail: jean.marc.fromentin@ifremer.fr

resultados demostraron que el VPA es robusto para estimar la SSB sea cual fuere el nivel de ruido en la captura y en las CPUE. Sin embargo, las F están por lo general sobrestimadas especialmente para las últimas edades y el último año del ensayo. Las CPUE generadas aleatoriamente tienen un fuerte impacto en las estimaciones para F a la edad 8-10+, que es coherente con el hecho de que las CPUE aleatorias utilizadas se refieran principalmente a estas edades. Cuando la mortalidad por pesca desciende durante los últimos años, la SSB estimada por el VPA no muestra ningún signo de recuperación, mientras que sí lo hace en el modelo operativo. Estos resultados indican que uno de los principales sesgos que podría conducir a estimaciones falsas de SSB y las F podría ser la estimación de edad a partir de la curva de von Bertalanffy.

KEYWORDS

Bluefin tuna, stock assessment, VPA, management regulations, TAC

1. Introduction

Quantitative stock assessments of Atlantic bluefin tuna (BFT) stocks (i.e. the so-called ‘eastern’ and ‘western’ stocks) have been mostly conducted using VPA’s separately for both stocks for more than two decades (see e.g. ICCAT 1999, 2003, 2009). The main weaknesses associated with these assessments are known. These are probably related to the stock delimitation for the Western component while uncertainties in catch and catch-at-size are of chief importance for the Eastern stock (Fromentin and Powers 2005, ICCAT 2005).

Furthermore, the unknown adequacy of available CPUE indices for the Eastern stock as measures of overall stock abundance make it difficult to interpret trends in reproductive biomass (SSB) and recruits estimated from the VPA. For instance, the apparent regime shift in the recruitment during the early 1980s is likely to reflect the important changes in the selectivity pattern of the Mediterranean purse seiners (Fromentin and Bonhommeau 2011). These fleets primarily targeted juveniles BFT, but progressively moved towards large fish in response to the demand of the sushi-sashimi market and then to management regulations. Consequently, the catch-at-size matrix of the East Atlantic and Mediterranean BFT includes a much higher proportion of catches of large fish since the mid-1980s. In the absence of corresponding auxiliary information (i.e. PS-CPUE index) or adequate scientific surveys (e.g. tagging or aerial surveys), the VPA naturally translates this change into a higher recruitment level since the early 1980s. However, it is unlikely that this higher level did, indeed, occur.

Similarly, the poor fit of ADAPT-VPA to the few CPUE indices used in the Eastern stock assessment could induce to another important bias (ICCAT 1999, 2003, 2007, 2009): to over-estimate stock abundance when PS catch (or catch from another key gear for which CPUE are unavailable) are increasing and under-estimating when total catches are decreasing in response to management regulations. Indeed, in the absence of auxiliary information, there is no information on the actual trends in abundance and the VPA is more likely to translate trends in catch as trends in abundance. To investigate such a potential bias, we developed a simulation framework to evaluate the effects of increasing/decreasing catch on the ICCAT stock assessment based upon ADAPT-VPA. To do so, we modelled a bluefin tuna population from which we sampled catch and CPUE with different levels of uncertainties and availability. This allowed the performances of the stock assessment model to be evaluated for uncertainty about the observation system.

2. Methods

In a similar way as (Kell et al. 2000, Kell et al. 2003, Fromentin and Kell 2007, Kell and Fromentin 2007), the simulation framework incorporated: (i) an Operating Model (OM), that represents plausible hypotheses about stock and fishery dynamics (including a higher level of complexity and knowledge than used within stock assessment models); (ii) an observation model that describes how pseudo-data are sampled from the Operating Model and (iii) stock assessment to derive estimates of stock status from the pseudo-data, here ADAPT-VPA (Porch 1997).

2.1 The Operating Model

The Operating Model was constructed on the basis of the standard age-structured equation:

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

where $N_{a,t}$ is the number of fish of age *a* at time *t*, and $Z_{a,t}$ is the total mortality from age *a*–1 to age *a*. $Z_{a,t} = M_a + F_{a,t}$, where M_a is the natural mortality at age *a* and $F_{a,t}$ is the fishing mortality at age *a* in year *t*. Life history traits of the East Atlantic and Mediterranean population that have been used are described in (Fromentin and Kell 2007): (i) annual spawning (1 cohort per year), (ii) 50% maturity at age 4, 100% maturity at ages 5+ (i.e. immature before age 4), (iii) fecundity is linearly proportional to weight, (iv) growth and length-weight equations used in the ICCAT working group, (iv) lifespan of 40 years and (v) the age-specific, but time-invariant, natural mortality vector in the ICCAT stock assessments since 1998.

