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ASSESSING THE APPLICABILITY OF ENVIRONMENTAL INDICATORS FOR IMPROVING THE FISHERIES ASSESSMENT OF THE ALBACORE (*THUNNUS ALALUNGA*) UNDER THE A4A APPROACH

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SUMMARY

In this study we explore the potential for improving the stock assessment of Mediterranean Albacore by integrating environmental indicators. For this purpose we developed a catch at age model within the A4A stock assessment approach. The input data was similar to that used in the official SCRS stock assessment in 2017 but with an updated larval index. The environmental indicator provides information on the interannual variability of the sea surface temperature in the Balearic Sea during the spawning season, and it is included in the "Environmental pressure" component of the Ecosystem Report Card. The indicator is included in the assessment model in different ways, as index of the class age 0, as vector for the Stock/recruitment model, and as productivity value in other stock recruitment models (Ricker, Beverton-Holt). The results showed that incorporating the environmental variability indicators provide a better stock assessment fits (AIC, BIC), and also show the need for more advanced techniques to test stock assessment performance when testing the inclusion of environmental variability.

RÉSUMÉ

Dans cette étude, nous explorons le potentiel d'amélioration de l'évaluation du stock de germon de la Méditerranée en intégrant des indicateurs environnementaux. À cette fin, nous avons développé un modèle de prise par âge dans le cadre de l'approche d'évaluation des stocks A4A. Les données d'entrée étaient similaires à celles utilisées dans l'évaluation officielle du stock du SCRS en 2017, mais avec un indice larvaire actualisé. L'indicateur environnemental fournit des informations sur la variabilité interannuelle de la température de la surface de la mer Baléares pendant la saison de frai, et il est inclus dans la composante « Pression environnementale » de la fiche informative sur les écosystèmes. L'indicateur est inclus dans le modèle d'évaluation de différentes manières, comme indice de la classe d'âge 0, comme vecteur du modèle de stock-recrutement, et comme valeur de productivité dans d'autres modèles de recrutement de stock (Ricker, Beverton-Holt). Les résultats ont montré que l'intégration des indicateurs de variabilité environnementale fournit de meilleurs ajustements de l'évaluation des stocks (AIC, BIC), et montrent également la nécessité de techniques plus avancées pour tester la performance de l'évaluation des stocks lors de l'évaluation de l'inclusion de la variabilité environnementale.

RESUMEN

En este estudio exploramos el potencial para mejorar la evaluación del stock de atún blanco del Mediterráneo integrando indicadores medioambientales. Con este fin, hemos desarrollado un modelo de captura por edad dentro del enfoque de evaluación del stock A4A. Los datos de entrada eran similares a los usados en la evaluación del stock oficial del SCRS en 2017, pero con un índice larvario actualizado. El indicador medioambiental proporciona información sobre la variabilidad interanual de la temperatura de la superficie del mar en el mar Balear durante la temporada de desove, y está incluido en el componente «presión medioambiental» de la ficha informativa sobre ecosistemas. El indicador está incluido en el modelo de evaluación de diferentes formas, como índice de la clase de edad 0, como vector para el modelo stock/reclutamiento y como valor de productividad en otros modelos stock reclutamiento (Ricker, Beverton-Holt). Los resultados demostraron que incorporar los indicadores de variabilidad medioambiental proporciona mejores ajustes de la evaluación del stock (AIC, BIC) y mostró también la necesidad de técnicas más avanzadas para probar el desempeño de la evaluación del stock al probar la inclusión de la variabilidad medioambiental.

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KEYWORDS

Albacore; environmental indicators; Balearic Sea; Mediterranean; stock assessment; operational fisheries oceanography

1. Introduction

In the last decades, an interest regarding the incorporation environmental indices and indicators into fisheries stock assessment has surged (e.g. Forrestal et al. 2019, Crone et al. 2019). The crucial effects that environment plays on marine ecosystems, as well as on particular fish populations and on the interactions among species, is been known for a long time (Hjort, 1926; Cury and Roy, 1989). The effects of environment on fish populations encompass a myriad of aspects of species biology and distribution, from larval growth performance and survival to global distribution or migration patterns. Specially in the present context of climate change, understanding these effects and incorporating them within the fisheries stock assessment has become it has become crucial to be able to provide reliable stock assessment and specially if trying to predict the future evolution of the species dynamics, which in turn is needed if one wants to ensure a sustainable exploitation of natural resources.

There are some examples of stock assessments that direct or indirectly use environmental data to set management regulations (e.g. Schirripa, 2007; Hill et al., 2017, Crone et al., 2019, Thorson et al. 2020). However, the incorporation of environmental indices and indicators to routine stock assessments is, in general, a pending task for many of the currently stock assessed at global scale and in the Mediterranean (Skern-Mauritzen et al. 2016). The possibility of evaluating environmental drivers within the stock models are expected to better capture the impact of these covariates on the stock status metrics.

