DEVELOPMENT OF INDICES OF LARVAL BLUEFIN TUNA (*THUNNUS THYNNUS*) IN THE WESTERN MEDITERRANEAN SEA

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SUMMARY

Fishery independent indices of bluefin tuna larvae in the western Mediterranean Sea are presented utilizing ichthyoplankton survey data collected from 2001 through 2005 and 2012 by the Spanish Institute of Oceanography. Indices were developed using larval catch rates collected using two different types of bongo gear, fished three ways, by first standardizing catch rates by gear/fishing-style and then employing a delta-lognormal modeling approach, including following covariates: average water temperature between the surface and the mixed layer depth, average salinity between the surface and the mixed layer depth, time of day, a systematic geographic area variable, month and year. Also, a separate model is developed using a spawning habitat quality variable to determine if the inclusion of such information reduces the variance in the index values.

RÉSUMÉ

Les indices de larves de thon rouge indépendants des pêcheries dans la mer Méditerranée occidentale sont présentés au moyen des données des prospections d'ichthyoplancton recueillies de 2001 à 2005 et en 2012 par l'Institut espagnol d'océanographie. Des indices ont été développés sur la base des taux de capture des larves recueillies au moyen de deux différents types de filets Bongo, pêchées de trois façons différentes, en standardisant avant tout les taux de capture par engin / mode de pêche et ensuite en appliquant une approche de modélisation delta-lognormale, en incluant les covariables suivantes: température moyenne de l'eau entre la surface et l'épaisseur de la couche de mélange, la salinité moyenne entre la surface et l'épaisseur de la couche de mélange, le moment de la journée, une variable de zone géographique systématique, mois et année. De plus, un modèle distinct est élaboré au moyen d'une variable de la qualité de l'habitat de frai afin de déterminer si l'ajout de ces informations réduit la variance dans les valeurs de l'indice.

RESUMEN

Se presentan índices de larvas de atún rojo independientes de la pesquería en el mar Mediterráneo occidental utilizando datos de prospecciones de ictioplancton recopilados desde 2001 hasta 2005 y en 2012 por el Instituto Español de Oceanografía. Se desarrollaron índices usando las tasas de captura de larvas recogidas utilizando dos tipos diferentes de artes bongo, pescadas de tres formas, estandarizando primero las tasas de captura por arte/estilo de pesca y, posteriormente, empleando un enfoque de modelación delta-lognormal, lo que incluye las siguientes covariables: temperatura media del agua entre la superficie y la profundidad de la capa de mezcla, la salinidad media entre la superficie y la profundidad de la capa de mezcla, la hora del día, una variable de área geográfica sistemática, mes y año. Además, se desarrolla un modelo separado utilizando una variable de calidad del hábitat de desove para determinar si la inclusión de dicha información reduce la varianza en los valores del índice.

KEYWORDS

Mathematical models, Fish larvae, Bluefin tuna

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1. Introduction

Managers became concerned of the status of Atlantic bluefin tuna (*Thunnus thynnus*) stocks in the late 1960's. During recent years, international assessments of Atlantic bluefin tuna (ABT hereafter) have been conducted at least biannually. Most abundance indices used during assessments of ABT were of a fishery dependent nature. Scott *et al*. (1993) presented a spawning biomass index for the western stock, which was based upon the abundance of bluefin tuna larvae collected during fishery independent surveys conducted by NOAA Fisheries in the Gulf of Mexico. Recently, Ingram *et al*. (2010) updated these indices using standardization via delta-lognormal models.

During recent decades ichthyoplankton surveys targeting ABT larvae were conducted in several areas of the Mediterranean Sea, the spawning area of the eastern stock of ABT. However, the surveys employed heterogeneous sampling strategies and methodologies, without any temporal continuity (e.g. Dicenta 1977; Dicenta and Piccinetti 1978; Oray and Karakulak 2005; Piccinetti and Piccinetti-Manfrin 1994; Piccinetti *et al*. 1996a, 1996b, 1997; Tsuji *et al*. 1997). In 2001 the IEO started a series of standardized ichthyoplankton surveys, named TUNIBAL, around the Balearic Islands, recognized as one of the main spawning areas of ABT within the Mediterranean (Garcia *et al*. 2005; Alemany *et al*. 2010), with the aim of characterizing the spawning habitat of this species and deepen in the knowledge of its larval ecology, assessing the influence of environmental factors on larval distribution and abundance. These surveys followed an adaptive sampling strategy, combining intensive sampling of high density larval patches with quantitative sampling over a systematic grid of stations. A similar survey was carried out on 2012, following the same sampling strategy, within the framework of a new research project named ATAME.

The results from these surveys have shown that spatial location of spawning habitats of ABT are strongly influenced by mesoscale oceanographic processes in the Balearic sea (Alemany 2010, Reglero 2013, Muhling 2012), as have been also demonstrated in the Gulf of Mexico (Muhling 2012). Therefore, larval index values may be influenced by the type of habitat sampled among years. Improving the knowledge of how habitat information can increase the performance of larvae index models is of paramount importance to the advancement of stock evaluation methodologies independent from fisheries data. Previous larval index calculations (Ingram *et al*. 2013) have included salinity and temperature as environmental linear covariates, but other recent studies (Reglero *et al*. 2012) have demonstrated that their effect on the spawning habitat characterization may not present a linear response.

The ABT larval abundance data gathered during these surveys are useful for developing an index of abundance, which would represent the second fishery-independent index of abundance of ABT in the world, and currently the only fishery-independent index concerning the eastern Atlantic stock. Therefore, the objective of this report is to present abundance indices of ABT larvae collected around the Balearic Islands based on delta-lognormal models and to assess how including spawning habitat information can improve the current larval index calculation methods.