The population dynamics of the OM was further based on a Beverton and Holt stock/recruitment relationship (Beverton and Holt 1957). Steepness was set at 0.99. The initial number of recruits was arbitrarily set to 2.10^6 to initialize the population. The study intended to provide strategic rather than tactical advice and results are presented as relative rather than absolute. To stochastic variations in the recruitment, the deterministic recruitment was multiplied by a moderate normally random noise, *N* (1, 0.3).

2.2 The Observation Model

The Observation Model generates catch-at-age (CAA) and CPUE from the Operating Model under different scenarios that that reflect different levels of uncertainty:

$$Obs.C_{a,t} = C_{a,t}\ x\ \varepsilon 1_t$$
$$Obs.CPUE_{a,t} = CPUE_{a,t}\ x\ \varepsilon 2_t$$

Where $\varepsilon 1_t$ *and* $\varepsilon 2t \sim N$ (1, σ) and σ = 0.5 and 1 to reflect low to large uncertainty in Catch and CPUE.

Regarding the historical fishing mortality, we considered three different historical *F*s over a period of 39 years (i.e. 1970-2008): (i) constant effort corresponding to *F* = M (and thus assumed to be closed to F_{MSY}); (ii) a linear increase in effort corresponding to an increase in F = M to F = 2.5*M over the 34 years, followed by F = 2.5*M over the last 5 years and (iii) a linear increase in effort corresponding to an increase in F = M to F = 2.5*M over the 34 years, followed by a decrease to F = M over the last 5 years (**Figure 1**).

We also considered four scenarios where (i) the CPUE for long-line and Spanish and Moroccan traps were not reflecting the actual population, i.e. a random number having a uniform distribution between the currently used values of the CPUEs, (ii) the terminal F-ratio set in the VPA model was not the one used in the operational model (1.5 instead of 0.8 in the OM), (iii) the F_ratio in the VPA was the one currently used, i.e. 0.6 over the first 15 years, 1 over the 10 following years and 1.2 over the last part of the period, (iv) the natural mortality in the VPA was not corresponding to the OM, i.e. 0.6, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.1, 0.1, 0.1 for age 1 to 10+ respectively while it is 0.49, 0.24, 0.24, 0.24, 0.24, 0.2, 0.175, 0.50, 0.125, 0.1 in the VPA of the stock assessment)

7 CPUEs were simulated to correspond to the current inputs of the VPA and the catchability for each gear was set in the range of those used in the stock assessment of the working group on BFT.

We ran the operational model over 250 years without fishing to reach an equilibrium of the population. Fishing was simulated over 50 years and the last 39 years were kept for the present analysis to avoid the early spin up of the fishing model (high catch the first years since fishing in a virgin stock). The main outputs of the model are illustrated in **Figure 2**.

2.3 Simulation design

30 scenarios were carried out resulting from the combination of 2 levels of noise, 3 F patterns, and the 4 scenarios mentioned hereinbefore. **Table 1** summarizes the scenario features.

We calculated the variations between the estimated F at age from the VPA (F_a_VPA) and the F at age from the operational model ($F_{a,\ OM}$): $|F_{a,\ VPA} - F_{a,\ OM}| / F_{a,\ OM}$ x 100 for age 2 and 10+ over 5 years before the last year and for the final F (since F is very well-known to be biased for the last year) and the variations between the SSB from the VPA (SSB_{VPA}; in number) and SSB from the operational model (SSB_OM; in number): $|SSB_{VPA} - SSB_{OM}| / SSB_{OM}$ x 100 over 5 years before the last year and for the final SSB.

As these variations may be biased by specific simulations stemming from the simulated noise, we run each simulation 100 times. The mean and the standard deviation were calculated for each simulation that has been run 100 times.

3. Results

When CPUE and catch-at-age matrix does not include noise and the inputs of the VPA corresponded to the operational model, the VPA did perfectly (and obviously) retrieve the F at age, the SSB and the number of fish in the population. An example of the differences between F at age, SSB, and the number of fish in the population is given for 50% noise in the CPUE and CPUEs (**Figures 3 and 4**).

Table 2 gives the outputs of F_2 and F_{10+} estimated by the VPA vs. F_2 and F_{10+} from the operational model for the 30 simulations ran 100 times. The main results are that F at age 2 are well retrieved by the VPA. The differences between estimated and modelled F_2 are around 60% (sd ~20%) and the variations are always positive. It means that the VPA mainly over-estimate the Fs. The differences between estimated and modelled F_{10+} are however much higher 160% and up to 300%. The difference is maximum when the terminal F ratio is wrongly set which is consistent with the fact that it concerns the oldest ages.

