ALBACORE (*THUNNUS ALALUNGA*) LARVAL INDEX IN THE WESTERN MEDITERRANEAN SEA, 2001-2015

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SUMMARY

Larval abundance indices express standardized abundances of larval densities from ichthyoplankton surveys. For more than two decades these indices have been used to assess the trends of the spawning stock biomass of various species in the Gulf of Mexico, being incorporated into the population models applied by ICCAT. Recently, the delta-lognormal models used for the calculation of the indices have been improved to incorporate the environmental variability and have been applied in the Balearic Sea to obtain a larval index for bluefin tuna (Thunnus thynnus). Here we apply the same methodological approach to calculate a larval index of albacore (Thunnus alalunga) from surveys conducted from 2001 to 2015 in the Balearic Sea, the most relevant spawning ground of this species in the Western Mediterranean. Results show a decreasing trend on albacore larval abundances and significant lower abundances from 2013 to 2015. This larval index, standardized for gears, sampling coverage, hour, salinity, date and sea surface temperature, attempt to provide information on the dynamic of the western Mediterranean stock of albacore, for which not much information available for assessment is available.

RÉSUMÉ

*Les indices d'abondance larvaire expriment les abondances standardisées de la densité larvaire à partir de prospections d'ichthyoplancton. Pendant plus de deux décennies, ces indices ont été utilisés pour évaluer les tendances de la biomasse du stock reproducteur de diverses espèces dans le golfe du Mexique et ont été incorporés dans les modèles de population utilisés par l'ICCAT. Récemment, les modèles delta log-normal utilisés pour calculer les indices ont été améliorés afin d'incorporer la variabilité environnementale et ont été appliqués dans la mer des Baléares afin d'obtenir un indice larvaire pour le thon rouge (*Thunnus thynnus*). La même méthodologie a été appliquée pour calculer un indice larvaire du germon (*Thunnus alalunga*) à partir des prospections réalisées entre 2001 et 2015 dans la mer des Baléares, la principale zone de frai de cette espèce de la Méditerranée occidentale. Les résultats présentent une tendance décroissante de l'abondance larvaire du germon et une abondance significativement plus faible de 2013 à 2015. Cet indice larvaire, standardisé pour les engins, la couverture de l'échantillonnage, l'heure, la salinité, la date et la température à la surface de la mer, vise à fournir des informations sur la dynamique du stock de germon de la Méditerranée occidentale, au sujet duquel il existe peu d'informations pour l'évaluation.*

RESUMEN

Los índices de abundancia de larvas expresan abundancias estandarizadas de densidades de larvas a partir de prospecciones de ictioplancton. Durante más de dos décadas estos índices se han utilizado para evaluar las tendencias de la biomasa reproductora del stock de varias especies en el golfo de México, y se han incorporado en los modelos de población aplicados

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por ICCAT. Recientemente los modelos delta lognormal utilizados para calcular los índices se han mejorado para incorporar la variabilidad medioambiental y se han aplicado al mar Balear para obtener un índice de larvas para el atún rojo (Thunnus thynnus). En este caso se ha aplicado el mismo enfoque metodológico para calcular un índice larvario de atún blanco (Thunnus alalunga) a partir de prospecciones realizadas desde 2001 a 2015 en el mar Balear, la zona de reproducción más importante para esta especie en el Mediterráneo occidental. Los resultados muestran una tendencia decreciente en la abundancia de larvas de atún blanco y unas abundancias significativamente inferiores de 2013 a 2015. Con este índice de larvas, estandarizado para los artes, la cobertura de muestreo, la hora, la salinidad, la fecha y la temperatura de la superficie del mar se intenta proporcionar información sobre la dinámica del stock de atún blanco del Mediterráneo occidental, para el que no se dispone de mucha información con vistas a su evaluación.

KEYWORDS

Abundance, Albacore, Catchability, Fish larvae,
Fishery sciences, Mathematical models, Pelagic environment, Spawning, Tuna fisheries

1. Introduction

Larval abundance indices express standardized abundances of larval densities from ichthyoplankton surveys. For more than two decades, after the first larval abundance index was proposed for bluefin tuna (*Thunnus thynnus*) in the Gulf of Mexico (Scott *et al.* 1993), temporal trends of the larval abundances have been used to assess the trends of the spawning biomass of the western stock of bluefin tuna. During the last decade the techniques developed to estimate the indices were improved by the application of the delta log-normal models (Ingram *et al.* 2010). This approach, appropriated for zero-inflated distributed data, implied a relevant advance in the standardization of larval catches regarding changes in fishing gear, effort and timing. Since then, the same techniques have been applied in the Gulf of Mexico to assess spawning stock biomass of the species *Katsuwonus pelamis* (Ingram 2014), *Euthynnus alletteratus* and *Coryphaena hippurus* (Ingram 2017) and for the genus *Auxis* (Ingram 2017).

The methods developed for the calculation of the larval index in the Gulf of Mexico were applied in the Balearic islands to assess the bluefin tuna spawning stock biomass (Ingram et al, 2013), showing that the ichthyoplankton surveys in the Balearic Sea are a relevant source of information that can provide independent fishery indices of tuna species reproducing in the area. Since then the methods applied to compute the bluefin tuna larval index in the Balearic sea has been improved to incorporate the variability on local oceanographic conditions (Alvarez-Berastegui 2016, Ingram *et al.* 2017) and specific coefficients for fishing gear calibrations (Alvarez-Berastegui *et al.* 2017). Such larval indices for the bluefin eastern stock will be also incorporated into the population models applied by ICCAT.

The objective of the study presented here is to calculate a larval index of albacore (*Thunnus alalunga*) from ichthyoplankton surveys conducted in the Balearic Sea (**Figure 1**) applying the same methodological approach. This area is known to be a relevant spawning ground of this species in the Western Mediterranean (Alemany *et al.* 2010). Larvae have been systematically captured around the archipelago in ichthyoplankton surveys conducted during June-July (Alemany et al 2010, Reglero *et al.* 2012, Torres *et al.* 2011) and adult individuals are also found around the archipelago during spring-summer (Saber *et al.* 2015 a, b). Histological gonad analyses show that mature individuals can spawn from May to August with a peak in gonadosomatic index during June-July (Saber *et al.* 2015b).

During June and July albacore adults are also found in other areas of the Western Mediterranean (See maps of Saber *et al.* 2015a), but within the region, albacore larvae are just found systematically around the Balearic archipelago. While presence of albacore larvae has been reported in specific areas of the Central and Eastern Mediterranean, as the Tyrrhenian Sea, South Adriatic Sea, Strait of Messina, Aeolian Islands and Aegean Sea (Nikolic *et al.* 2015), ichthyoplankton surveys in other areas of the Western Mediterranean did not report presences of albacore (Sabatés *et al.* 2007; Olivar *et al.* 2010). Presences and abundances of albacore larvae in the Balearic Sea are related to specific hydrographical conditions derived, among other factors, by the sea surface temperature and the spatial distribution of the summer salinity front (Alemany *et al.* 2010, Reglero *et al.* 2012, Reglero *et al.* 2017). These results suggest that the Balearic Sea could be functioning as restricted spawning ground in the Western Mediterranean for albacore as it is for bluefin tuna (Muhlling et al, 2017), even

though the spawning ecology of albacore is less hydrographically driven than that of bluefin tuna (Reglero *et al.* 2012). In this case a larval index of albacore in the Balearic Sea could provide fishery independent information about the trends of the spawning stock biomass in the region. This information could result especially valuable considering that very few fishery independent indices are available in the region, what is forcing to assess the population status using methods based on catch data only (ICCAT 2011, Nikolic *et al.* 2016).