2. Methods

Field sampling methodology

The sampling methodologies for the period 2001-2005 are described in detail in Alemany *et al*. (2010). ABT larvae were collected by oblique tows performed down to 70 m in the open sea or down to 5 m above the sea floor in shallower stations, using a 333 µm mesh fitted to 60 cm mouth opening Bongo nets. In addition, subsurface tows between 5 m deep and surface were carried out at the same stations in 2004 and 2005 by means of a Bongo 90 net equipped with a 500 µm mesh. Also, in 2012, ABT larvae were collected by oblique tows performed down to the thermocline (~30 m), using a 500 µm mesh fitted to a Bongo 90. In each of those years around 200 stations, located over the nodes of a regular grid of 10 x 10 nautical miles, covering most of the known ABT spawning areas in this region (from 37.85º to 40.35º N and from 0.77º to 4.91º E), were sampled during the spawning peak of ABT in the Western Mediterranean. The exact number of sampled stations and the dates of the surveys are shown in **Table 1**. In all haul-types, flowmeters 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. Tuna larvae were then identified to species level. In addition, at each station, a vertical profile of temperature, salinity, oxygen, turbidity, fluorescence and pressure was obtained using a CTD probe SBE911. The numbers of specimens collected at a station, with corresponding gear-type, were adjusted to the number of 2-mm larvae, using the decay in numbers at size, derived from a length-based catch curve for each gear-type (**Figure 1**). Due to the decreased selectivity in both gears for 2-mm larvae a coefficient was also used for adjustment: 1.582459 for Bongo 60 and 2.331549 for Bongo 90. For years 2004 and 2005, the Bongo 90 larval catches were not measured. Therefore, in order to adjust these numbers as the others, the length distribution of the 2004-2005, Bongo 90 was assumed to be that summarized from 2012 survey Bongo 90 length data. Finally, larval density was calculated by dividing the adjusted catch numbers by the volume filtered by the gear; and larval abundance was calculated by multiplying the density by the tow depth.

Statistical methodology

From the larval abundance dataset, two larval indices were computed to assess the effect of including the spawning habitat information in the model development. The first model denoted as "standard larval index" (SLI), included salinity and sea surface temperature to evaluate if there were any linear effects of these environmental variable, following previous versions of the larval index in the Balearic Sea (Ingram *et al*. 2013). The second model, denoted as "habitat corrected larval index" (HLI) included a spawning habitat quality variable obtained from a general additive model were the effects of same variables (SST and Salinity) were combined with day of the year and spatial location. This habitat quality variable used in the HLI accounted for non linear effects of SST and Salinity on the characterization of the spawning habitat. Coefficients of variation from both models were used as parameter of model performance.

Model configuration of the "Standard Larval Index" (SLI)

The delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) was estimated as

(1) $$I_y = c_y p_y,$$

where c_y is the estimate of mean CPUE for positive catches only for year y; p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y were estimated using generalized linear models. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $$\ln(\mathbf{c}) = \mathbf{X\beta} + \boldsymbol{\varepsilon}$$

and

(3) $$\mathbf{p} = \frac{e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}{1 + e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}, \text{ respectively,}$$

where c is a vector of the positive catch data, p is a vector of the presence/absence data, X is the design matrix for main effects, β is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance σ^2.

We used the GLIMMIX and MIXED procedures in SAS (v. 9.1, 2004) to develop the binomial and lognormal submodels, respectively.

Similar covariates were tested for inclusion for both submodels to develop abundance indices: time of day (three categories: night, day, and crepuscular), month, and year. For the SLI, both the average salinity and temperature in the mixed layer were included. A backward selection procedure was used to determine which variables were to be included into each submodel based on type 3 analyses with a level of significance for inclusion of $\alpha = 0.05$. If year was not significant then it was forced into each submodel in order to estimate least-squares means for each year, which are predicted annual population margins (i.e., they estimate the marginal annual means as if over a balanced population). The fit of each of the submodels were evaluated using AIC, residual analysis for the lognormal submodel, and the area under a receiver operating curve (AUC), methodology presented by Steventon *et al*. (2005), for the binomial submodel.

Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated as

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c, p),$$

where

(5) $$\mathrm{Cov}(c, p) \approx \rho_{c,p}\left[\mathrm{SE}(c_y)\mathrm{SE}(p_y)\right],$$

and $\rho_{c,p}$ denotes correlation of c and p among years.

Model configuration of the "Habitat corrected Larval Index" (HLI).

Model design was the same as that for the SLI with one modification; a habitat quality indicator was included as an additional covariate in both the binomial and lognormal submodels, while the temperature and salinity variables were removed. For the calculation of the habitat quality indicator, the densities of larvae (LD) that were below 4.5 millimeters in length were standardized to the minimum and maximum values within each year. This length limitation was selected as proxy of spawning locations. For estimating the habitat quality indicator (HQ) associated with each sampled station of a given year, the dataset (six years of data), was split into two datasets, the prediction data set and the fitting dataset: the first one containing data from the considered year and the second one with data from the other five years. Using the fitting data set, a general additive model (GAM) was designed to fit the LD to the following explanatory variables: latitude (Lat), longitude (Lon), sea surface salinity (Sal), day of the year (yd) and residual sea surface temperature (rSST). rSST was defined as the residual of SST against the day of the year, as both variables were strongly correlated. This variable accounted for stations where the temperatures were above or below the average for a specific time in the year. This GAM configuration, the variable selection, and length limitation for the larval followed previous studies of BFT spawning habitat in the area (Reglero *et al.*, 2012). The GAM model, obtained by relating the LD values to the environmental information and based on the fitting dataset only, was used to predict LD values for the prediction data set. These predictions were used as the habitat quality indicator (HQ). This process was applied for each sampling campaign, so predictions of HQ for each year were always based on data from the other five years.

3. Results and Discussion

Table 2 summarizes the data used in these analyses. Sampling occurred during June and July, and the number of stations per year ranged from 173 to 205 for the Bongo-60 gear and from 197 to 217 for the Bongo-90 gear. Sizes of larvae collected in the Bongo-60 gear ranged from 1.39 to 8.5 mm and those from Bongo-90 between 1.74 and 11.49mm. Length data for the Bongo-90 gear from 2004 and 2005 surveys are currently unavailable.

The backward selection procedure used to develop the delta-lognormal model for the SLI is summarized in **Table 3**. For the binomial submodel, all variables except the time of day variable were retained. For the lognormal submodel, all variables were dropped from the model except year (**Table 3**). The AIC for model runs #5 and #6 increased as area and salinity variables were dropped from the model indicating a possible increase in lack-of-fit. However, due to the large *p*-values of the type 3 test for the inclusion, we chose to remove these variables. **Figure 2** summarizes the resulting indices, and **Figures 3 and 4** contain diagnostic plots for model development. The results of the binomial model performance are shown in **Figure 3**. The AUC value for the binomial submodel for the SLI was 0.8003. This means that in 80 out of 100 instances, a station selected at random from those with larvae had a higher predicted probability of larvae being present than a station randomly selected from those that had no larvae. The residual plot in **Figure 4** indicates the approximately normal distribution of the residuals of the lognormal submodel.