Table 3 gives the outputs of final F_2 and F_{10+} estimated by the VPA vs. F_2 and final F_{10+} from the operational model for the 30 simulations ran 100 times. As expected, the final Fs are not correctly estimated and a high variation between simulated and retrieved values (up to 1000% in average) is observed for F_{10+}. Moreover the standard deviations have high values which indicates the high variability of the retrievals.

Table 4 gives the outputs of SSB estimated by the VPA vs. SSB from the operational model for the 30 simulations ran 100 times. SSB is correctly estimated in most cases and a high variation between simulated and retrieved values (500%) is observed when CPUE are randomly generated and the F is equal to F_{MSY}.

These simulations show that the estimations by the VPA can be considered as robust for SSB and F_{2-3}. These is however not the case for F_{8-10+}.

4. Discussion

The simulation framework developed in this study enables to test different hypotheses to assess the potential biases of the VPA. When there are no biases in the estimation of age (derived from the von Bertalanffy curve of BFT) is correct, the VPA performs well to retrieve the SSB even if CPUE and catch-at-age are strongly biased.
The main outcomes from the simulations that have been led can be summarized as follows:

- Final Fs are always overestimated and the current method to estimate the final Fs, i.e. mean over the last three years, is essential for projections
- Even if fishing mortality strongly decreases during the last 5 years, the SSB estimated by the VPA does not show any sign of recovery while it does in the operational model
- One of the strongest bias that could lead to bad estimations by the VPA may be the bias in age estimates. This could be tested in this simulation framework and the slicing method for age estimation could be assessed
- VPA works better when F is high and the stock strongly declines so a high TAC would be appropriate to ensure the good performance of the VPA

References

Beverton, R.J.H. and Holt, S.J. 1957, On the dynamics of exploited fish populations. Fishery Investigations London Serie 2 19:533 pp.

Fromentin, J.-M. and Bonhommeau, S. 2011, Estimates of selectivity for the East Atlantic and Mediterranean bluefin tuna from 1970 to 2009. Collect. Vol. Sci. Pap. ICCAT, 66. *(in this issue).*

Fromentin, J.-M. and Kell, L.T. 2007, Consequences of variations in carrying capacity or migration for the perception of Atlantic bluefin tuna population dynamics. Canadian Journal of Fisheries and Aquatic Science 67:627-836.

Fromentin, J.-M. and Powers, J.E. 2005, Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. Fish and Fisheries 6:281-306.

ICCAT. 1999, 1998 SCRS Detailed Report on Bluefin Tuna. Collect. Vol. Sci. Pap. ICCAT 49(2): 1-191.

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

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

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

ICCAT. 2009, Report of the 2008 Atlantic Bluefin Tuna Stock Assessment Session. Collect. Vol. Sci. Pap. ICCAT, 64(1): 1-352.

Kell, L.T., Die, Restrepo, V., Fromentin, J.-M., Ortiz de Zarate, V. and Pallares, P. 2003, An evaluation of management strategies for Atlantic tuna stocks. Scientia Marina 67:353-370.

Kell, L.T., Fromentin, J.-M., Gauthiez, F. and Restrepo, V. 2000, A simulation framework to evaluate management strategies for Atlantic tunas: a preliminary example based on East Atlantic bluefin tuna. Collect. Vol. Sci. Pap. ICCAT 51(6): 2095-2116.

Kell, L.T. and Fromentin, J.M. 2007, Evaluation of the robustness of MSY-based management strategies to variations in carrying capacity or migration pattern of Atlantic bluefin tuna Canadian Journal of Fisheries and Aquatic Science 64:837-847.

Porch, C.E. 1997, A User's Manual for VPA-2BOX Version 2.0., National Marine Fisheries Service, Miami. USA.

Table 1. Main features of the 30 scenarios performed.