Albacore (*Thunnus alalunga*) from the Mediterranean Sea is considered a data-poor stock, and so suitable methods have been used to assess its status (Anon., 2017). The update of the albacore abundance index (from longliners and larval abundances, Alvarez-Berastegui et al. 2018) suggest that a downward trend. Unfortunately, the incomplete and limited quantitative information available makes albacore abundance trends to suffer from a high uncertainty of mean estimates (Anon., 2017). Changing environmental conditions incorporate sources of uncertainty in the assessment processes. One example is the variability of the hydrographic conditions in the spawning grounds during the early life stages of the tuna species. This variability affects a number of ecological processes, affecting the location of the spawning sites, egg hatching and larval survival. One of the most relevant hydrographic features driving these processes is the surface water temperature, which affects the spatial distribution of tuna eggs and larvae in the Western Mediterranean Sea (Alemany et al. 2010, Alvarez-Berastegui et al. 2014,2016, 2018, Reglero et al. 2017) and in the Central Mediterranean (Koched et al. 2016, Russo et al. 2019), the timing of reproduction (Gordoa and Carreras 2014, Reglero et al. 2018) , and the survival during the early life stages (Reglero et al. 2019). Therefore, time series of sea temperature at the most relevant spawning grounds of tuna species in the Mediterranean provides a reference data set to explore temperature trends to identify potentially anomalous years and test potential improvement in fitting population models.

Since 2018, a sea surface temperature indicator in the Mediterranean spawning grounds, during the spawning season is incorporated in the ICCAT ecosystem report card (Alvarez-Berastegui et al. 2018, Alvarez-Berastegui 2020). The aim of the present study is to explore the potential for improving stock assessment by integrating this environmental indicator. For this purpose we developed an a4a assessment model for Mediterranean albacore with available abundance indices used in the official SCRS stock assessment (Anon, 2017) and compare different model fits incorporating this SST indicator in different ways, as forcing vector of the class 0 abundance and as forcing vector of the productivity parameter of various stock-recruitment models (3 different SR models). The results obtained showed that incorporating the environmental variability indicators provide a better stock assessment fits (AIC, BIC), even if the model outputs cannot be considered for assessment of the species due to the need of abundance indices data update and revision.

2. Material and Methods

2.1 Data sources

Different type of information is available for developing a population model. These sources of information are related to: 1) the biology of the Mediterranean albacore stock, 2) the commercial catches (landings), 3) abundance indices from commercial fisheries, 4) larval indices informing on spawning stock biomass (fisheries independent of information) and 5) Sea Surface Temperature (SST) environmental indicator from hydrodynamic models.

Data on the biology of the species was retrieved from previously published information in the area (Saber et al. 2015) and refers to the gonadosomatic index (GSI) and length-frequency distributions (**Figure 1**). Abundance indices from commercial fisheries (**Figure 2**, from Anon. 2017) include an abundance index from the Spanish longline from the western Mediterranean from 2004 to 2015 (SPLL), an Italian long-line fisheries index from the central Mediterranean from 2011 to 2015 (ITLL) and another Italian long-line fisheries index, from the Adriatic from 1990 to 2000. Only the indices from the year 2000 onwards were used for modeling, as were considered more reliable. Regarding the larval index (LARV), it is a larval abundance index obtained from ichthyoplankton surveys performed around the Balearic Islands (**Figure 3**). The larval index is standardized by the habitat characteristics and back projected to 2.5 mm, in order to be a proxy of the spawning stock biomass (see Alvarez-Berastegui et al. 2018), following similar concept as the egg-production method (**Figure 3**). Data on Mediterranean albacore available from the ICCAT a database was also retrieved (**Figure 4**).

2.2 Environmental indices from hydrodynamic models

An update of the temperature derived indicator included in the ecosystem report card (Alvarez-Berastegui et al. 2018, 2019) was produced. This indicator, denoted as Mean temperature in the Balearic Sea Spawning ground (Western Mediterranean), "Temp_Bal_SG" which is computed in the Western Mediterranean, Balearic Sea (**Figure 5**), accounts for surface water temperature at 1.5 m and is trying to cope the higher relevance of the temperature during the phase of egg development, hatching process and the yolksac stage (Reglero et al. 2017). Temp_Bal_SG is computed from the temperature field of the "Mediterranean Forecasting System" hydrodynamic model (Simoncelly et al. 2014), that provides two different datasets: i) the Mediterranean Sea Physics Reanalysis product, covering the period for 1990 to 2018 period, and ii) the Mediterranean Sea Physics Analysis and Forecast product covering the 2019 year. Data was extracted from the daily resolution product at the 1.5-meter depth, as a proxy for the mean sea surface temperature. The diary temperature data for each spatial region is averaged along the months of May to August, both included. This time coverage has been selected as it covers the spawning season of most tuna species in the region (Reglero et al., 2018a, Saber et al., 2015). Values were scaled to represent the indicators.

2.3 Fisheries assessment model

We used a catch-at-age stock assessment model integrated in the Assessment For All (a4a) approach of the European Commission Joint Research Centre (Jardim et al. 2017). This approach is implemented in R (http://www.r-project.org/), within the Fisheries Library in R, FLR (http://www.flr-project.org/) and in the framework of the Automatic Differentiation Model Builder, ADMB (http://www.admb-project.org/). The FLR library is a flexible framework that allows the integration information from different sources into the assessment models.

The a4a approach allowed integrating population growth, natural mortality and reproduction (stock-recruitment), and to estimate population abundance and fishing mortality by the stock assessment model. Following Jardim et al. (2014), we conducted a 4-step modelling framework (**Figure 6**) structured into 4 steps: (i) reading the data from external source, (ii) converting length data to age data using a growth model, (iii) modelling natural mortality and finally (iv) assessing the stock.