2. Material and methods

2.1 Ichthyoplankton surveys

Albacore larval samples were collected from ichthyoplankton surveys around the Balearic Sea (Figure 1) along 9 years between 2001 and 2015. Samples were located over a standard geographical grid of 10x10 nautical miles. Sampling campaigns belong to different research projects with differences in calendars of sampling and total number of stations (see details in **Table 1 and Figure 2**). Samples for the 2001-2005 period belonged to the Tunibal project (Alemany *et al.*, 2010), in which number of samples and the spatial coverage was the highest of the entire time series. The 2012 field sampling (ATAME and BLUEFIN TUNA projects) was the first field campaign of the second period, running from 2012 to 2015, with the widest geographical extension along these last four years. Field work from years 2013, 2014 and 2015 was designed to cover the main tuna spawning areas Ibiza and Mallorca channels, south of Menorca waters and south west of Cabrera. These areas are related to the location of the continental slope, where most of adult albacore are caught by professional long liners and by the recreational fishery (Saber, 2015a), and also where the main oceanic salinity front is located during the season. This frontal area separates the recently arrived surface Atlantic Waters from the resident and more haline surface waters, and plays a key role in defining the geographical location of albacore spawning grounds, (Alemany *et al.* 2010, Reglero *et al.* 2012, Reglero *et al.* 2017).

Collection of larvae was performed with bongo nets. Specific methods changed from the 2001-2005 and the 2012-2105 periods. In the first period fishing was carried out with bongo 60 using a 333 µm mesh, performing oblique tows down to 70 meters in the open sea or down to 5 m above the sea floor in shallower stations (see **Table 1**). During the second period larvae were collected with bongo 90 by oblique tows performed down to the thermocline (~30 m), using a 500 µm mesh. Stations where adaptive sampling was performed, or otherwise were not strictly part of the survey regular grid, were not included in the dataset for analysis. In all haul-types, flow meters were fitted to the net mouths for determination of the volume of water filtered. Plankton samples were fixed on board with 4% formaldehyde in seawater. In the laboratory, all fish larvae were sorted under a stereoscopic microscope. Albacore larvae were then identified to species level (Alemany 1997) and standard length measured by means of an Image Analysis System. In addition, at each station, a vertical profile of temperature, salinity, oxygen, turbidity, fluorescence and pressure was obtained using a CTD probe SBE911.

2.2 Number of larvae per unit area and fishing gear calibration

Laval abundances of different sizes were standardized to larval abundances at 2mm. The numbers of specimens collected at a station was adjusted to the number of 2-mm larvae, using the decay in numbers at size, derived from the length-based catch curve of the sampled larvae (**Figure 3**). Number of individuals at 2 mm per tow were then standardized to capture per unit area (CPUA, equation 1), obtaining the total larvae abundance per 10 square meters, a standard unit used in other larval indices (Ingram *et al.* 2015, Alvarez-Berastegui *et al.* 2017)

(1) CPUA= 10 x (Number of larvae / volume filtered (m^3)) x Tow depth (m)

Differences in CPUA derived from the use of two different fishing methods between the 2001-2005 and the 2012-2015 periods were corrected using the calibration model comparing both methodologies obtained from experimental fishing on bluefin tuna larval (R^2=0.998,$p<0.001$, see **Figure 4**, Alvarez-Berastegui *et al.* 2017).

2.3 Selection of representative field work campaigns

One of the main steps when developing larval abundance indices is the selection of the most representative data set in relation to those factors potentially introducing bias on the inter annual variability of the mean abundances. For selecting the most appropriate data set we assessed inter annual variability of sampling dates, filtered volumes by bongo nets and individual larval lengths through descriptive statistics (Box whisker plots, **Figure 5**), together with temperature and salinity in the mixed layer depth, affecting the timing of spawning and spatial distribution of spawning habitats in the area (Alemany *et al.* 2010, Reglero 2012).

To investigate potential differences in the beginning of the spawning each year, we explored the variability of the climatic temperature regime in the area over the albacore reproductive months calculating the mean sea surface temperature around the Balearic Sea during June and July (**Figure 6**). Sea surface temperature data was obtained from the hydrodynamic model "Mediterranean Sea Physics Reanalysis (1987-2015) (E.U. Copernicus Marine Service Information)". From the same data and for the same area we assessed how the mean temperature changed along the two months (June and July) for each year (**Figure 7**) and when the temperatures reached 20.9ºC, the minimum temperature at which Albacore larva has been found in the Balearic Sea.

To ensure that samples were representative of the same temporal window of albacore spawning, we first selected field sampling campaigns falling into the temporal window of the gonad maturity of this species in the Western Mediterranean. Gonadosomatic development has been defined in previous studies by Saber *et al.* (2015b) who found 100% of gonads of adult individuals sampled to be in spawning phase during June and July, 90% in August, and 0% in September, authors also found a 100% of adult individuals in the phase of "spawning capable" during May. Secondly we ensured that the campaigns were developed in a similar temporal window of larval presence in the Balearic Sea and for similar temperature ranges. Date limits of the temporal window of larval presence were assessed from larval abundances and CPUAs along dates obtained from the larvae dataset (**Figure 8**), and temperature ranges from histograms of temperature in the mixed layer depth for each collected larvae (**Figure 9**).

2.3 Delta lognormal larval index model

The inter annual variability of the CPUA of larvae at 2 mm was modeled with a delta log-normal model. The methods described herein follow the same approach as proposed by Ingram *et al.* (2010). This method combines two submodels, a binomial general linear model (GLM) predicting probabilities of larval presence and a lognormal GLM model to predict log–transformed positive abundances. This is the methodological approach used for the calculation of other species in the framework of ICCAT (see references from Ingram *et al.* 2010, 2017; Ingram 2014, 2017a, 2017b). As proposed in Ingram *et al.* (2017) and Alvarez-Berastegui (2016), environmental variables were included to improve the standardization of the larval indices. The explanatory variables considered in the delta log-normal approach were: "year", "survey area", "day time" (night or day), "mean salinity in the mixed layer depth" accounting for the spatial distribution of water masses (Balbín *et al.*, 2014) affecting the spawning of albacore (Alemany *et al.* 2010, Reglero *et al.* 2014), "Day of the year" accounting for differences on sampling dates in relation to the beginning of the spawning, and the "temperature residual" as the residual of a GLM where temperature was fitted to the "day of the year". The residual temperature allowed including inter annual differences of temperature in the models considering the existing correlation between the mean temperature in the mixed layer depth and the day of the year (R^2=0.65). More information about the input variables considered for inclusion in both the binomial and lognormal submodels are presented in **Table 2**. For the variable selection, not significant variables (*p*-value>=0.05) were excluded from the null models (binomial and lognormalmodels containing all variables) and then a backward and forward stepwise variable exclusion was tested to minimize the AIC using the stepAIC function from the R library "MASS" (Venables & Ripley, 2002). The lognormal model fit was assessed with the QQ plot and the residual distribution. The binomial model performance was assessed with the AUC (are under the receiver operating characteristic (ROC) curve) and plots of predicted presence probabilities distributions for real absences and real presences. All calculations were computed in R software ("R" development core team, 2008).

The mean probabilities (p_y) of larval presence from the binomial GLM models and the mean logtransformed CPUAs ($\ln(c_y)$) for each year were estimated by least-squares means for factor combinations using the R-package "lsmeans" (Lenth, 2017), together with the associated standard errors $SE(c_y)$, $SE(p_y)$. The index value for each year was calculated as in equation 2:

(2) $I_y=c_y p_y$

Where: I_y=Index value at year "y"; c_y= back transformed mean CPUA from the lognormal submodel; p_y= probability of presence from the binomial submodel.

The variance of the index each year was calculated using the Goodman (1960) approximation, following Lauretta *et al.* (2015) and Ingram *et al.* (2010).