The backward selection procedure used to develop the delta-lognormal model for the HLI is summarized in **Table 4**. For the binomial submodel, all variables except the time of day variable were retained. For the lognormal submodel, all variables were dropped from the model except year and habitat quality (**Table 4**). **Figure 5** summarizes the resulting indices, and **Figures 6 and 7** contain diagnostic plots for model development. Again, the binomial submodel residuals plotted in **Figure 6** have bimodal tendencies. The AUC value for the binomial submodel for the HLI data was 0.7370. This means that in 74 out of 100 instances, a station selected at random from those with larvae had a higher predicted probability of larvae being present than a station randomly selected from those that had no larvae. The residual plot in **Figure 7** indicates the approximately normal distribution of the residuals of the lognormal submodel.

The final results of the SLI and HLI models showed differences in their coefficients of variation (CVs) along the six years of data (**Table 5**). While some years presented very low differences in the CVs (2012, improvement of 0.6%), other years presented CV improvements up to 16% (2003). Three years presented improvements above 10% (2003, 2004 and 2005). The mean improvement of CVs of the HLI against SLI along the six years was 9.07 %. The fact that the highest improvement of HLI against SLI is associated to one of the years where the effect of temperature was the strongest (2003) may suggest that the spawning habitat quality indicator improves the capability of the larval index model to account for interannual effects on the sampling distribution due to differences is the spawning habitat locations. Improving the models by the use of spawning habitat has demonstrated reduction in the CVs in the larval index. New advances towards the capability of modeling the spawning habitats will be relevant for future improvements of the ABT stock assessments when including fishery independent larval indexes.

Another important result from our analysis is the increase in the 2012 survey larval index in relation to the values calculated for the period 2001-2005. Part of this difference is possibly attributable to the higher ABT larvae sampling efficiency of the Bongo 90 nets towed obliquely through the first meters of the water column, above the thermocline, as our own results indicate and have also been observed in the Gulf of Mexico (Habtes *et al*., 2014). Thus, the use of Bongo 90 nets fitted with 500 microns meshes allow to capture larger larvae, and the higher volume of water filtered, in our case 2-3 times larger in Bongo 90 versus Bongo 60 tows, would increase the probability of capturing ABT larvae in the areas were their density is extremely low. However, considering that in 2004 and 2005 Bongo 90 nets towed through the upper mixed layer, where the maximum concentrations of ABT larvae have been observed (unpublished personal data), were also used, we hypothesize that these differences in the LI are a direct reflection of an increase in the ABT eastern stock spawning biomass, which occurred during the last several years. Also, the gear selectivities were accounted for and abundances adjusted as described in Section 2. Moreover, this increase has been observed by other authors using both fishery dependent methodologies, such as CPUE variations (Gordoa 2013) and fishery independent, such as aerial surveys of juvenile ABT (Fromentin *et al*. 2013). One of the causes of this increase have probably been the effectiveness of the protective measures established within the ABT recovery plan initiated in 2007, as the ban on juvenile captures and the lower TACs in recent years (Anon. 2013). However, environmental factors have also contributed to this improvement in the ABT eastern stock state. Specifically, the high proportion of individuals belonging to the 2003 cohort (Rodriguez-Marin *et al*. 2013) could be attributed to an exceptionally good recruitment resulting from environmentally driven higher larval survival rates, associated to very high sea surface temperatures during the 2003 ABT spawning season in the Mediterranean, as proposed in Garcia *et al*. (2013).

Acknowledgements

This work have been carried out within the framework of the projects ATAME (2011-29525-004-02), funded by the Spanish Ministry of Science, and the European Community's Seventh Framework Programme (FP7/2007-2013) PERSEUS, under grant agreement nº 287600-2011-29525-004-02, with base data provided by the TUNIBAL project (REN 2003-01176), . We also express our gratitude to the crew of the RV 'Vizconde de Eza' (2001 to 2002), RV 'Cornide de Saavedra' (2003 to 2005) and R/V Ramón Margalef (2012) and to all the scientific staff that participated in surveys and carried out lab analysis.

References

Alemany, F., L. Quintanilla, P. Velez-Belchí, A. García, D. Cortés, J.M. Rodríguez, M.L. Fernández de Puelles, C. González-Pola and J.L. López-Jurado. 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. CLimate Impacts on Oceanic TOp Predators (CLIOTOP) – International Symposium.

Anon. 2013. Report of the 2012 Atlantic Bluefin Tuna Stock Assessment Session *(Madrid, Spain – September 4 to 11, 2012).* Collect. Vol. Sci. Pap. ICCAT, 69(1): 1-198.

Dicenta, A. 1977. Zonas de puesta del atún (*Thunnus thynnus*) y otros túnidos del Mediterráneo occidental y primer intento de evaluación del “stock” de reproductores de atún. Boletin del Instituto Español de Oceanografía. 234: 109-135.

Dicenta, A. and C. Piccinetti. 1978. Desove de atún (*Thunnus thynnus* L.) en el Mediteráneo Occidental y evaluación directa del stock de reproductores basado en la abundancia de sus larvas. Collective Volumes of Scientific Papers of ICCAT. 7(2): 389-395.

Fromentin, J.-M., Bonhommeau S., Brisset B. 2013. Update of the index of abundance of juvenile bluefin tuna in the western Mediterranean Sea until 2011. Collect. Vol. Sci. Pap. ICCAT, 69(1): 454-461.

García, A., Alemany F., Velez-Belchí P., López Jurado J.L., Cortés D., de la Serna J.M., González Pola C., Rodríguez J.M., Jansá J. and T. Ramírez. 2004. Characterization of the bluefin tuna spawning habitat off the Balearic archipelago in relation to key hydrographic features and associated environmental conditions. CGPM/ICCAT 7th Joint Ad-hoc meeting, May, Málaga, 2004.

Gordoa, A. 2013. Analyses of connections between Atlantic bluefin tuna fisheries at both sites of the Atlantic comprising Balfegó catch rates in Balearic spawning ground. Collect. Vol. Sci. Pap. ICCAT, 69(2): 878-890.