First, we tested the performance of the catch-at-age assessment model to eight different configurations (Table 1), including different abundance indices. Two recruitment vectors were considered: recruitment as the geometrical mean (geom.mean) or as a factor of year. Particularly, model 1 incorporated the recruitment as a geometrical mean while models 2 to 8 included recruitment as factor=year. The model number 8 included the environmental indicator (Temp_Bal_SG) as FLR_index for fitting the trends in the class 0, as it is supposed to affect recruitment. The objectives of this analysis was to obtain the best fit possible to get a fisheries model to use for testing further analyses with different recruitment models and the Temp_Bal_SG. For each model, the Aikaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were computed. Model residuals were inspected by means of plots of log residuals plots of catch and abundance indices by age, bubble plots of log residuals of catch an abundance index and quantile-quantile plots of log residuals of catch and abundance indices. Plots of the assessment outputs, showing the stock summary (trends in recruitment, SSB, catch and harvest), 3D plots of catch at age per year, fishing mortality at age per year and biomass population at age per year were also revised.

After the assessment model was developed, we tested the impact of inclusion of different stock/recruitment models (SR models) (Table 2). The Temp_Bal_SG was considered in different ways, as a direct vector of recruitment (i) (see specifications in Table 2), and as part of the productivity parameter of the Beverton-Holt (ii) and the Ricker model (iii). In order to analyze the impact of the different SR relationships (with and without Temp_Bal_SG) we computed for each model the AIC, BIC and plot the assessment outputs (recruitment, spawning stock biomass, catch and fishing mortality).

3. Results

Model performance to different model configurations (**Table 3**) showed that the model with the lowest AIC and BIC was the model with only the SPLL index included, although the plots of the model outputs revealed very variable time series response. Models that only included the ITLL or the LARV indices (model 3 and 4) did not converge as it didn't model containing Temp_Bal_SG to improve 0-age class did not converge (model 8). Model 7 was selected as the candidate for the analyses of inclusion of environmental variability in the recruitment model, according to the model residuals plots and the plots of the output summaries (**Figure 7A**, **7B**).

The results of the analyses for testing stock/recruitment models with and without the Temp_Bal_SG showed that the lowest AIC was the Ricker model adjusted for SST in the productivity parameter (**Table 4).** It is also important to highlight that the lowest BIC did not coincide with the lowest AIC. Here the models with the lowest BIC were the ones where the stock-recruitment is directly assigned to the SST and the SSTrandom vector. These two models showed no temporal trend in the recruitment as seen in the output plots of these models (**Figure 8**). We know that these results do not respond to a biological reason as the SSTradom vector is an artificial artifact used to test error of type I in the analyses performed. It is also important to note that the fisheries model with the Ricker SR did not converge, and it only did when the SST series was considered.

The exploration of the AIC, BIC and output plots justified selecting the Ricker adjusted with SST as the best stock assessment model.

4. Discussion

This study served as a baseline for the integration of environmental indicators and indices within the stock assessments in order to improve currently applied models for the albacore in the Mediterranean.

1- The results of this analysis showed that the sea surface temperature index in the spawning ground (Temp_Bal_SG) improved the performance of the fisheries assessment model. This result is relevant for advancing in the integration of environmental variability into the fisheries assessment, a relevant task in "operational fisheries oceanography" (Alvarez-Berastegui et al. 2016).

2- The a4a assessment approach provides a quite adequate framework for advancing in the integration of environmental variability into the fisheries assessment process. Improvements can be done in order to facilitate the application of this framework by researchers in the field of marine ecology but not experts in fisheries assessment models. One example is the development of more quantitative indicators allowing to compare performance of different model results, as the AIC and BIC have demonstrated here to present limitations when being applied to select the best model (contrasting results between the 2 indicators, or not providing the most biological plausible model), therefore careful investigation of output plots have been decisive to choose best models.

3- The tools within the a4a allowed direct inclusion of environmental indices in the fisheries assessment models for the Mediterranean albacore at various levels. Here we tested the inclusion of new abundance indices as “FLR abundance index object”, and the inclusion of an environmental indicator, related to the sea surface temperature during the development of early life stages of this species. This environmental indicator was assigned to the recruitment process in different ways within the Stock Recruitment model in the catch at age population model. The possibility of assigning the SST vector directly to the productivity parameter “a” in the Ricker model resulted in the most useful functionality for this test.

4- The models here presented provide a useful framework for testing hypothesis related to the application of information related to environmental variability, but they cannot be considered for official assessment of the stock. In order to obtain a model for advice some revisions need to be performed on input data, especially for the catch matrix in year 2009where data errors were identified and could have direct effects on the model results in 2009 not fitting the input data (see **Figure 7B**).

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References

Alemany, F., Quintanilla, L., Velez-Belchí, P., García, A., Cortés, D., Rodríguez, J. M., ... & López-Jurado, J. L. (2010). Characterization of the spawning habitat of Atlantic bluefin tuna and related species in the Balearic Sea (western Mediterranean). Progress in Oceanography, 86(1-2), 21-38.

Anon. 2017 Report of the 2017 ICCAT albacore species group intersessional meeting (including assessment of Mediterranean albacore) Collect. Vol. Sci. Pap. ICCAT, 74(2): 508-583.

Álvarez-Berastegui D., Ciannelli L., Aparicio-Gonzalez A., Reglero P., Hidalgo M., López-Jurado J. L., Tintoré J., Alemany F. (2014) Spatial Scale, Means and Gradients of Hydrographic Variables Define Pelagic Seascapes of Bluefin and Bullet Tuna Spawning Distribution. PloS one 9: e109338.