Upper and lower 95% confidence limits (UCL and LCL) for the index were calculated to measure the precision of the mean (CV=standard error of the index value/index value), instead of measuring the variability of the data (CV=standard deviation / mean), as proposed by Ingram et al (2010) (Equations 3).

(3) UCL = (I × C) and LCL = (I/C) ; where $C = e^{\left(2\sqrt{\ln(1+CV^2)}\right)}$

3. Results

The fishing effort per tow (volume filtered) was similar for years when same gear was used (B60 and B90, **Figure 5A & B**). In relation to the sampling dates, all campaigns were carried out during June – July (**Table 1**). The 2002 campaign was conducted significantly earlier than the other years (**Table 1, figure 5C**), and coincided with lowest temperatures (**Figure 5E**). In 2002, 95% of the samples occurred before the first larva presence was recorded that year (24 June), 50% of samples of that same year also occurred at temperatures lower than the minimum temperature of albacore larval presence in the area at any year (20.9ºC). **Figure 8** shows abundances and CPUAs over time for all campaigns, and the high number of zeros and low abundances of the 2002 campaign can be observed. The field survey in 2003 was conducted later in the season (**Figure 5C**) and the temperatures were significantly higher than other years, both along the sampling stations (**Figure 5E**) and for the all area during the spawning season (See **Figures 6 and 7A**). Larvae abundances sampled that year provides information about larval populations at the end of the spawning period, while the other campaigns are representative for the first half, what combined with the high temperatures that year provided a non comparable data set for this species (**Figure 9**). Based on these results, the data belonging to the 2002 and the 2003 years were excluded from the analyses of abundances.

Mean salinities at station present inter-annual variability between campaigns, with higher values in years 2012 and 2013 (**Figure 5F**) which reinforces the need of accounting for environmental descriptors during the model development.

The adjustment of the curve to model the decay of larvae in number, used to standardize larvae at 2 mm, provided good fit against the length distribution from in situ larval lengths distribution, returning a R^2=0.99 (**Figure 3**). Summary statistics of the larval abundances and nominal CPUAs based on the 2 mm standardized larvae are presented in table 3.

The variable selection process for the binomial submodel (See supplementary material) resulted in the exclusion of the variable “Residual_temperature”, “Area”, and “Day_time”, the first one excluded for being non significant ant the others excluded during the AIC stepwise processing. The final model resulted was:

(4) Probability of Presence ~ Year + Year_day + Salinity

The models diagnostic plots of the binomial model are presented in **Figure 10A**. The AUC of the selected model reached a value of 0.782, and the histograms of probabilities at real presences and absences presented a good separation of both categories (**Figure 10B**), with a better performance of the binomial model to assign low values to real absences than to real presences. The response function showed negative effect of salinity and positive of “Year_day” (**Figure 11**).

For the lognormal submodel the variable “Area” was non significant (P<=0.05), and the variable “Day_time” was excluded in the stepwise process. The best model resulted was:

(5) log(CPUA) ~ Year + Year_day + Salinity + Residual_temp

The models diagnostic plots of the log-normal model are presented in **Figure 12**. Response function of the explanatory variables are presented in **Figure 13**. The salinity, presented a negative effect and the “Year_day” a positive trend. Both variables follow the same trend than in the binomial submodel.

The values of the larval index (I_y) as well as the associated dispersion parameters resulting from the delta lognormal modeling approach are presented in **Table 6** and in **Figure 15**. The larval index show a decreasing trend from the first years (2001-2005) to the second (2012-2015), with a clear drop in abundances from the 2012 to the 2015. The values of the larval index were also compared to the nominal CPUA (both standardized to the mean of one). This comparison show that both abundance indicators present a negative trend over the years.

4. Discussion

We calculated a larval abundance index for albacore (*Thunnus alalunga*) based on data collected from 2001 to 2015 in the Balearic Sea, their main spawning area in the Western Mediterranean. The index was estimated using delta lognormal models that standardized larval catches for differences in gears, sampling depth, geographic sampling coverage, time of day, water masses sampled, date and sea surface temperature. Sampling campaigns were representative of the spawning time in the area since larvae were observed coincident with mature adults as observed from gonad analyses in June-July (Saber *et al.* 2015b). The first larval presence recorded occurred on the 18th of June at a sea surface temperature of 20.9ºC (average temperature in the mixed layer depth). This must be considered when designing campaigns directed to collect valid data for the development of larval indices of albacore in the area. Data exploration justified the exclusion from the larval index computation of samples from the field campaigns of 2002 and 2003, as both resulted non comparable to other campaigns in relation to the sampling dates and temperatures.

Both the standardized larval index and the nominal CPUA show a decreasing trend in abundances from the first sampling period (years 2001 to 2005) to the second period (years 2012 to 2015). The larval index did not vary significantly from 2001-to 2004 and 2005, but index values drop significantly from 2012 to 2015.

Differences between nominal CPUA and the larval index, mainly along the first period of the study, show the relevance of the standardization process when assessing the larval abundances. In both submodels, the binomial and the lognormal, the "Year" variable was significant and always reducing the AICs, showing that there are significant changes on larval abundances over the time series. One key element on the development of the methodological approach to provide reliable indices was the inclusion of environmental variables in the models. The variable "Salinity" was significant in both submodels showing the role that the spatio-temporal distribution of the water masses play on the distribution of albacore larvae. The spatial location of the summer salinity front, where less haline recent Atlantic surface waters mix with more resident and more haline waters, determine the preferred locations for adults to spawn, what affects the larvae captures. It is relevant to consider this relation, already identified in previous studies (Alemany *et al.* 2010, Reglero *et al.* 2012), in the standardization process of larval abundances, other way inter annual changes of abundances could be confounded with changes on the quality of larval habitat sampled. Considering changes on temperature was also relevant. Sea surface temperature are highly correlated with date, for this reason the variable included in the models was the residual of temperature in relation to the date. The variable "day of the year" was relevant in both submodels showing a positive effect. This result indicates that both larvae presence probabilities and abundances are affected by the sampling date, what agrees with the reproductive ecology of albacore, that spawn in a limited temporal window during the summer. Nevertheless we expect that the response function of the variables "date" would reach a maximum at some point during the spawning temporal window and drop from there, showing a dome shaped functional response, as found in the studies from gonad development (Saber *et al.* 2015b). A previous study found larvae abundance probabilities to reach an asymptote approximately on June 30th (see **Figure 6** in Reglero *et al.* 2012), when analyzing the larvae data with general additive models (Wood, 2006), a technique that allow modeling non linear effects of the explanatory variables. The trend found in this study suggest that both presence-absence and abundance models could be improved by the application of modeling techniques allowing including non-linear responses. In fact, the results show by the histograms of probabilities at real presences and absences suggest that binomial models could be improved to identify better the real presences. In general, functional responses of larval abundances and environmental variables are non linear (Alvarez-Berastegui *et al.* 2014) so linear models may show restricted capabilities to incorporate that information into the standardization of larval abundances. Additional improvements could focus on the integration of information from spawning ecology of adults into the larvae abundance models. Information on the beginning of the spawning date could serve as reference to assess the time lag between that time and the sampling time.

For bluefin tuna, the trend of the Balearic larval index has shown a good agreement with the spawning biomass reported from ICCAT assessments (Ingram *et al.* 2017). In the case of albacore, the spatio-temporal distribution of reproductive adults (Saber *et al.* 2015a,b) and larval abundances suggest that the larval index could provide information on the trends of the spawning biomass in the area during the last years of the time series.

Designing environmental descriptors to parameterize hydrographic and biological processes defining larval habitats, and identifying methods to incorporate nonlinear responses in the standardization models are two ways on the roadmap to improve the assessment of larval abundances. Integration of environmental information from multiple observing platforms to advance on this line can be achieved through real time data collection and dissemination (Tintoré *et al.* 2013). Developing derived variables from oceanographic data sources can give insight about key ecological and oceanographic processes and facilitate the development of improved spatial habitat models that significantly improve the estimation of larval indices (Hobday *et al.* 2014, Alvarez-Berastegui 2016).