	Noise level	*F pattern*	*Bias type in the VPA inputs*
Scenario 1	50	$F=F_{MSY}$	None
Scenario 2	100	$F=F_{MSY}$	None
Scenario 3	50	F increases up to 2.5 F_{MSY}	None
Scenario 4	100	F increases up to 2.5 F_{MSY}	None
Scenario 5	50	F increases and decreases	None
Scenario 6	100	F increases and decreases	None
Scenario 7	50	$F=F_{MSY}$	Random CPUE
Scenario 8	100	$F=F_{MSY}$	Random CPUE
Scenario 9	50	F increases up to 2.5 F_{MSY}	Random CPUE
Scenario 10	100	F increases up to 2.5 F_{MSY}	Random CPUE
Scenario 11	50	F increases and decreases	Random CPUE
Scenario 12	100	F increases and decreases	Random CPUE
Scenario 13	50	$F=F_{MSY}$	Varying terminal F ratio
Scenario 14	100	$F=F_{MSY}$	Varying terminal F ratio
Scenario 15	50	F increases up to 2.5 F_{MSY}	Varying terminal F ratio
Scenario 16	100	F increases up to 2.5 F_{MSY}	Varying terminal F ratio
Scenario 17	50	F increases and decreases	Varying terminal F ratio
Scenario 18	100	F increases and decreases	Varying terminal F ratio
Scenario 19	50	$F=F_{MSY}$	Wrong terminal F ratio
Scenario 20	100	$F=F_{MSY}$	Wrong terminal F ratio
Scenario 21	50	F increases up to 2.5 F_{MSY}	Wrong terminal F ratio
Scenario 22	100	F increases up to 2.5 F_{MSY}	Wrong terminal F ratio
Scenario 23	50	F increases and decreases	Wrong terminal F ratio
Scenario 24	100	F increases and decreases	Wrong terminal F ratio
Scenario 25	50	$F=F_{MSY}$	Wrong natural mortality
Scenario 26	100	$F=F_{MSY}$	Wrong natural mortality
Scenario 27	50	F increases up to 2.5 F_{MSY}	Wrong natural mortality
Scenario 28	100	F increases up to 2.5 F_{MSY}	Wrong natural mortality
Scenario 29	50	F increases and decreases	Wrong natural mortality
Scenario 30	100	F increases and decreases	Wrong natural mortality

Table 2. Mean and standard deviation of the variations between the VPA outputs and the operational model for the F at age 2 and at age 10+.

Simulation	Mean % variation in F2	sd % variation in F2	Mean % variation in F10+	sd % variation in F10+
noise 50 scenario1	43	14	136	113
noise 100 scenario1	62	25	233	188
noise 50 scenario2	37	12	79	61
noise 100 scenario2	49	15	121	89
noise 50 scenario3	39	15	89	85
noise 100 scenario3	59	19	125	88
false CPUE 50 scenario1	42	16	136	117
false CPUE 100 scenario1	64	27	222	181
false CPUE 50 scenario2	34	11	78	58
false CPUE 100 scenario2	50	18	120	89
false CPUE 50 scenario3	38	13	81	68
false CPUE 100 scenario3	56	22	151	121
varying F ratio 50 scenario1	44	16	220	193
varying F ratio 100 scenario1	69	28	302	248
varying F ratio 50 scenario2	35	12	108	74
varying F ratio 100 scenario2	53	18	138	109
varying F ratio 50 scenario3	38	13	133	120
varying F ratio 100 scenario3	57	21	197	147
wrong F ratio 50 scenario1	46	19	306	182
wrong F ratio 100 scenario1	64	25	437	274
wrong F ratio 50 scenario2	35	14	118	72
wrong F ratio 100 scenario2	52	16	195	134
wrong F ratio 50 scenario3	38	14	165	131
wrong F ratio 100 scenario3	57	21	278	203
wrong M 50 scenario1	51	21	134	99
wrong M 100 scenario1	70	32	243	196
wrong M 50 scenario2	35	13	85	56
wrong M 100 scenario2	52	18	104	63
wrong M 50 scenario3	40	14	82	67
wrong M 100 scenario3	55	20	148	121

Table 3. Mean and standard deviation of the variations between the VPA outputs and the operational model for the final F at age 2 and at age 10+.

Simulation	Mean % variation in F2 final	Sd % variation in F2 finals	Mean % variation in F10+ final	sd % variation in F10+ final
noise 50 scenario1	43	211	313	585
noise 100 scenario1	62	257	523	793
noise 50 scenario2	37	157	276	353
noise 100 scenario2	49	171	392	384
noise 50 scenario3	39	109	193	499
noise 100 scenario3	59	195	483	827
false CPUE 50 scenario1	42	233	269	435
false CPUE 100 scenario1	64	362	702	914
false CPUE 50 scenario2	34	113	332	379
false CPUE 100 scenario2	50	177	362	377
false CPUE 50 scenario3	38	276	178	458
false CPUE 100 scenario3	56	221	401	762
varying F ratio 50 scenario1	44	259	332	650
varying F ratio 100 scenario1	69	362	638	1031
varying F ratio 50 scenario2	35	101	344	489
varying F ratio 100 scenario2	53	142	526	584
varying F ratio 50 scenario3	38	323	326	806
varying F ratio 100 scenario3	57	245	661	1217
wrong F ratio 50 scenario1	46	290	725	1121
wrong F ratio 100 scenario1	64	297	857	1295
wrong F ratio 50 scenario2	35	114	471	654
wrong F ratio 100 scenario2	52	180	644	720
wrong F ratio 50 scenario3	38	331	482	1134
wrong F ratio 100 scenario3	57	242	1011	1630
wrong M 50 scenario1	51	262	315	522
wrong M 100 scenario1	70	345	515	794
wrong M 50 scenario2	35	107	386	387
wrong M 100 scenario2	52	144	350	382
wrong M 50 scenario3	40	60	230	545
wrong M 100 scenario3	55	451	440	820

Table 4. Mean and standard deviation of the variations between the VPA outputs and the operational model for the SSB.