Habtes, S., Muller-Karger, F. E., Roffer, M. A., Lamkin, J. T., & Muhling, B. A. (2014). A comparison of sampling methods for larvae of medium and large epipelagic fish species during spring SEAMAP ichthyoplankton surveys in the Gulf of Mexico. Limnol. Oceanogr.: Methods, 12, 86-101

Ingram, G. W., Jr., W. J. Richards, J. T. Lamkin and B. Muhling. 2010. Annual indices of Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico developed using delta-lognormal and multivariate models. Aquatic Living Resources. 23: 35-47.

Ingram, G. W., Jr., F. Alemany, D. Alvarez, and A. García. 2013. Development of indices of larval bluefin tuna (*Thunnus thynnus*) in the western Mediterranean Sea. Collect. Vol. Sci. Pap. ICCAT, 69(2): 1057-1076.

Lo, N. C. H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-1526.

Muhling B.A., Reglero P, Ciannelli L, Alvarez-Berastegui D, Alemany F, Lamkin JT, Roffer MA (2013) Comparison between environmental characteristics of larval bluefin tuna *Thunnus thynnus* habitat in the Gulf of Mexico and western Mediterranean Sea.

Muhling B.A., Lamkin, J.T., Roffer, M.A. (2010) Predicting the occurrence of Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the northern Gulf of Mexico: building a classification model from archival data. Fisheries Oceanography 19: 526-539.

Oray, I. K. and F.F. Karakulak. 2005. Further evidence of spawning of bluefin tuna (*Thunnus thynnus* L., 1758) and the tuna species (Auxis rochei L., 1810, Euthynnus alletteratus Raf., 1810) in the eastern Mediterranean Sea: preliminary results of TUNALEV larval survey in 2004. Journal of Applied Ichthyology. 21: 226-240.

Piccinetti, C. and G. Piccinetti Manfrin. 1994. Distribution des larves de Thonidés en Méditerranée. FAO Fisheries Report. 494: 186, 206.

Piccinetti, C., Piccineti-Manfrin G. and S. Soro. 1996a. Larve di tunnidi in Mediterraneo. Biologia Marina Mediterranea. 3(1): 303-309.

Piccinetti, C., Piccineti-Manfrin G., and S. Soro. 1996b. Résultats d'une campagne de recherche sur les larves de thonidés en Mediterranée.

Piccinetti, C., Piccinetti-Manfrin G. and S. Soro. 1997. Résultats d'une campagne de recherché sur les larves de thonidés en Méditerranée. ICCAT. Collective Volume of Scientific Papers. 46: 207-214.

Reglero P, Ciannelli L, Álvarez-Berastegui D, Balbín R, López-Jurado JL, Alemany F (2012) Geographically and environmentally driven spawning distributions of tuna species in the western Mediterranean Sea. MEPS 463: 273-284.

Rodriguez-Marin, E., M. Ruiz, B. Pérez, P. Quelle, P.L. Luque and J. Ortiz de Urbina. 2013. Have the Atlantic Bluefin Tuna Management Measures Influenced the Age Composition of the Bay of Biscay Baitboat Catches? Collect. Vol. Sci. Pap. ICCAT, 69(1): 252-258.

Scott, G. P., S.C. Turner, C.B. Grimes, W.J. Richards, and E.B. Brothers. 1993. Indices of larval bluefin tuna, *Thunnus thynnus*, abundance in the Gulf of Mexico; modeling variability in growth, mortality, and gear selectivity. Bull. Mar. Sci. 53(2):912-929.

Steventon, J.D., W.A. Bergerud and P.K. Ott. 2005. Analysis of presence/absence data when absence is uncertain (false zeroes): an example for the northern flying squirrel using SAS®. Res. Br., B.C. Min. For. Range, Victoria, B.C. Exten. Note 74.

Tsuji, S., Segawa K. and Y. Hiroe. 1997. Distribution and abundance of *Thunnus* larvae and their relation to the oceanographic condition in the Gulf of Mexico and the Mediterranean Sea during May through August of 1994. Collective Volumes of Scientific Papers of ICCAT. 46(2): 161-176.

Table 1. Surveys from which data were used for analyses.

Survey	*Year*	*Start Date*	*End Date*	*Number of stations*
TU0601	2001	16JUN2001	07JUL2001	173
TU0602	2002	07JUN2002	30JUN2002	205
TU0703	2003	03JUL2003	29JUL2003	198
TU0604	2004	18JUN2004	10JUL2004	378
TU0605	2005	27JUN2005	23JUL2005	385
ATAME0612	2012	21JUN2012	08JUL2012	153

Table 2. Summary of data used in these analyses. B60 and B90 gear type indicate bongo-60 and bongo-90 gear, respectively.

Gear	*Haul Type*	*Survey Year*	*Number of Stations Used in Analysis*	*Start Date*	*End Date*	*Number of Specimens*	*Mean Length (mm)*	*Size Range (mm)*
B60	deep oblique	2001	173	17-Jun-01	7-Jul-01	123	3.589	2.0 - 5.0
B60	deep oblique	2002	205	7-Jun-02	29-Jun-02	332	2.820	2.0 - 6.0
B60	deep oblique	2003	199	3-Jul-03	29-Jul-03	211	2.709	2.0 - 8.0
B60	deep oblique	2004	181	22-Jun-04	10-Jul-04	265	3.760	2.0 - 8.5
B60	deep oblique	2005	204	28-Jun-05	23-Jul-05	182	3.046	1.39 - 8.0
B90	subsurface	2004	197	22-Jun-04	9-Jul-04	3300	NA	NA
B90	subsurface	2005	217	28-Jun-05	23-Jul-05	866	NA	NA
B90	mixed layer oblique	2012	153	21-Jun-12	8-Jul-12	28761	3.616	1.74 - 11.49

Table 3. Backward selection procedure for building delta-lognormal submodels for the SLI.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 7180.5)*						*Lognormal Submodel Type 3 Tests (AIC 1343.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	303	11.23	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	1	303	0.43	0.5149
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	2	303	0.55	0.5755
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	40	303	1.13	0.2756
Salinity	1	1390	18.01	18.01	<.0001	<.0001	1	303	2.07	0.1509
Temperature	1	1390	16.78	16.78	<.0001	<.0001	1	303	0.00	0.9711

Model Run #2	*Binomial Submodel Type 3 Tests (AIC 7180.5)*						*Lognormal Submodel Type 3 Tests (AIC 1342.2)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	304	11.34	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	1	304	0.47	0.4940
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	2	304	0.58	0.5611
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	40	304	1.17	0.2263
Salinity	1	1390	18.01	18.01	<.0001	<.0001	1	304	2.12	0.1467
Temperature	1	1390	16.78	16.78	<.0001	<.0001			dropped	