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Table 1. Ichthyoplankton surveys, type of fishing and sampling effort.

Year	*Dates*	*Gear/Haul type*	*Number of samples*	*Mean tow depth*
2001	16Jun-7Jul	B60 deep oblique	162	70
2002	8Jun-29Jun	B60 deep oblique	171	70
2003	3Jul-29Jul	B60 deep oblique	197	68
2004	18Jun-10-Jul	B60 deep oblique	166	69
2005	27Jun-23Jul	B60 deep oblique	186	69
2012	21Jun-9Jul	B90 mixed layer oblique	153	32
2013	20Jun-10Jul	B90 mixed layer oblique	124	27
2014	12Jun-29Jun	B90 mixed layer oblique	92	28
2015	23Jun-9Jul	B90 mixed layer oblique	94	24

Table 2. Candidate variables for the binomial and log-normal submodels of the delta modeling approach.

Variable name	*Acronym*	*Definition*	*Variable type*
CPUA of larvae at 2mm	CPUA2mm	Larvae abundances per 10 m^2 calculated to 2mm using in situ decay function; gear, depth and volume filter standardized .	Response variable
Year	Year	Year of sampling (n=9)	Factor
Day of de year	Year_day	From 1 to 365	Continuous
Day time	Day_time	2 level variable, before and after sunrise and sunset	Factor
Sampling area	Area	variable identifying geographic units of 1x1 degree	Factor
Mixed layer salinity	Salinity	Mean salinity in the mixed layer depth	Continuous
Residual temperature	Resid_Temp	Residual of the model: GLM (temperature~day of the year)	Continuous

Table 3. Input data summary statistics. Larval counts refers to the original number of larvae previous to the back calculation to number of larvae at 2 millimeters. Nominal CPUA refers to the number of larvae at 2 millimeters standardized for gear, depth of fishing and filtered volume.

Year	*number of samples*	*larval counts*	*Nominal CPUA*	*CV*	*LCI*	*UCI*
2001	162	166	1,674	0,496	0,655	4,276
2004	166	313	1,283	0,211	0,845	1,948
2005	186	771	2,801	0,206	1,863	4,210
2012	153	510	1,006	0,278	0,583	1,736
2013	124	80	0,282	0,622	0,090	0,886
2014	92	46	0,122	0,455	0,051	0,290
2015	94	77	0,165	0,431	0,072	0,376

Table 6. Larval index (n larvae/ 10m^2) and dispersion parameters, scaled larval index.

year	*index*	*var_i*	*se_i*	*UCI*	*LCI*
2001	3,810	0,572	0,756	5,645	2,571
2004	7,284	1,292	1,137	9,933	5,341
2005	7,410	0,626	0,791	9,169	5,989
2012	2,967	0,210	0,458	4,034	2,182
2013	2,347	0,278	0,527	3,657	1,506
2014	1,098	0,083	0,288	1,839	0,656
2015	0,314	0,008	0,089	0,546	0,180

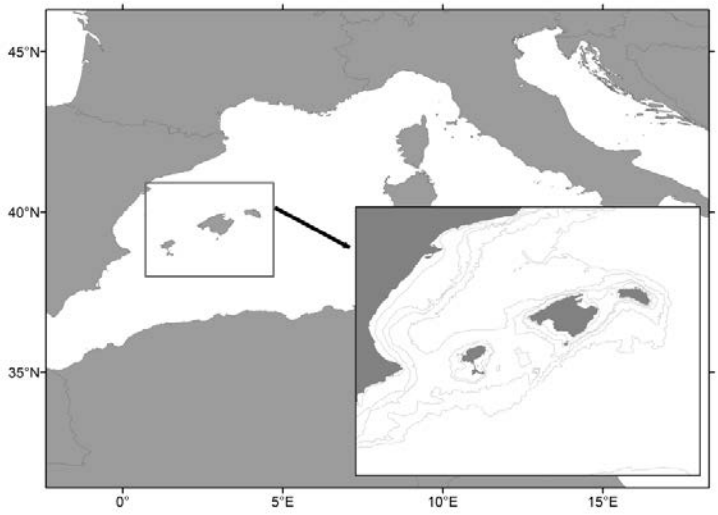

Figure 1. Study area.

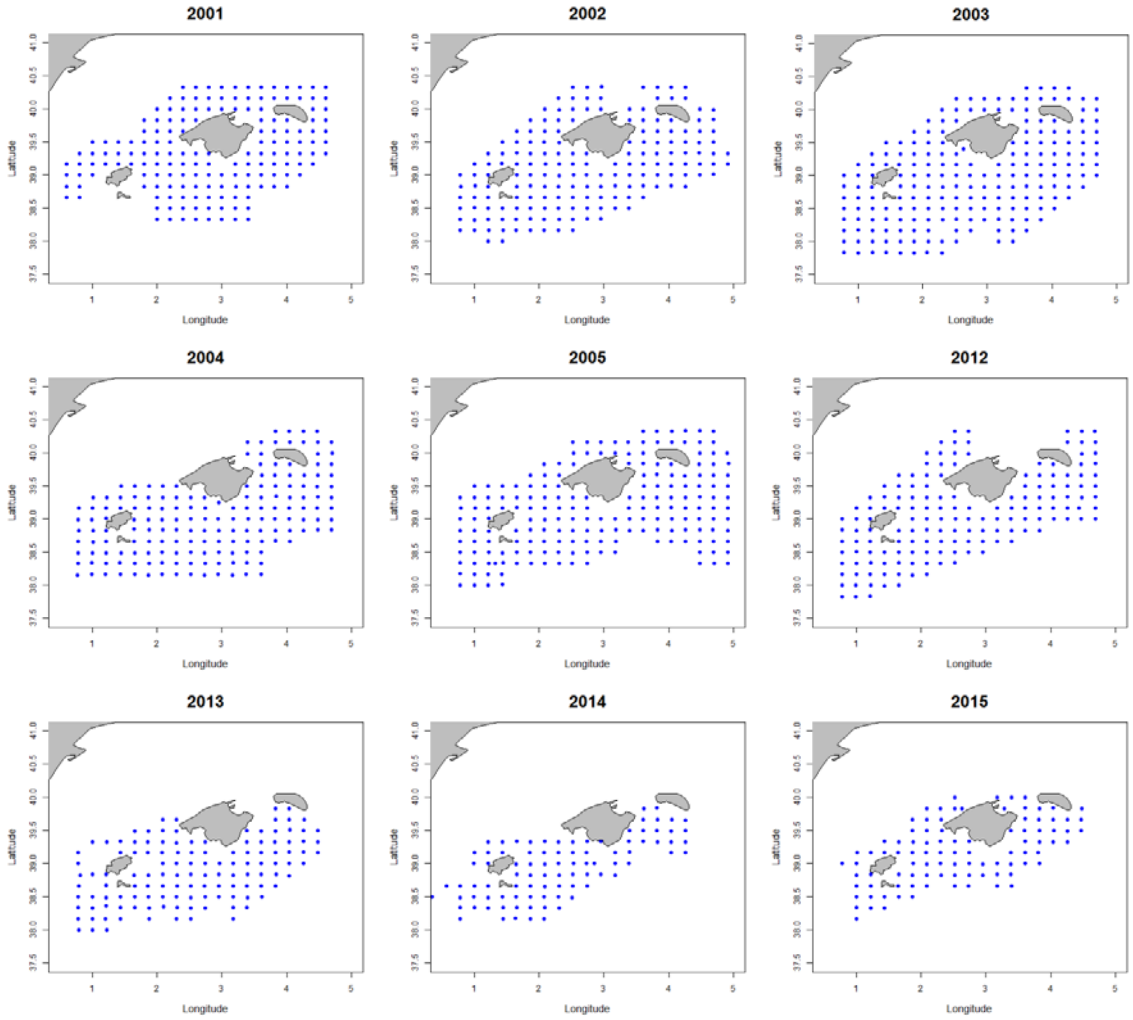

Figure 2. Spatial distribution of the samples.