Simulation	Mean % variation in SSB	sd % variation in SSB
noise 50 scenario1	25	14
noise 100 scenario1	18	10
noise 50 scenario2	12	5
noise 100 scenario2	22	8
noise 50 scenario3	12	7
noise 100 scenario3	19	8
false CPUE 50 scenario1	504	121
false CPUE 100 scenario1	499	126
false CPUE 50 scenario2	37	12
false CPUE 100 scenario2	35	12
false CPUE 50 scenario3	24	10
false CPUE 100 scenario3	24	9
varying F ratio 50 scenario1	27	15
varying F ratio 100 scenario1	19	13
varying F ratio 50 scenario2	12	5
varying F ratio 100 scenario2	23	8
varying F ratio 50 scenario3	12	6
varying F ratio 100 scenario3	20	8
wrong F ratio 50 scenario1	38	15
wrong F ratio 100 scenario1	25	13
wrong F ratio 50 scenario2	11	4
wrong F ratio 100 scenario2	24	8
wrong F ratio 50 scenario3	12	7
wrong F ratio 100 scenario3	19	6
wrong M 50 scenario1	31	16
wrong M 100 scenario1	22	13
wrong M 50 scenario2	11	4
wrong M 100 scenario2	22	7
wrong M 50 scenario3	14	8
wrong M 100 scenario3	18	8

Simulation	SSB VPA/SSB OM	sd SSB VPA/SSB OM
noise_50_scenario1	5.86	3.46
noise_100_scenario1	2.6	3.78
noise_50_scenario2	-1.19	1.69
noise_100_scenario2	-4.08	2.19
noise_50_scenario3	0.38	2.2
noise_100_scenario3	-2.89	2.49
false_CPUE_50_scenario1	95.26	25.39
false_CPUE_100_scenario1	95.23	25.06
false_CPUE_50_scenario2	-6.76	3.06
false_CPUE_100_scenario2	-7.02	2.7
false_CPUE_50_scenario3	-2.47	3.79
false_CPUE_100_scenario3	-2.64	4.1
varying_F_ratio_50_scenario1	5.2	3.03
varying_F_ratio_100_scenario1	2.57	3.49
varying_F_ratio_50_scenario2	-1.37	1.69
varying_F_ratio_100_scenario2	-4.24	1.9
varying_F_ratio_50_scenario3	-0.11	2.1
varying_F_ratio_100_scenario3	-3.03	2.34
wrong_F_ratio_50_scenario1	7.48	3.42
wrong_F_ratio_100_scenario1	3.26	2.79
wrong_F_ratio_50_scenario2	-1.3	1.69
wrong_F_ratio_100_scenario2	-3.95	2.17
wrong_F_ratio_50_scenario3	1.01	2.41
wrong_F_ratio_100_scenario3	-2.63	2.74
wrong_M_50_scenario1	6.31	3.66
wrong_M_100_scenario1	3.09	4.34
wrong_M_50_scenario2	-0.38	1.48
wrong_M_100_scenario2	-3.41	2.06
wrong_M_50_scenario3	1.13	2.27
wrong_M_100_scenario3	-1.19	3.11