Model Run #3	*Binomial Submodel Type 3 Tests (AIC 7180.5)*						*Lognormal Submodel Type 3 Tests (AIC 1341.7)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	306	11.49	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	1	306	0.38	0.5365
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	dropped			
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	40	306	1.21	0.1919
Salinity	1	1390	18.01	18.01	<.0001	<.0001	1	306	2.42	0.1207
Temperature	1	1390	16.78	16.78	<.0001	<.0001	dropped			

Model Run #4	*Binomial Submodel Type 3 Tests (AIC 7180.5)*						*Lognormal Submodel Type 3 Tests (AIC 1341.7)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	307	12.05	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	dropped			
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	dropped			
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	40	307	1.20	0.1991
Salinity	1	1390	18.01	18.01	<.0001	<.0001	1	307	2.15	0.1440
Temperature	1	1390	16.78	16.78	<.0001	<.0001	dropped			

Model Run #5			*Binomial Submodel Type 3 Tests (AIC 7180.5)*				*Lognormal Submodel Type 3 Tests (AIC 1445.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	347	11.53	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	dropped			
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	dropped			
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	1	347	2.03	0.1550
Salinity	1	1390	18.01	18.01	<.0001	<.0001	dropped			
Temperature	1	1390	16.78	16.78	<.0001	<.0001	dropped			

Model Run #6			*Binomial Submodel Type 3 Tests (AIC 7180.5)*				*Lognormal Submodel Type 3 Tests (AIC 1447.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1390	158.28	31.66	<.0001	<.0001	5	348	12.65	<.0001
Month	1	1390	7.55	7.55	0.0060	0.0061	dropped			
Time of Day	2	1390	5.72	2.86	0.0573	0.0577	dropped			
Geographic Area	40	1390	63.63	1.59	0.0101	0.0115	dropped			
Salinity	1	1390	18.01	18.01	<.0001	<.0001	dropped			
Temperature	1	1390	16.78	16.78	<.0001	<.0001	dropped			

Model Run #7			*Binomial Submodel Type 3 Tests (AIC 7174.3)*				*Lognormal Submodel Type 3 Tests (AIC 1447.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	5	1392	156.04	31.21	<.0001	5	348	12.65	<.0001
Month	1	1	1392	7.45	7.45	0.0063	dropped			
Time of Day	dropped						dropped			
Geographic Area	40	1392	62.94	1.57	0.0118	0.0132	dropped			
Salinity	1	1392	17.02	17.02	<.0001	<.0001	dropped			
Temperature	1	1392	17.69	17.69	<.0001	<.0001	dropped			

Table 4. Backward selection procedure for building delta-lognormal submodels for the HLI.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 7178.0)*						*Lognormal Submodel Type 3 Tests (AIC 1447.1)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1482	158.52	31.70	<.0001	<.0001	5	344	13.22	<.0001
Month	1	1482	27.01	27.01	<.0001	<.0001	1	344	0.01	0.9427
Time of Day	2	1482	5.92	2.96	0.0517	0.0520	2	344	1.45	0.2360
Larval Habitat Quality	1	1482	12.42	12.42	0.0004	0.0004	1	344	7.59	0.0062

Model Run #2	*Binomial Submodel Type 3 Tests (AIC 7178.0)*						*Lognormal Submodel Type 3 Tests (AIC 1446.1)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1482	158.52	31.70	<.0001	<.0001	5	345	14.38	<.0001
Month	1	1482	27.01	27.01	<.0001	<.0001	dropped			
Time of Day	2	1482	5.92	2.96	0.0517	0.0520	2	345	1.46	0.2345
Larval Habitat Quality	1	1482	12.42	12.42	0.0004	0.0004	1	345	7.62	0.0061

Model Run #3	*Binomial Submodel Type 3 Tests (AIC 7178.0)*						*Lognormal Submodel Type 3 Tests (AIC 1447.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1482	158.52	31.70	<.0001	<.0001	5	347	14.18	<.0001
Month	1	1482	27.01	27.01	<.0001	<.0001	dropped			
Time of Day	2	1482	5.92	2.96	0.0517	0.0520	dropped			
Larval Habitat Quality	1	1482	12.42	12.42	0.0004	0.0004	1	347	7.22	0.0076

Model Run #4	*Binomial Submodel Type 3 Tests (AIC 7157.1)*						*Lognormal Submodel Type 3 Tests (AIC 1447.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	5	1484	157.95	31.59	<.0001	<.0001	5	347	14.18	<.0001
Month	1	1484	27.29	27.29	<.0001	<.0001	dropped			
Time of Day	dropped						dropped			
Larval Habitat Quality	1	1484	11.98	11.98	0.0005	0.0006	1	347	7.22	0.0076

Table 5. Coefficients of variation for the larval index models (SLI and HLI) associated with each year.

Year	*CV-SLI*	*CV-HLI*	*CV improvement (%)*
2001	0.416	0.395	5.053
2002	0.454	0.414	8.870
2003	0.513	0.431	15.984
2004	0.293	0.261	10.862
2005	0.269	0.231	14.116
2012	0.228	0.226	0.693