Álvarez-Berastegui D., Hidalgo M., Tugores M.P., Reglero P., Aparicio-González A., Ciannelli L., Juza M., Mourre B., Pascual A., López-Jurado J. L., García A., Rodríguez J. M., Tintoré J., & Alemany F. (2016) Pelagic seascape ecology for operational fisheries oceanography: modelling and predicting spawning distribution of Atlantic bluefin tuna in Western Mediterranean. ICES Journal of Marine Science: Journal du Conseil.

Álvarez-Berastegui D., Saber S., Ingram W.G.Jr, Díaz-Barroso L., Reglero P., Macías D., García-Barcelona S., Ortiz de Urbina J., Tintoré J., Alemany F. (2018). Integrating reproductive ecology, early life dynamics and mesoscale oceanography to improve albacore tuna assessment in the Western Mediterranean. Fisheries Research, 208C (2018) pp. 329-338. https://doi.org/10.1016/j.fishres.2018.08.014

Crone, P.R., Maunder, M.N., Lee, H.H., Piner, K.R. Good practices for including environmental data to inform spawner-recruit dynamics in integrated stock assessments: small pelagic species case study. Fisheries Research, 217: 122-132 https://doi.org/10.1016/j.fishres.2018.12.026

Cury, P., Roy, C. (1989). Optimal environmental window and pelagic fish recruitment success in upwelling areas. Canadian Journal of Fisheries and Aquatic Sciences, 46 (4): 670-680

Gordoa A, Carreras G (2014) Determination of Temporal Spawning Patterns and Hatching Time in Response to Temperature of Atlantic Bluefin Tuna (Thunnus thynnus) in the Western Mediterranean. PLoS ONE 9(3): e90691. https://doi.org/10.1371/journal.pone.0090691

Hill, K.T., Crone, P.R., Zwolinski, J.P. (2017). Assessment of the Pacific Sardine Resource in 2017 for U.S.A. Management in 2017-18. NMFS-SWFSC-576. 146 pp. U.S. Dep. Commer. NOAA Tech. Memo. http://www.pcouncil.org/wp-content/uploads/2017/05/Appendix-C-2017-sardine-assessment-NOAA-TM-NMFS-SWFSC-576.pdf

Hjort, J. (1926) Fluctuations in the year classes of important food fishes, J. Cons., 1: 5-38

Jardim E., Damalas D., Mosqueira I., Osio C., Rouyer T., Scarcella G., Scott F. (2014). Stock assessment and multi-fleet forecast methods for some Mediterranean stocks, JRC Scientific and Policy Reports, Report EUR 26716 EN

Jardim E., Millar C., Scott F., Osio C., Mosqueira I. (2014). Assessment for All initiative (a4a)The a4a Stock Assessment Modelling Framework, European Commission, Joint Research Centre, http://www.flr-project.org/FLa4a/articles/sca.pdf

Koched, W., Alemany, F., Benmessaoud, R., Hattour, A. & Massuti, E. (2016). Characterization of the spawning area of tuna species on the northern Tunisian coasts. Scientia Marina. 80. 10.3989/scimar.04332.27A.

Reglero P., Blanco E., Alemany F., Ferré C., Alvarez-Berastegui D., Ortega A., de la Gándara F., Aparicio-González A., Folkvord A. (2018b) Vertical distribution of Atlantic bluefin tuna Thunnus thynnus and bonito Sarda sarda larvae is related to temperature preference. Marine Ecology Progress Series 594: 231-243.

Reglero P., Ortega A., Balbín R., Abascal F. J., Medina A., Blanco E., de la Gándara F., Alvarez-Berastegui D., Hidalgo M., Rasmuson L. (2018a) Atlantic bluefin tuna spawn at suboptimal temperatures for their offspring. Proc.R.Soc.B 285: 20171405.

Reglero, P., Santos, M., Balbín, R., Laíz-Carrión, R., Alvarez-Berastegui, D., Ciannelli, L., (...), Alemany, F. (2017). Environmental and biological characteristics of Atlantic bluefin tuna and albacore spawning habitats based on their egg distributions. Deep Sea Research Part II: Topical Studies in Oceanography, 140, 105-116.

Russo S. Patti B., Torri M., Reglero Barón P., Álvarez Berastegui D., Sarà G., Cuttitta A., (2019). Characterization of the larval habitat of tuna species in the Central Mediterranean Sea, Larval Fish Conference, May 2019, Palma de Mallorca, Spain,

Saber, S., de Urbina, J.O., Gómez-Vives, M.J., Macías, D. (2015). Some aspects of the reproductive biology of albacore *Thunnus alalunga* from the western Mediterranean Sea. J. Mar. Biol. Assoc. U.K. 95 (08), 1705–1715.

Schirripa, M.J. (2007). Status of the sablefish resource off the continental U.S. Pacific Coast in 2005. Pacific Fishery Management Council, 770 NE Ambassador Place, Suite 101, Portland, Oregon 97220, USA.

Simoncelli, S., Fratianni, C., Pinardi, N., Grandi, A., Drudi, M., Oddo, P., & Dobricic, S. (2014). "Mediterranean Sea physical reanalysis (MEDREA 1987-2015) (Version 1)". set. E.U. Copernicus Marine Service Information. DOI: https://doi.org/10.25423/medsea_reanalysis_phys_006_004

Skern-Mauritzen, M., Ottersen, G., Handegard, N. O., Huse, G., Dingsør, G. E., Stenseth, N. C., & Kjesbu, O. S. (2016). Ecosystem processes are rarely included in tactical fisheries management. Metroeconomica, 67(3), 165–175. https://doi.org/10.1111/faf.12111

Thorson, J. T., Maunder, M. N., & Punt, E. (2020). The development of spatio-temporal models of fishery catch-per-unit-effort data to derive indices of relative abundance. Fisheries Research, 230. https://doi.org/10.1016/j.fishres.2020.105611

Table 1. Fisheries model fit configurations. SPLL: Spanish long-line; ITLL: Italian long-line, LARV: larval index; Temp_Bal_SG: temperature indicator.