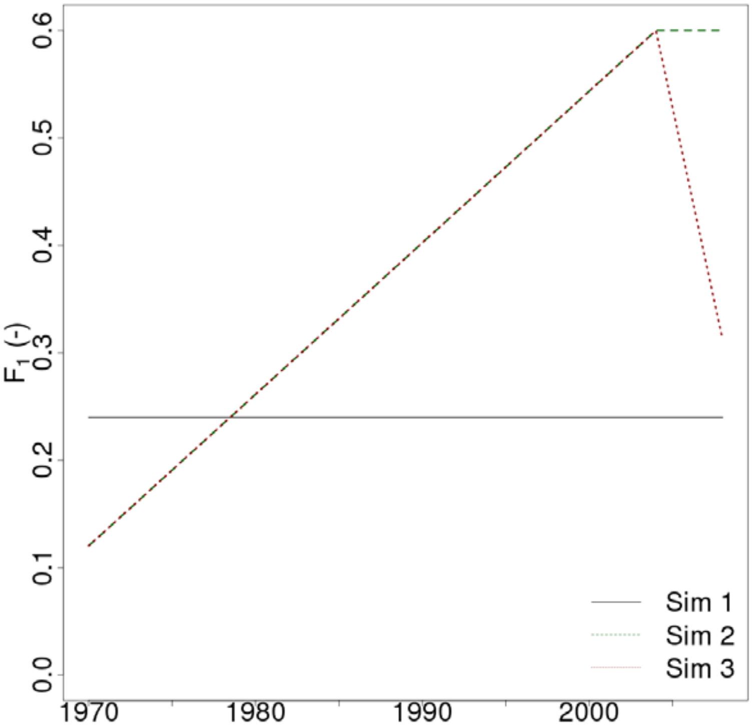

Figure 1. Patterns for F for a given age (here age 3, with initial F=0.24).

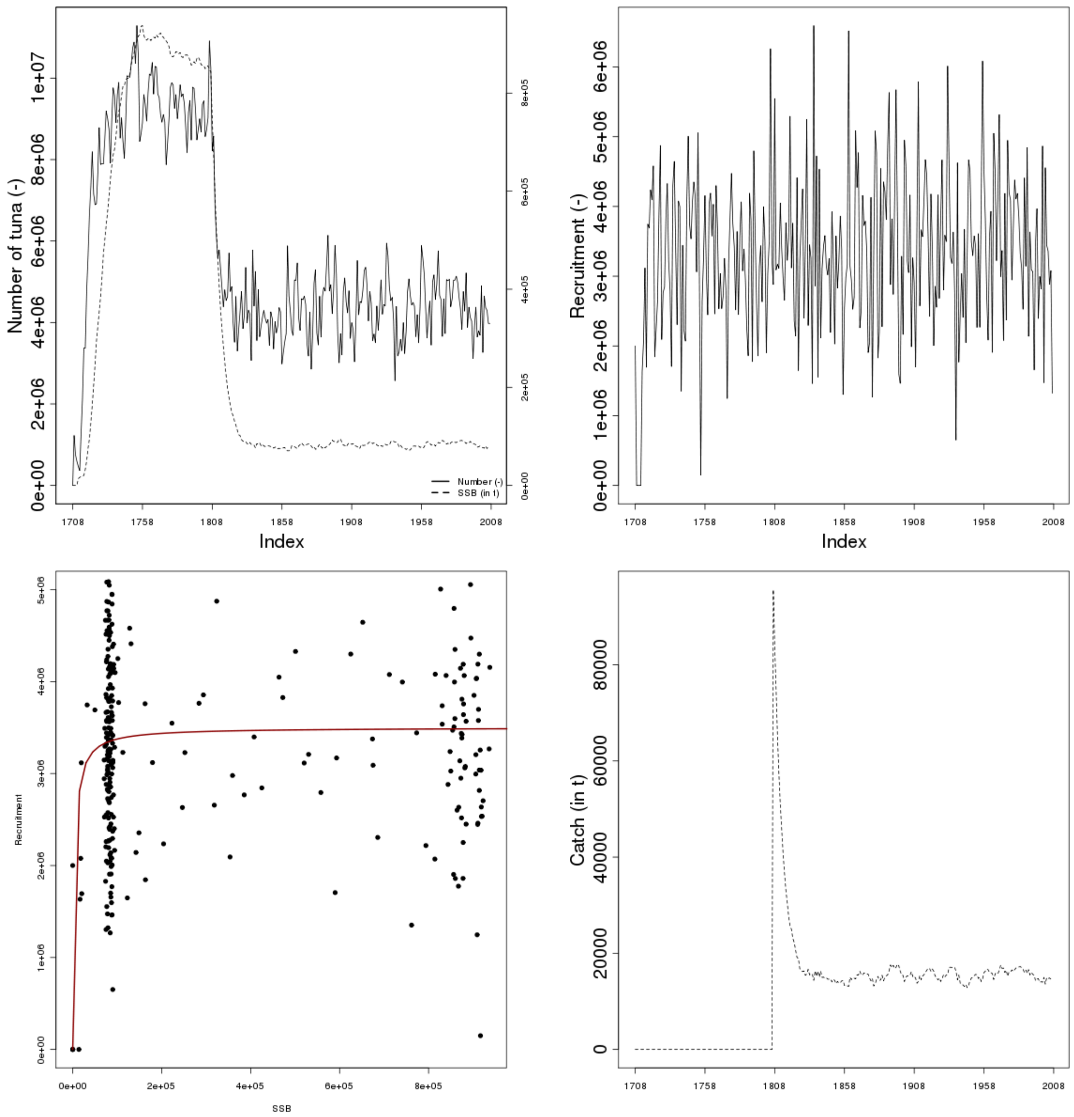

Figure 2. Outputs of the operational model for a constant F = M, 50% noise in CPUE and catch data over the 300 years that are simulated. Top left panel: total number of tuna in the population and SSB, top right panel: recruitment, bottom left panel, stock-recruitment relationship, bottom right panel: catch of tuna.