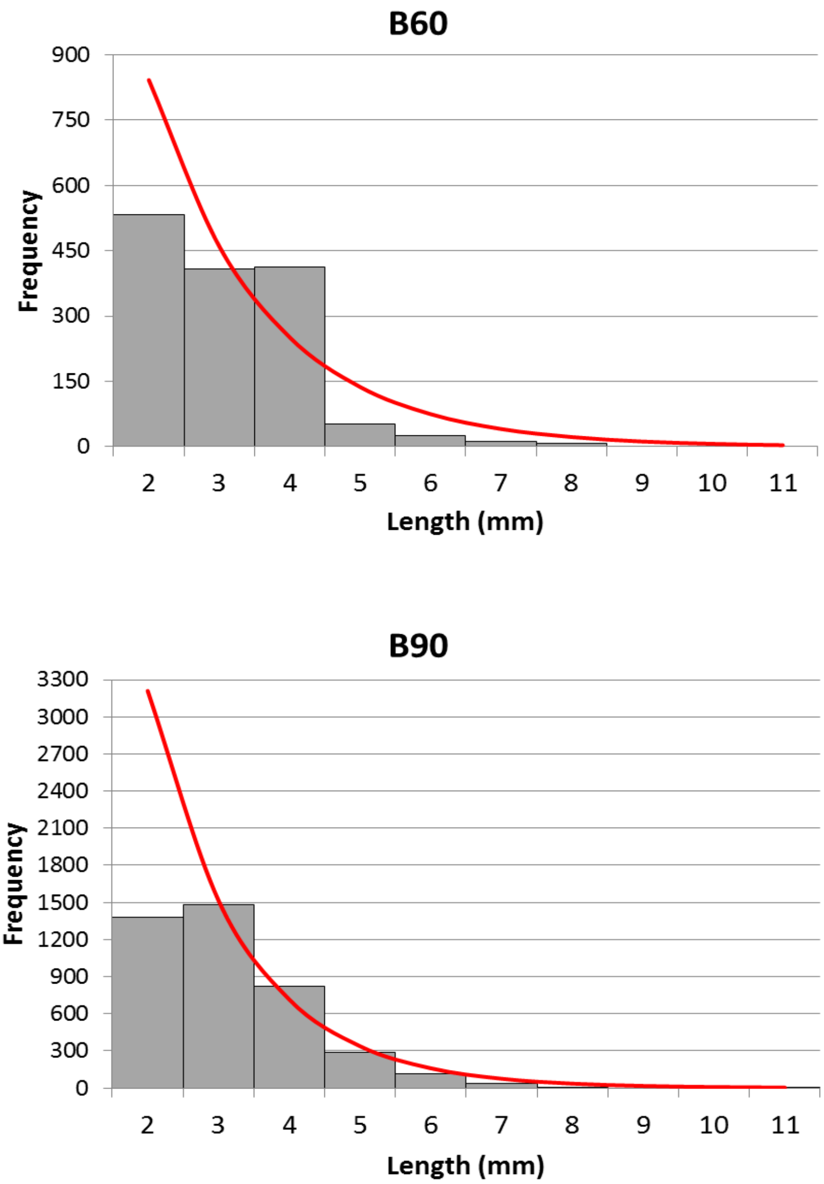
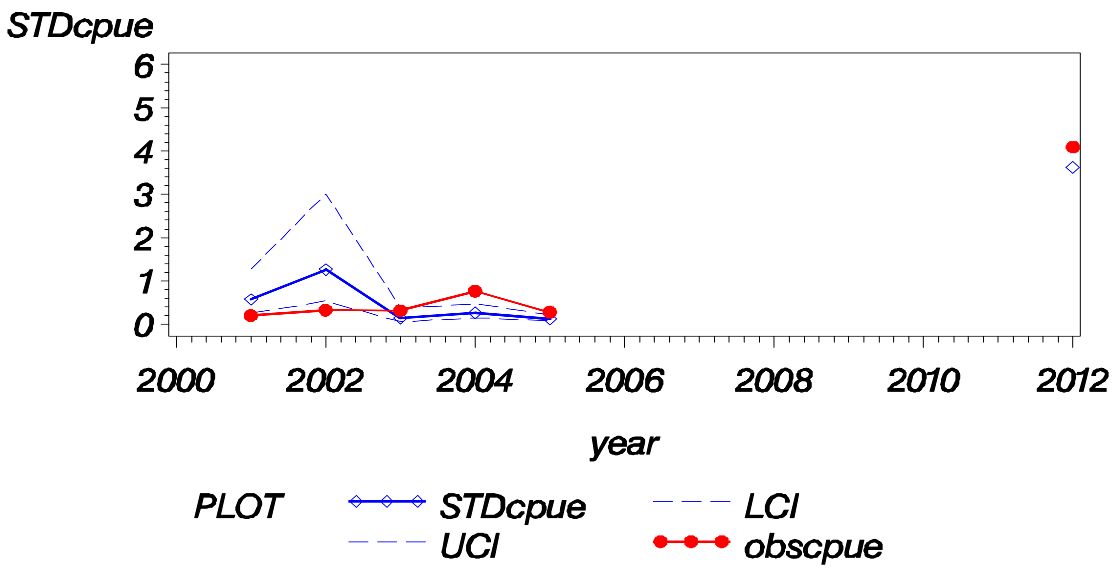


Figure 1. Decay curves used to back-calculate the number of 2-mm larvae. The equation for the bongo-60 (B60) curve is $N = 2821.37\ e^{-0.6046(\text{length})}$, where N is numbers of larvae and length is in mm, and the equation for the B90 curve is $N = 14401.42e^{-0.7504(\text{length})}$.



Survey Year	*Frequency*	*N*	*Index*	*Scaled Nominal*	*Scaled Index*	*CV*	*LCL*	*UCL*
2001	0.16185	173	4.5955	0.20606	0.57401	0.41577	0.25827	1.27571
2002	0.12195	205	10.1553	0.32849	1.26847	0.45410	0.53356	3.01559
2003	0.12121	198	1.1346	0.31804	0.14172	0.51294	0.05391	0.37258
2004	0.18783	378	2.1117	0.76586	0.26377	0.29322	0.14852	0.46846
2005	0.27013	385	1.0196	0.28561	0.12735	0.26898	0.07506	0.21605
2012	0.66667	153	29.0191	4.09594	3.62469	0.22788	2.31119	5.68468

Figure 2. Standard larval indices (SLI) for Atlantic bluefin tuna in the western Mediterranean Sea. STDcpue is the index scaled to a mean of one over the time series. Obscpue is the average nominal CPUE, and LCI and UCI are 95% confidence limits. In the table below, the *frequency* listed is nominal frequency, *N* is the number of bottom longline stations, *Index* is the abundance index in CPUE units, *Scaled Index* is the index scaled to a mean of one over the time series, *CV* is the coefficient of variation on the index value, and *LCL* and *UCL* are 95% confidence limits.