	Test indices		
Model	**Abundance index**	**Environmental index**	**Recruitment**
1	SPLL	-	geom.mean
2	SPLL	-	as.factor (year)
3	ITLL	-	as.factor (year)
4	LARV	-	as.factor (year)
5	SPLL + ITLL	-	as.factor (year)
6	SPLL + LARV	-	as.factor (year)
7	SPLL + ITLL + LARV	-	as.factor (year)
8	SPLL + ITLL + LARV	Temp_Bal_SG	as.factor (year)

Table 2. Stock recruitment (SR) models configuration and specifications. Models names "*.sst" where those including the Temp_Bal_SG.

Acronym	**SR model configuration**	**Specifications**
year	srmod <- ~ factor(year)	Recruitment model fit, equal to the mean per year
Sr.SST	~ SST	Recruitment model fit, equal to the SST values
Sr.SSTr	~ SSTrandom	Recruitment productivity parameter equal to a random vector with min and max equal to SST
Sr.geomean	~ geomean(CV=0.1)	Constant recruitment model fit, equal to the historical geometric mean recruitment.
Sr.bevholt	~ bevholt(CV=0.1)	Beverton-Holt stock-recruitment model
Sr.bevholt.sst	~ bevholt(a=~SST.1, CV=0.1)	*a* is related to productivity (recruits per stock unit at small stock size)
Sr.Ricker	~ Ricker(CV=0.1)	Ricker stock-recruitment model fit
Sr.Ricker.sst	~ Ricker(a=~SST.1, CV=0.1)	Ricker , *a* is related to productivity (recruits per stock unit at small stock size)

Table 3. Model performance for the different configurations showing the AIC and BIC. In color: heat map with higher (blue) to lower values (red), NA: models with no convergence and computation of AIC and BIC was impossible.

Model fit	Test indices	AIC	BIC
1	SPLL and recruitment =geom.mean	581	793
2	SPLL	440	581
3	ITLL	NA	NA
4	LARV	NA	NA
5	SPLL and ITLL (fisheries dependent)	462	610
6	SPLL and LARV (fisheries dependent and independent)	469	618
7	SPLL, ITLL, LARV (all abundance indices)	482	639
8	SPLL, ITLL, LARV +SST (All abundance indices and environmental)	NA	NA

Table 4. Model performance of the stock assessment model 7, when included different stock/recruitment model approximations showing the AIC and BIC. Letters in red are models including the SSTrandom variable. Cell colors indicating lower (red) and higher (blue) AIC and BIC values (the lower the better)

Model acronym	Stock recruitment configuration	AIC	BIC
year	srmod <- ~ factor(year)	482	639
Sr.SST	~ SST	493	604
Sr.SSTr	~ SSTrandom	491	602
Sr.geomean	~ geomean(CV=0.1)	478	638
Sr.bevholt	~ bevholt(CV=0.1)	NA	NA
Sr.bevholt.sst	~ bevholt(a=~SST.1, CV=0.1)	NA	NA
Sr.Ricker	~ Ricker(CV=0.1)	NA	NA
Sr.Ricker.sst	~ Ricker(a=~SST.1, CV=0.1)	452	618

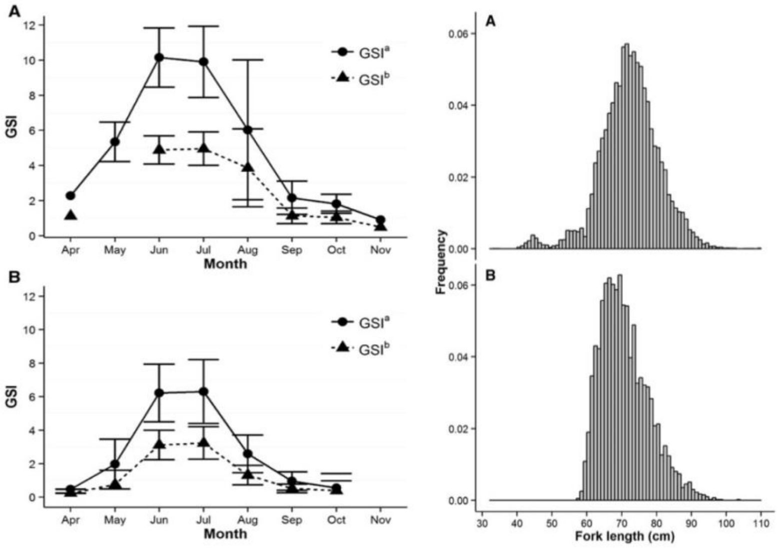

Figure 1. Biological information on albacore from the western Mediterranean Sea: (Left) Gonadosomatic index of individuals from mature females (A) and mature males (B); (Right): Fork length (cm) of long line fishery catches (A) and the recreational fishery (B). Figures from Saber et al. 2015

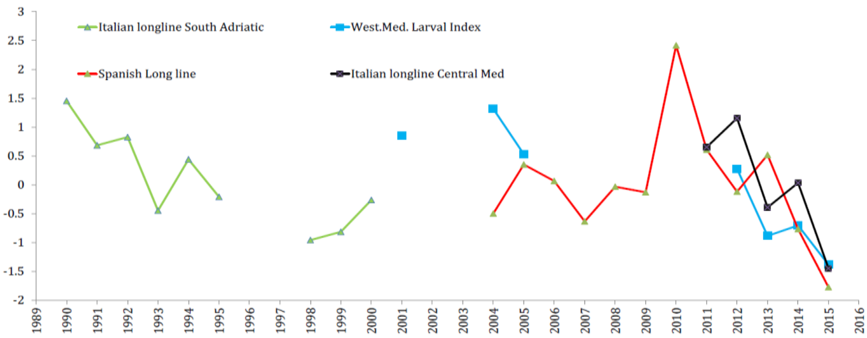

Figure 2. Indices available for the assessment models including the larval index (from Anon. 2017).