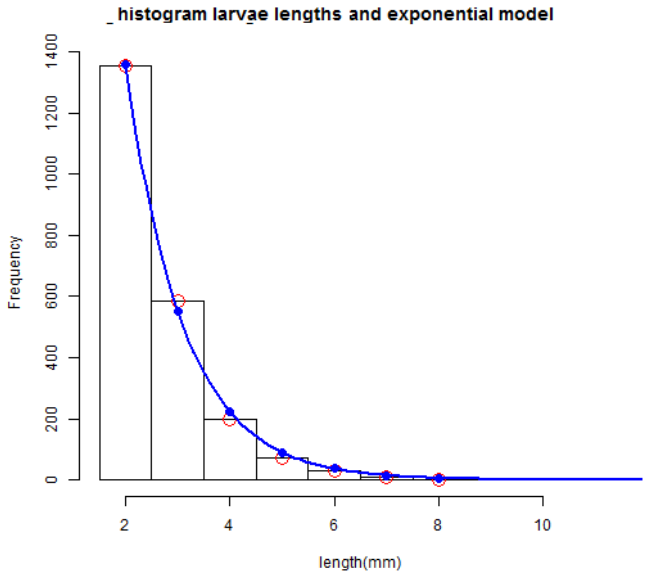

Figure 3. Distribution of number of larvae at length (bars) and adjusted exponential model (blue line) used for calculating the number of larvae at 2 millimeters.

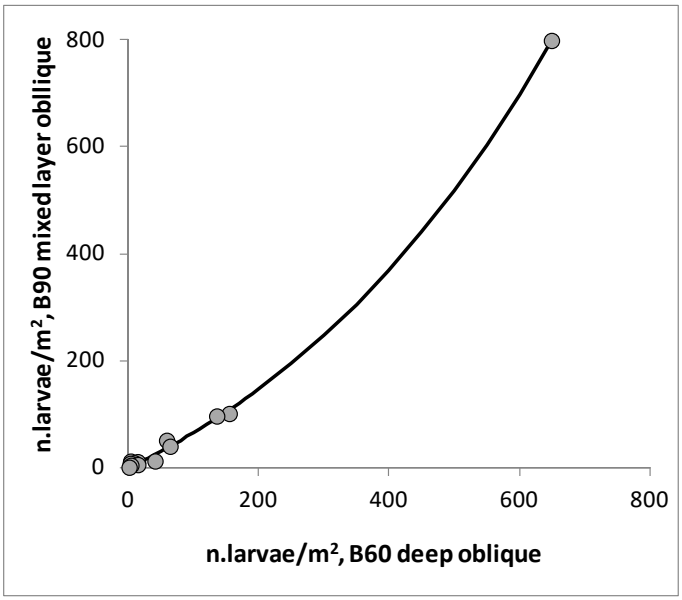

Figure 4. Larvae abundances (number of larvae per square meter) of B90ml and B60do from experimental fishing to calibrate gear catchability on bluefin tuna larvae (R2=0.998; *CPUA-B90ml = (a*CPUA B60do)*(exp(b*CPUA B60do); a= 0.5823 ; b=0.00115;* model and figure from Alvarez-Berastegui *et al*., 2017).

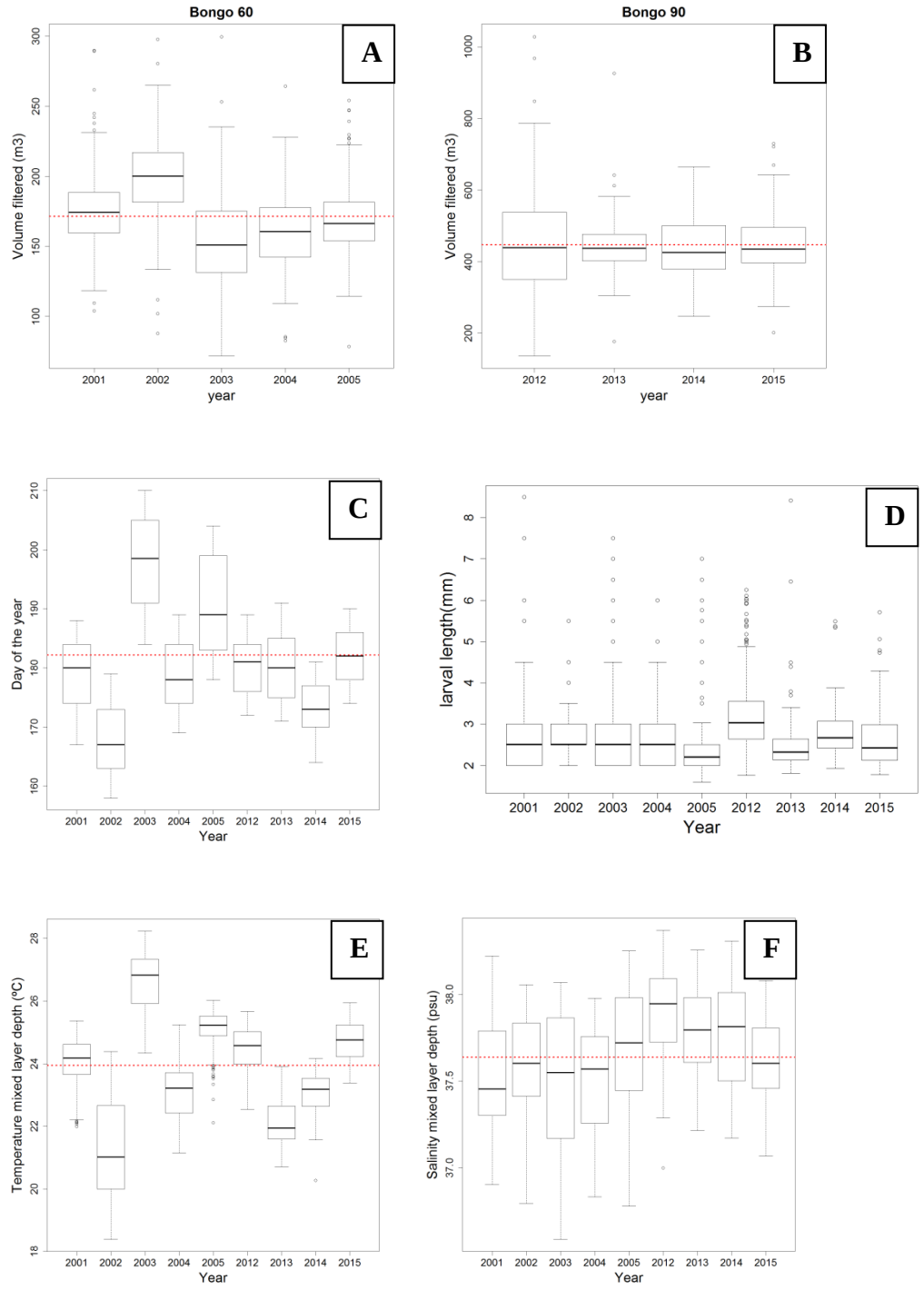

Figure 5. Filtered volumes by bongo nets (A: bongo 90, B: bongo 60); C: Temporal distribution of samples over day of the year; D: Larval length distributions; E: mean temperature in the mixed layer depth; F: mean salinity in the mixed layer depth. Red dotted lines indicating the mean value of each variable for the entire data set.