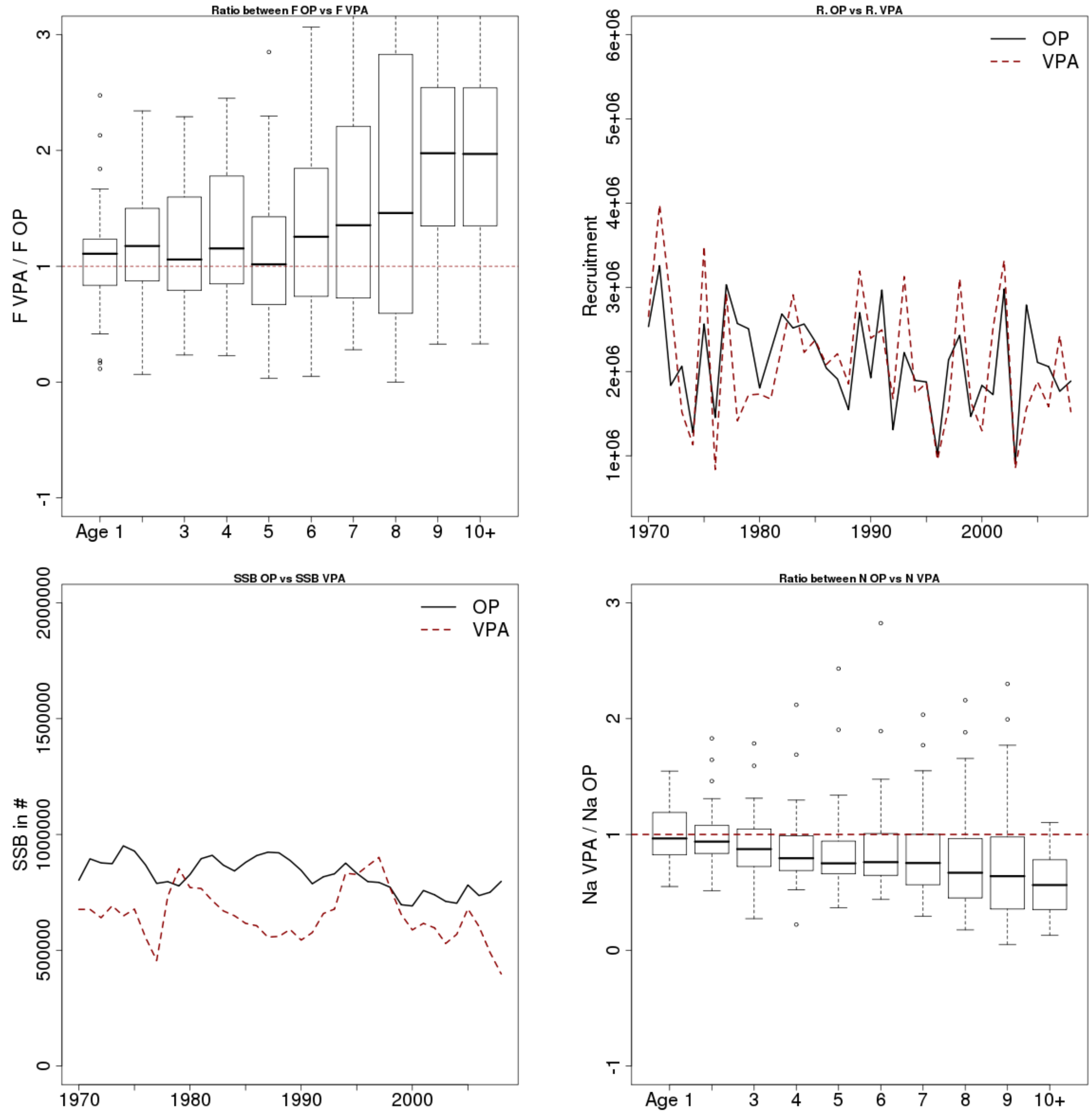

Figure 3. Outputs from the VPA for a 50% noise in CPUEs and catch-at-age with constant Fs set at M. Top left panel: ratio between Fs estimated by the VPA and Fs of the operational model, top right panel, recruitment estimated by the VPA and recruitment of the operational model, bottom left panel: SSB estimated by the VPA and SSB of the operational model (SSB in number), bottom right: ratio between the number of fish in the population estimated by the VPA and the number of fish in the population of the operational model.