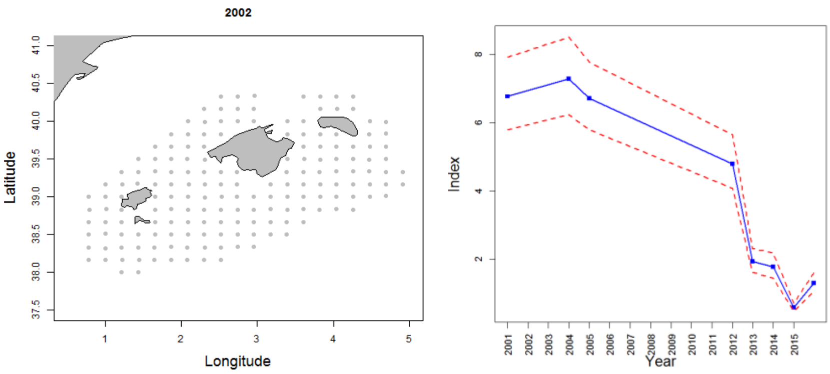

Figure 3. Albacore larval index: (Left) location of ichthyoplankton surveys in the Balearic Sea (Western Mediterranean) and (Right) larval index values with 95% confidence intervals. Figures from Alvarez-Berastegui et al. 2018

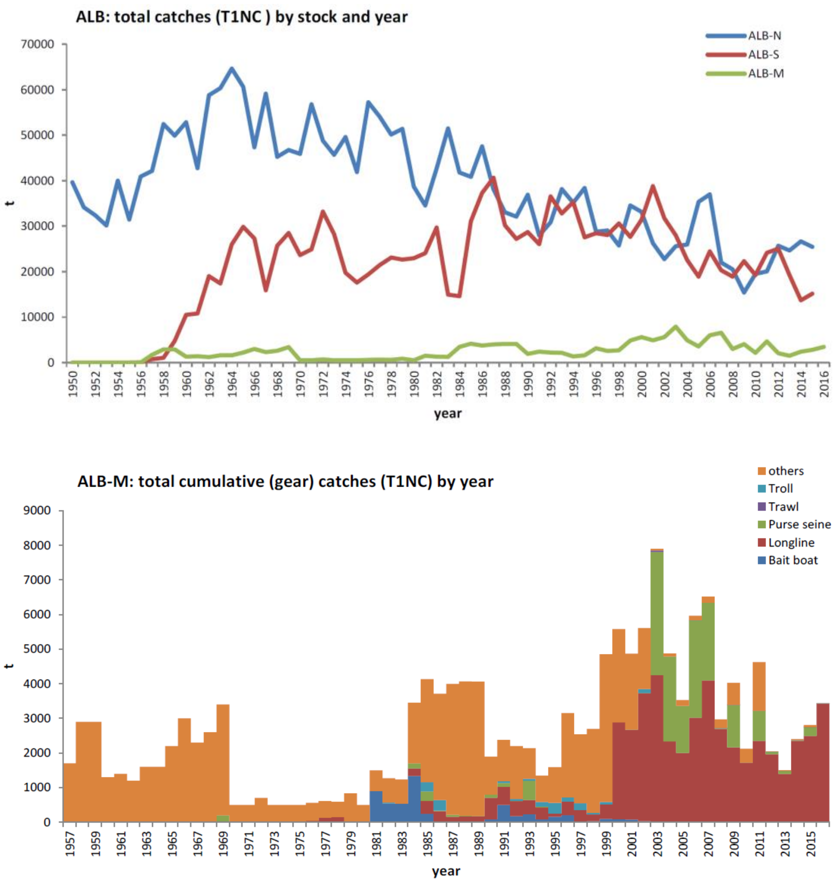

Figure 4. Albacore catches in different areas: (A) Total albacore catches (TINC: landings and dead discards) by stock and year. ALB-N - North Atlantic; ALB-S - South Atlantic; ALB-M-Mediterranean; (B) Mediterranean albacore total cumulative (by gear) catches (TLNC: landings + dead discards) by year. Figures from Anon. 2017

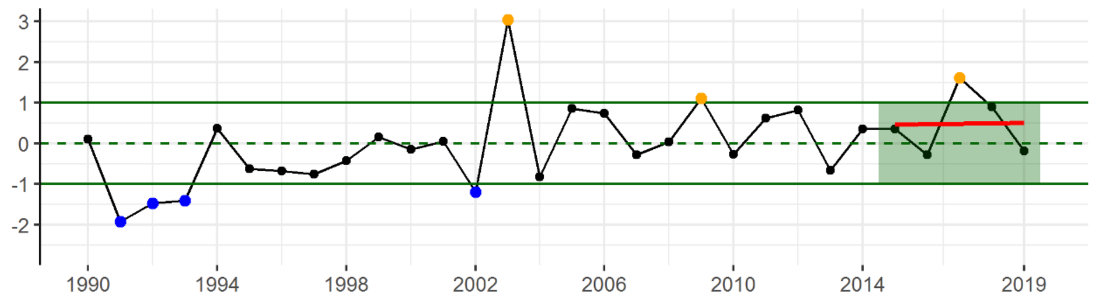

Figure 5. Sea surface temperature index (SST): mean surface water temperature (May-Aug) in the Balearic spawning ground.