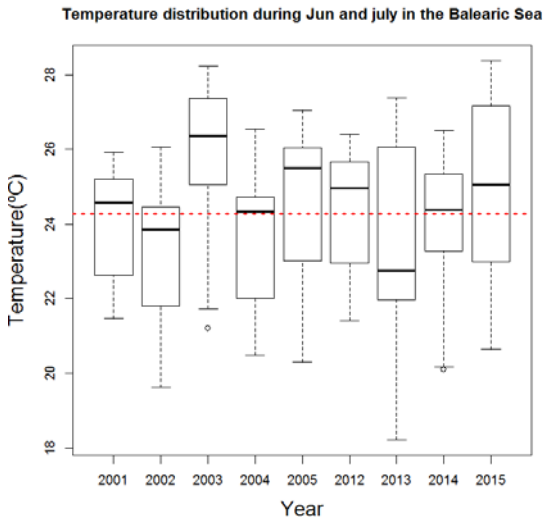

Figure 6. Mean sea surface temperature in the study area (see Figure 1) from ROMS hydrodynamic models during June and July. Red line showing mean value for the entire data set.

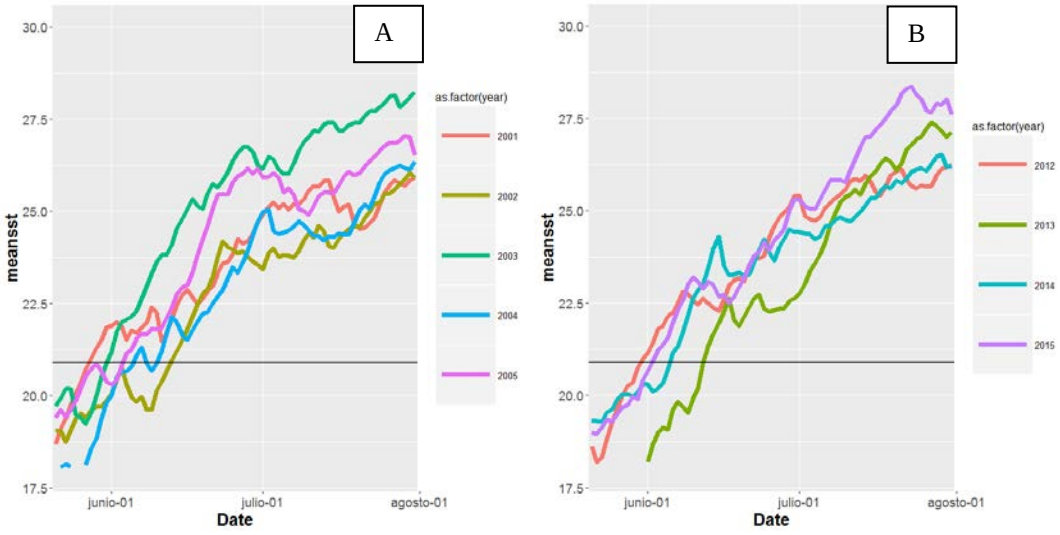

Figure 7. Temporal evolution of the mean sea surface temperature in the study area (see Figure 1) from ROMS hydrodynamic models. Horizontal line indicating 20.9 ºC, minimum temperature at which Albacore larvae has been found in the Balearic Sea. A: years from the first period (2001-2005), B: Years from the second period (2012-2015).

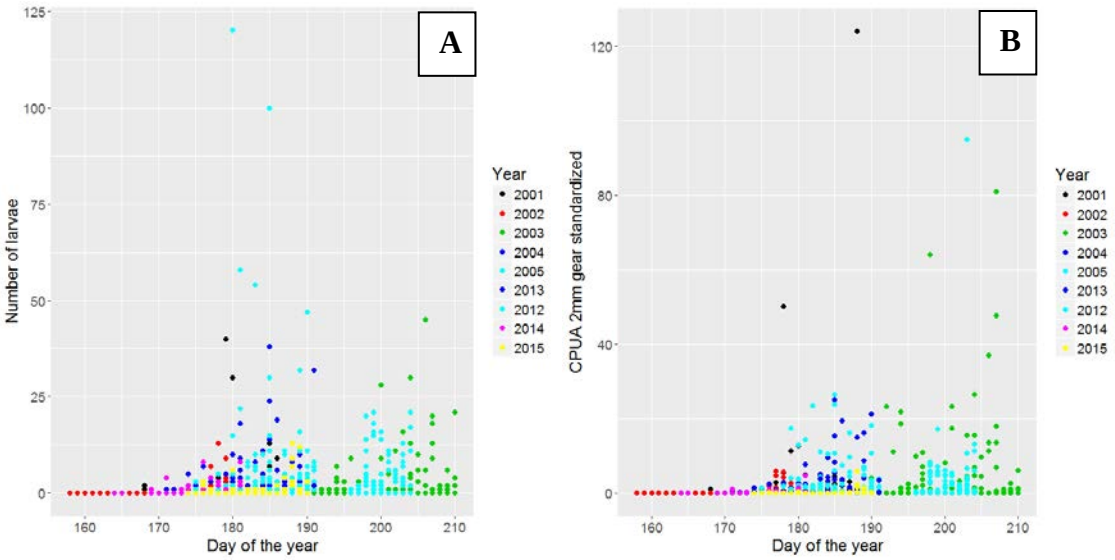

Figure 8. A: Number of albacore larvae and B: CPUA captured along dates for all campaigns. Note the zero catches along most of the 2002 camping (samples in red) distributed from day 158(8 June) to 179 (29 June).

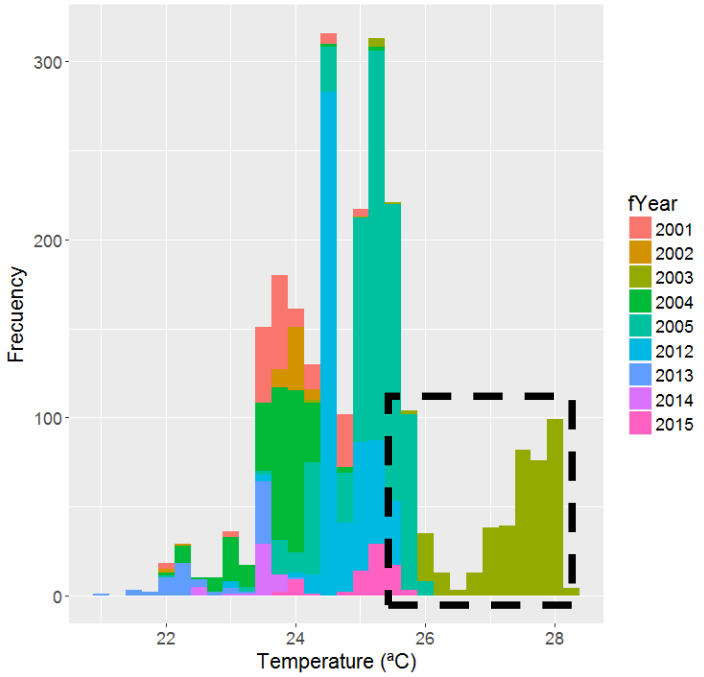

Figure 9. Histogram of temperature in the mixed layer depth from in situ CTD. Data from only positive catches, frequency values expressing the number of larvae at each temperature. Colors indicating the sampling year. Black box indicating samples from the 2003 year.