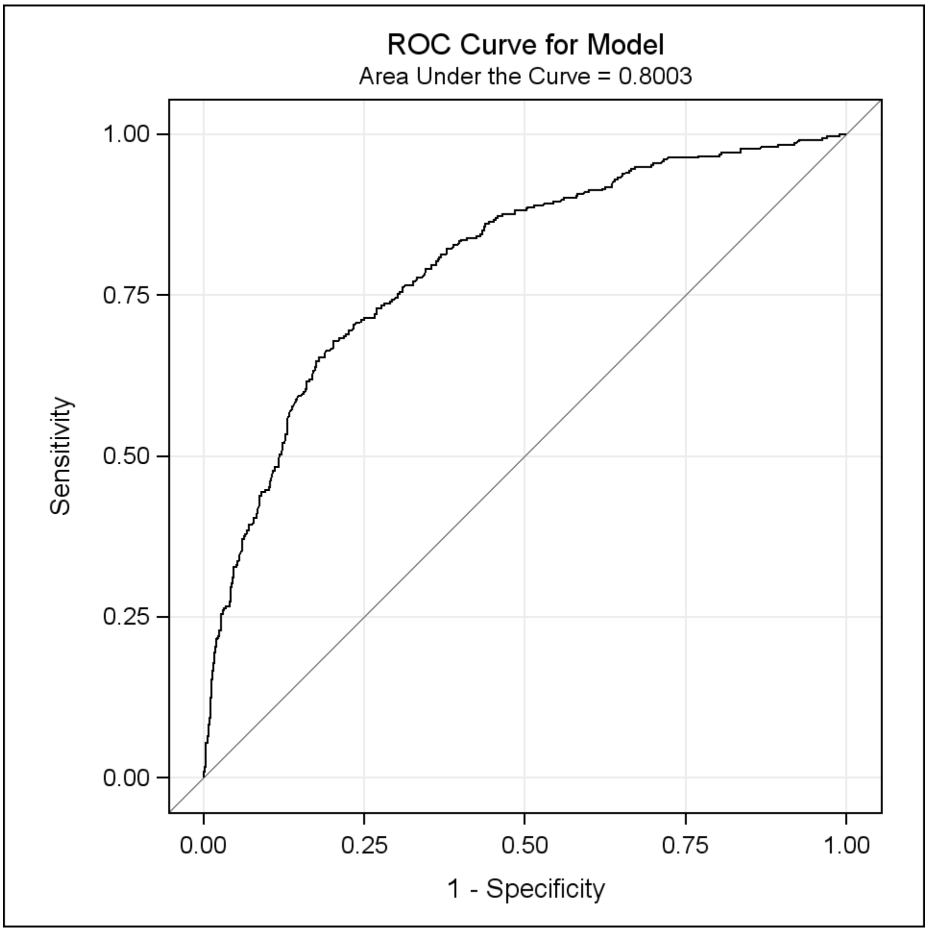


Figure 3. ROC curve diagnostic of the binomial submodel for SLI in the western Mediterranean Sea.

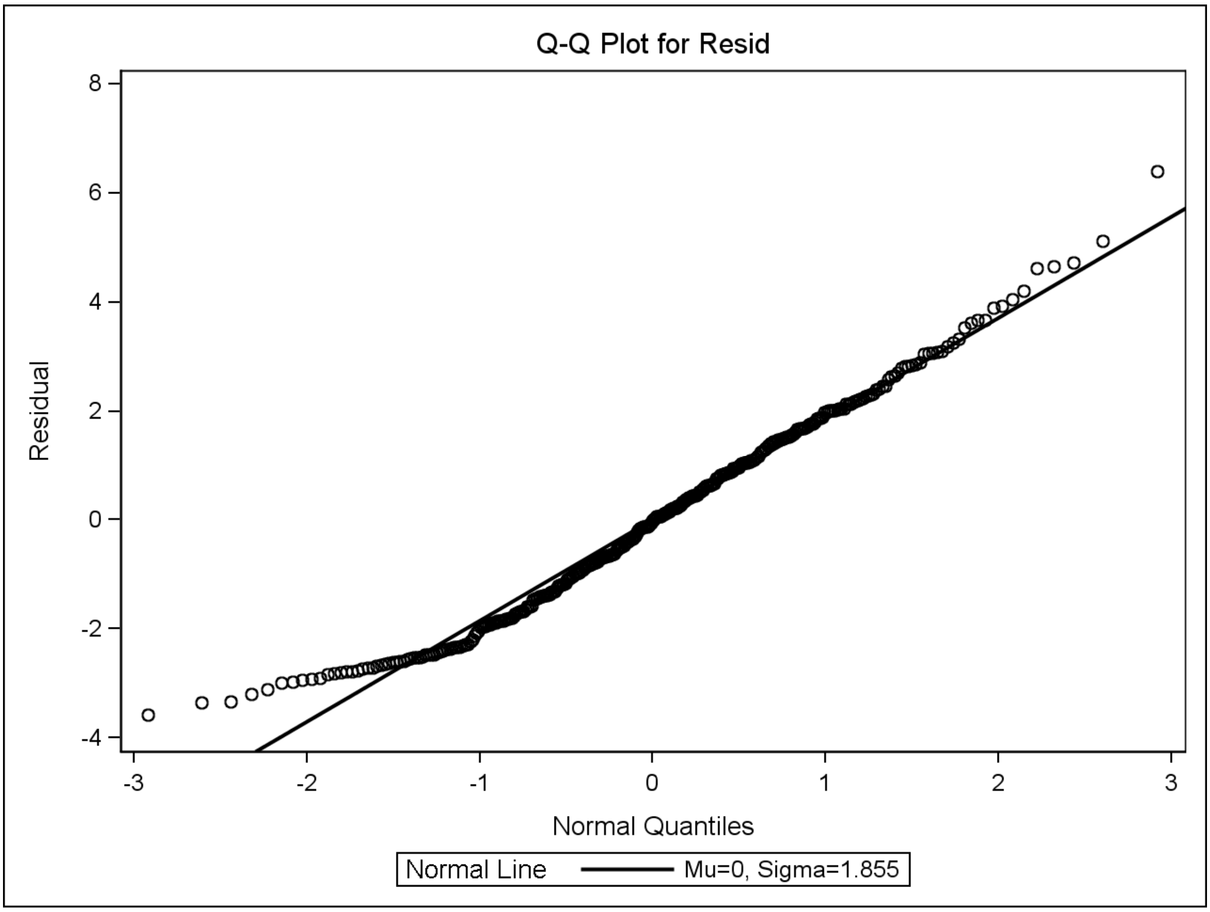
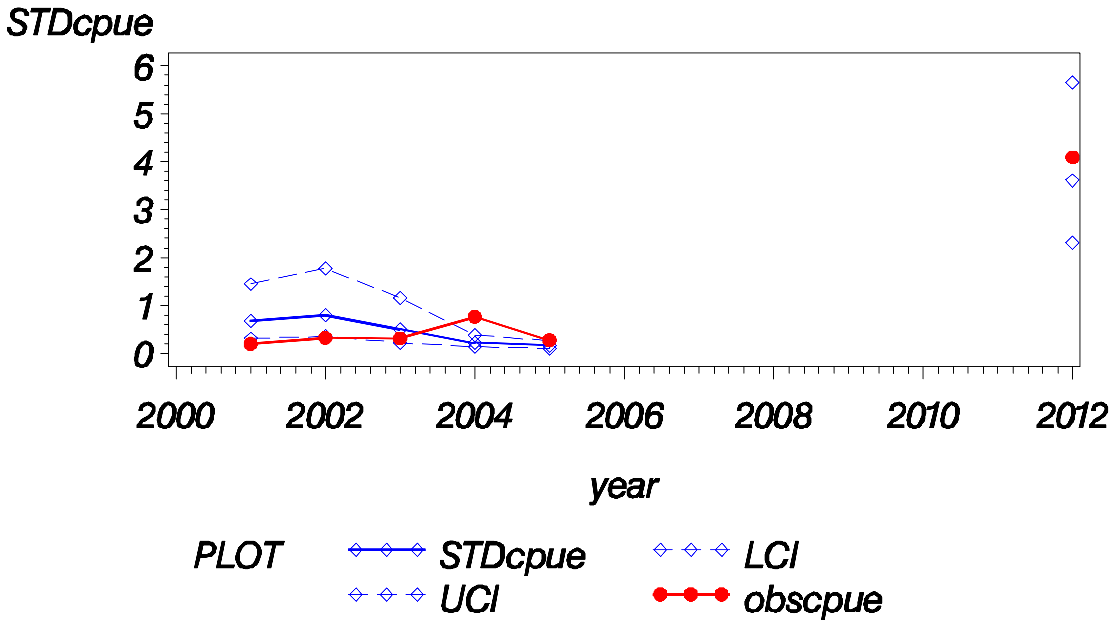