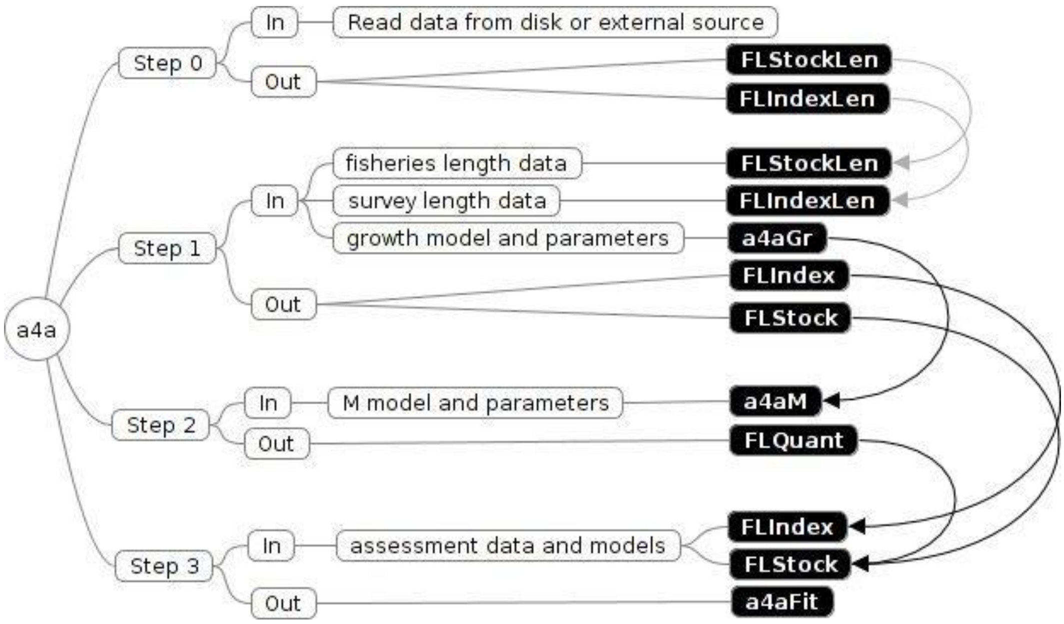

Figure 6. In/Out process of the a4a approach (Jardim et al. 2014). The boxes in black represent the classes of the objects that carry the information in and out of each step.