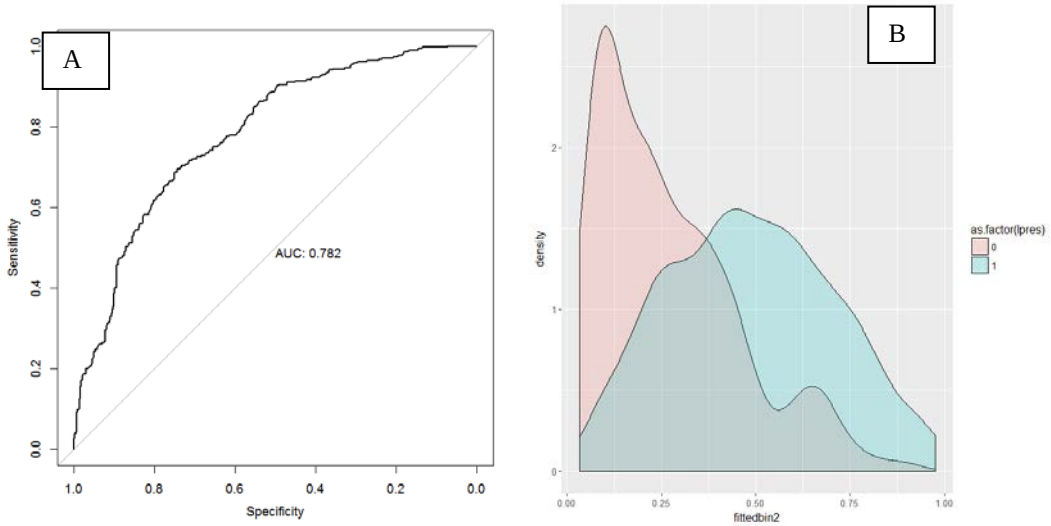

Figure 10. PROC curve of the binomial model (left) and presence probability distributions for the real presences and real absences.

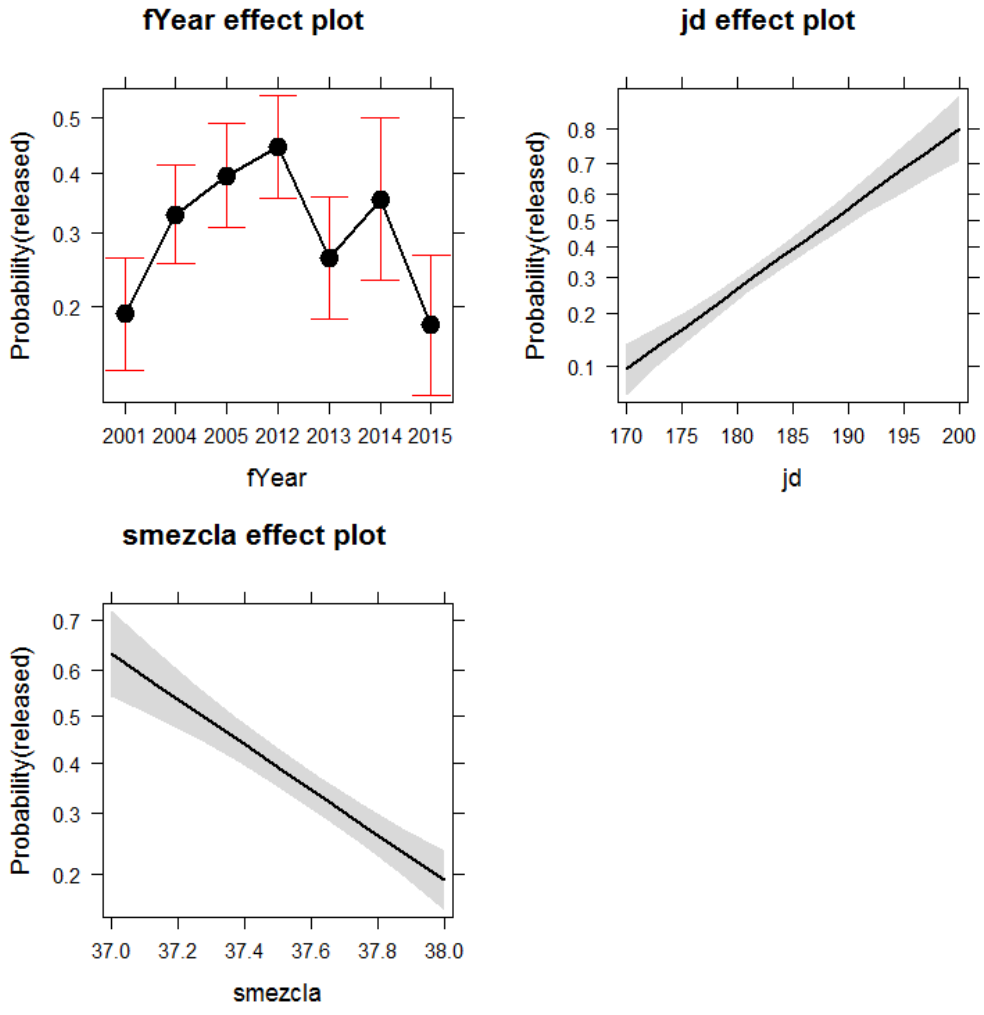

Figure 11. Functional responses of the explanatory variables in the Binomial submodel.

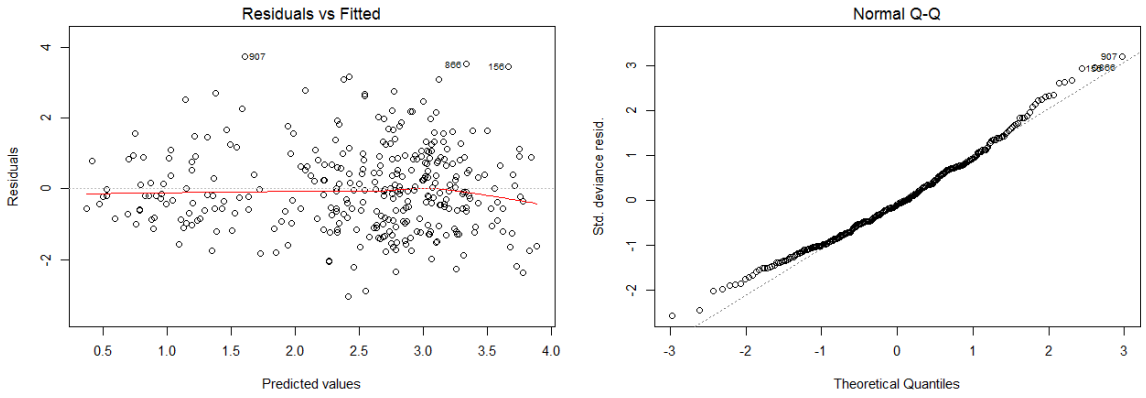

Figure 12. Lognormal model diagnostic plots.