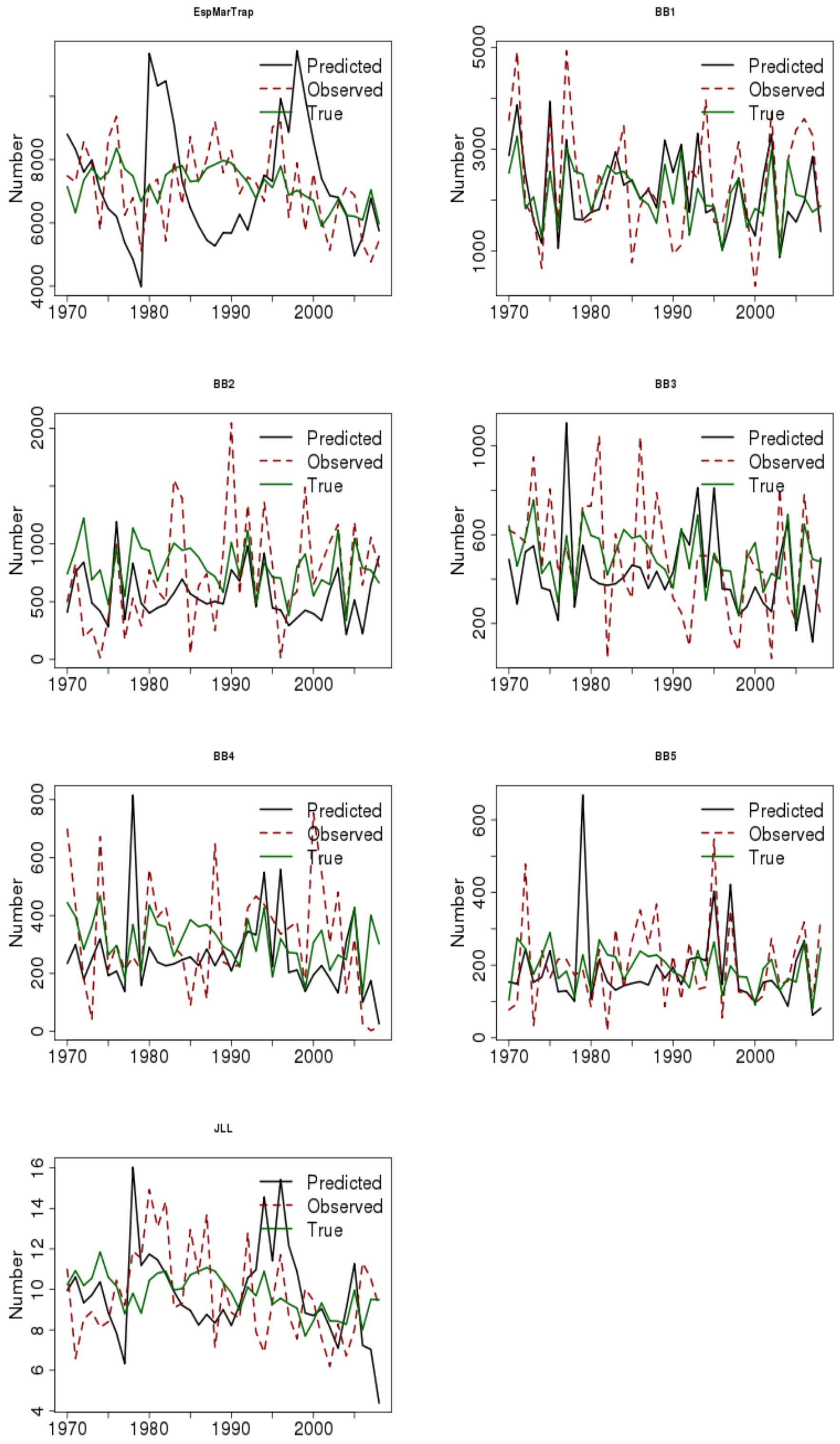

Figure 4. CPUEs estimated by the VPA for a 50% noise in CPUEs and catch-at-age with constant Fs set at M. Top left panel: ratio between Fs estimated by the VPA and Fs of the operational model, top right panel, recruitment estimated by the VPA and recruitment of the operational model, bottom left panel: SSB estimated by the VPA and SSB of the operational model (SSB in number), bottom right: ratio between the number of fish in the population estimated by the VPA and the number of fish in the population of the operational model.