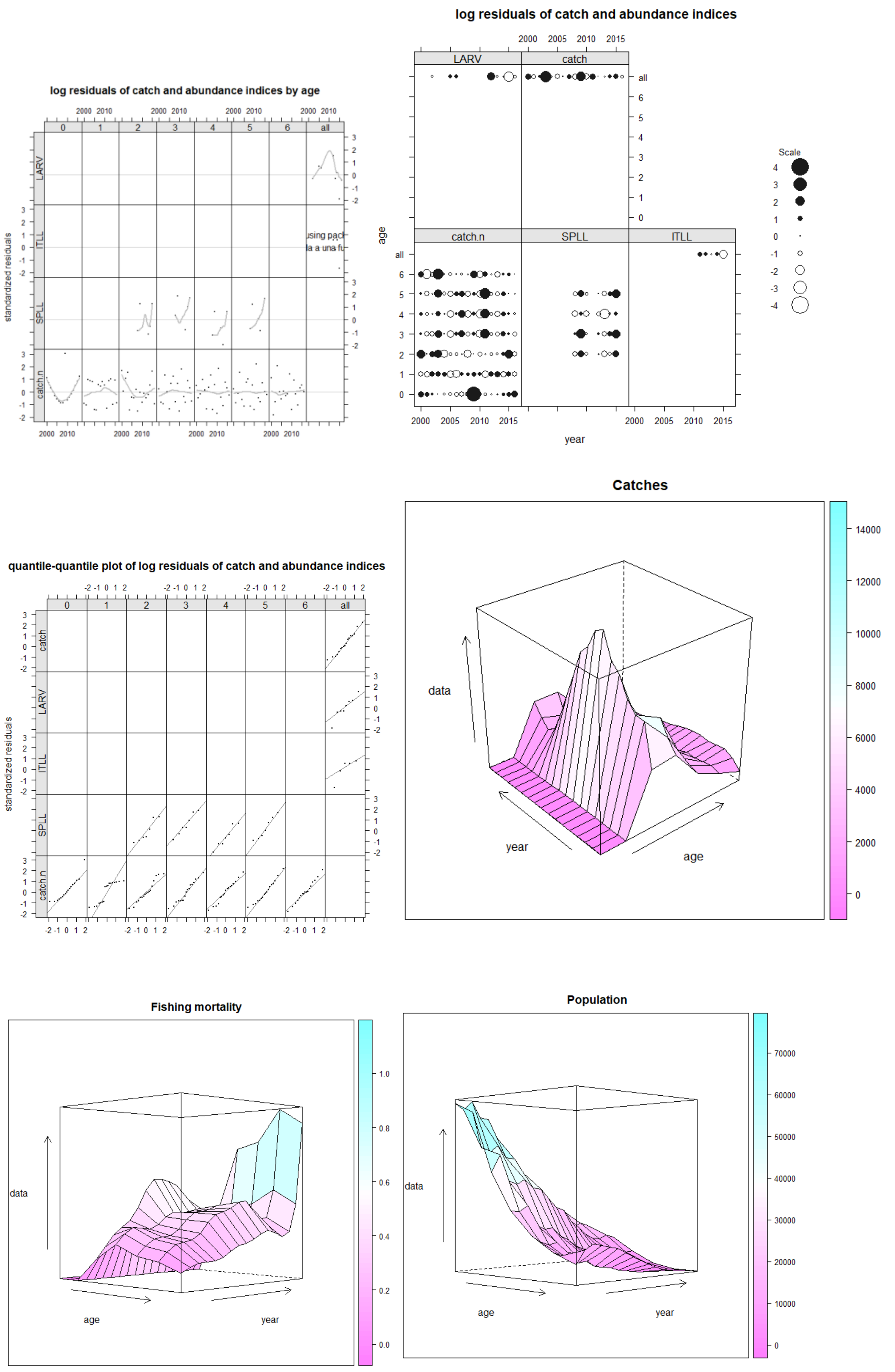

Figure 7A. Check plots for the selected assessment model.

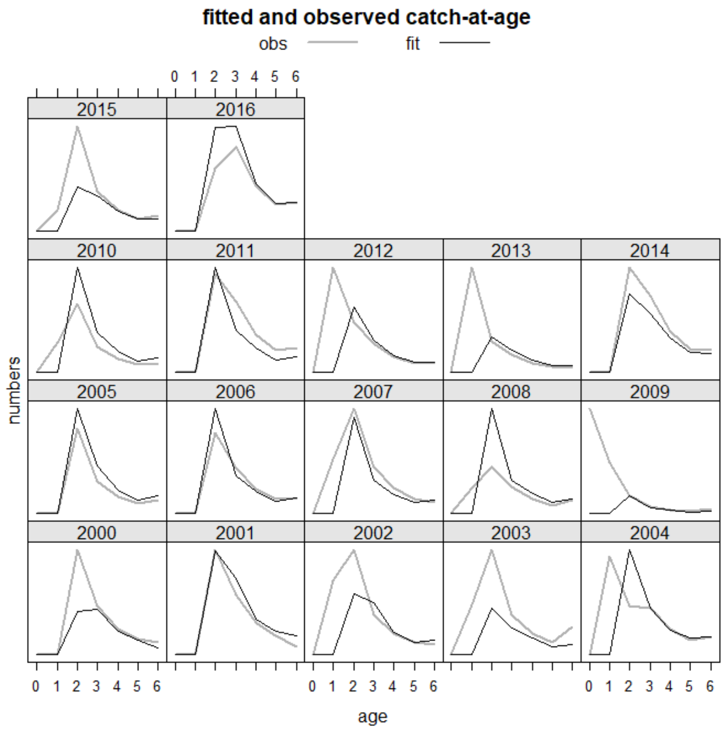

Figure 7B. Check plots for the selected assessment model.

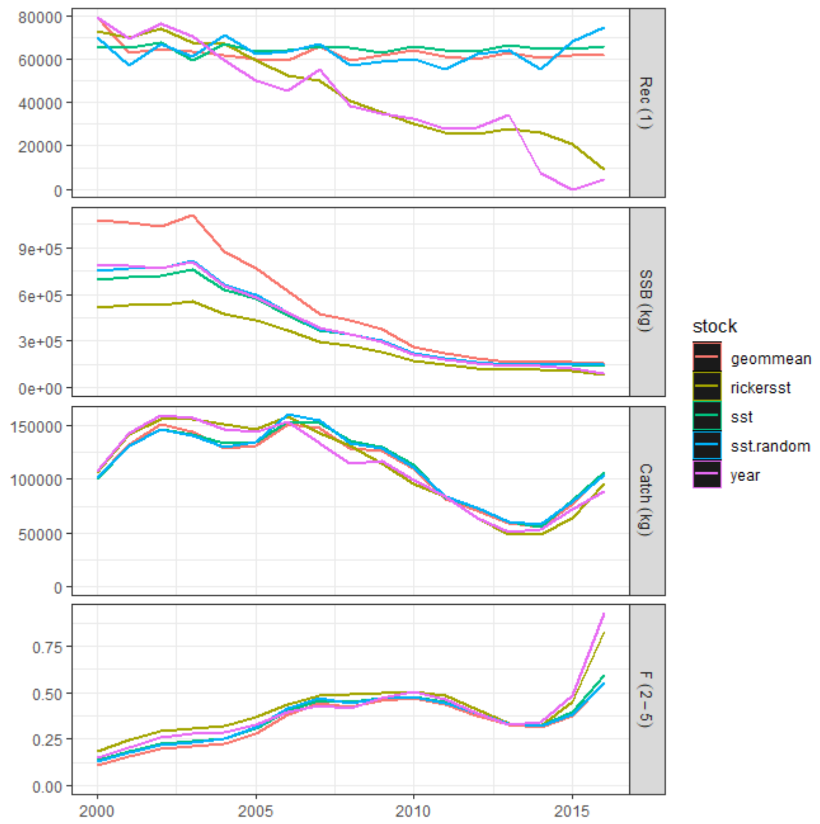

Figure 8. Fisheries assessment models, outputs with different stock recruitment models.