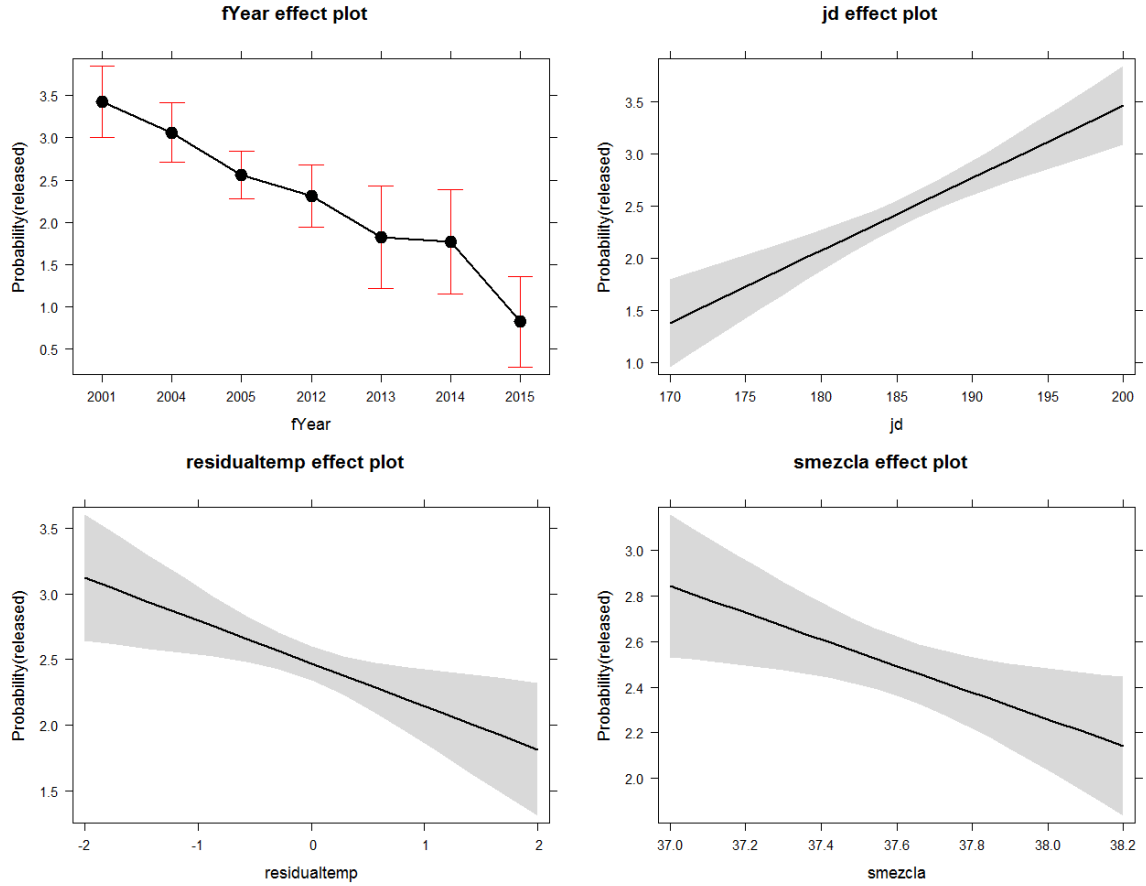

Figure 13. Functional responses of the explanatory variables in the lognormal submodel.

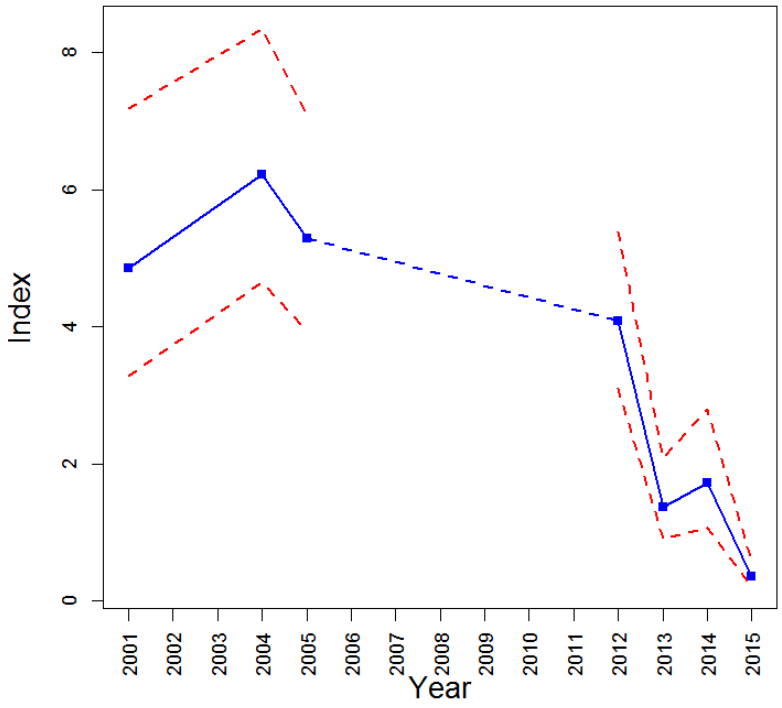

Figure 14. Albacore larval index in the Balearic Sea for the 2001-2015 period. Index is expressed as mean number of larvae of 2 millimeters per 10 square meters. Red dashed lines indicating 95% confidence intervals.

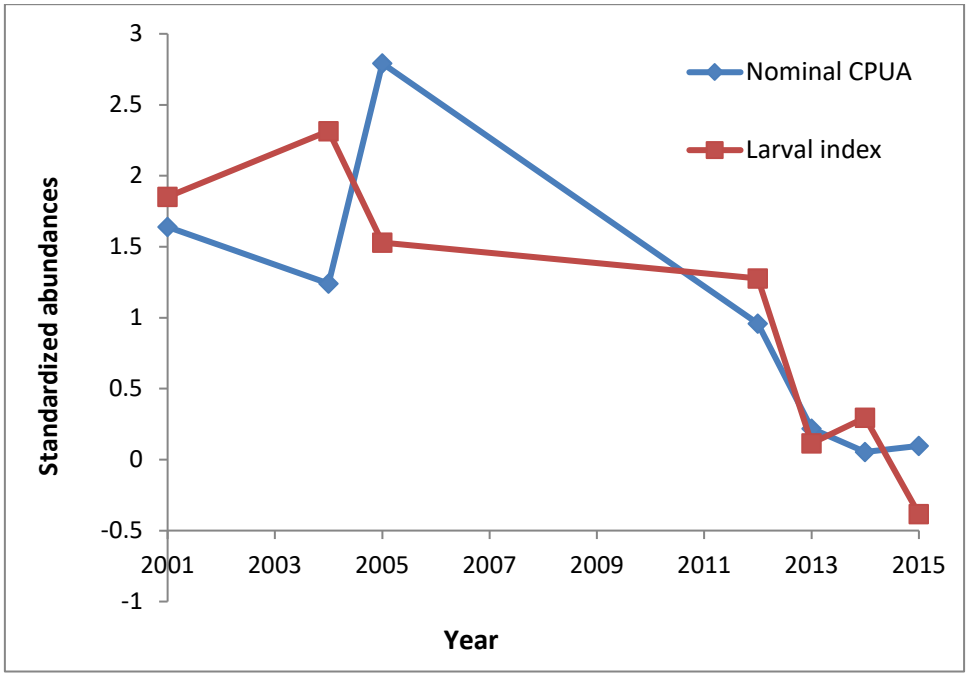

Figure 15. Comparative between Albacore larval index and Nominal CPUA. Values are standardized to a mean of one for comparison.

Supplementary material

Variable selection process for the binomial submodel.

Null model: Presence ~ Year + Year_day + Salinity + Area + Day_timet + Residual_temp

Step1 (exclude non significant variables variables, p<=0.05):
Variable excluded: “Residual_temp”

Step 2 (Select variables that minimize model AIC):
Output of the stepAIC function (R package “MASS”)
Stepwise Model Path
Analysis of Deviance Table
Initial Model:
Probability of Presence ~ Year + Year_day + Salinity + Area + Day_time

Final Model:
lpres ~ Year + Year_day + Salinity

	Step	Df	Deviance	Resid. Df	Resid. Dev	AIC
1				948	999.8645	1045.864
2	- Area	12	19.969262	960	1019.8338	1041.834
3	- Day_time	1	1.296120	962	1022.3438	1040.344

Variable selection process for the lognormal submodel.

Null model: log(CPUA) ~ Year + Year_day + Salinity + Area + Daynight + Residual_temp

Step1 (exclude non significant variables variables, p<=0.05):
Variable excluded: “Area”

Step 2 (Select variables that minimize model AIC):
Output of the stepAIC function (R package “MASS”)
Stepwise Model Path
Analysis of Deviance Table

Initial Model:
log(ALBab_gs) ~ Year + Year_day + Salinity + Day_timet + Residual_temp

Final Model:
log(ALBab_gs) ~ Year + Year_day + Salinity + Residual_temp

	Step	Df	Deviance	Resid. Df	Resid. Dev	AIC
1				324	468.6623	1087.166
2	– Day_time	1	0.04524964	325	468.7075	1085.198