Figure 4. QQplot of chi-square residuals of the lognormal submodel for the SLI in the western Mediterranean Sea.



Survey Year	*Frequency*	*N*	*Index*	*Scaled Nominal*	*Scaled Index*	*CV*	*LCL*	*UCL*
2001	0.16185	173	5.0638	0.20606	0.67769	0.39476	0.31658	1.45070
2002	0.12195	205	5.9756	0.32849	0.79972	0.41382	0.36108	1.77122
2003	0.12121	198	3.7981	0.31804	0.50830	0.43095	0.22265	1.16041
2004	0.18783	378	1.7123	0.76586	0.22916	0.26137	0.13704	0.38319
2005	0.27013	385	1.2700	0.28561	0.16997	0.23101	0.10772	0.26817
2012	0.66667	153	27.0132	4.09594	3.61517	0.22630	2.31216	5.65250

Figure 5. Habitat-adjusted larval abundance indices (HLI) for larval Atlantic bluefin tuna collected in the western Mediterranean Sea. STDcpue is the index scaled to a mean of one over the time series. Obscpue is the average nominal CPUE, and LCI and UCI are 95% confidence limits. In the table below, the *frequency* listed is nominal frequency, *N* is the number of bottom longline stations, *Index* is the abundance index in CPUE units, *Scaled Index* is the index scaled to a mean of one over the time series, *CV* is the coefficient of variation on the index value, and *LCL* and *UCL* are 95% confidence limits.

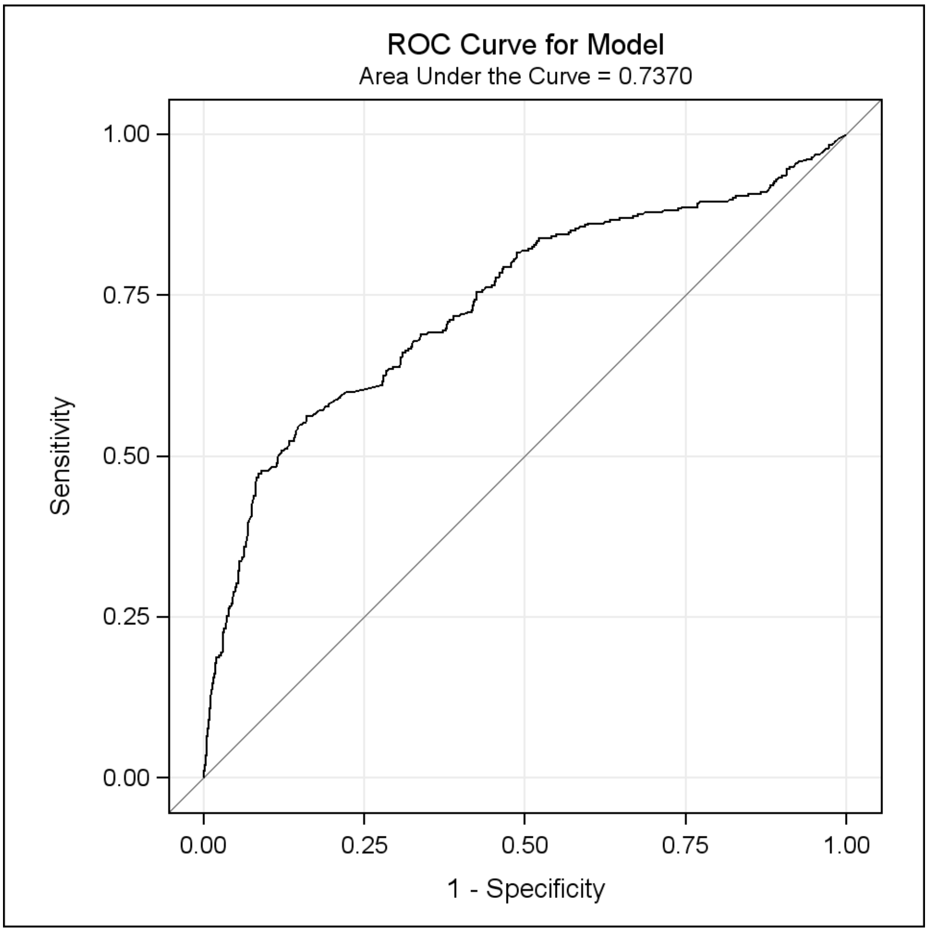


Figure 6. ROC curve diagnostic of the binomial submodel for HLI in the western Mediterranean Sea.

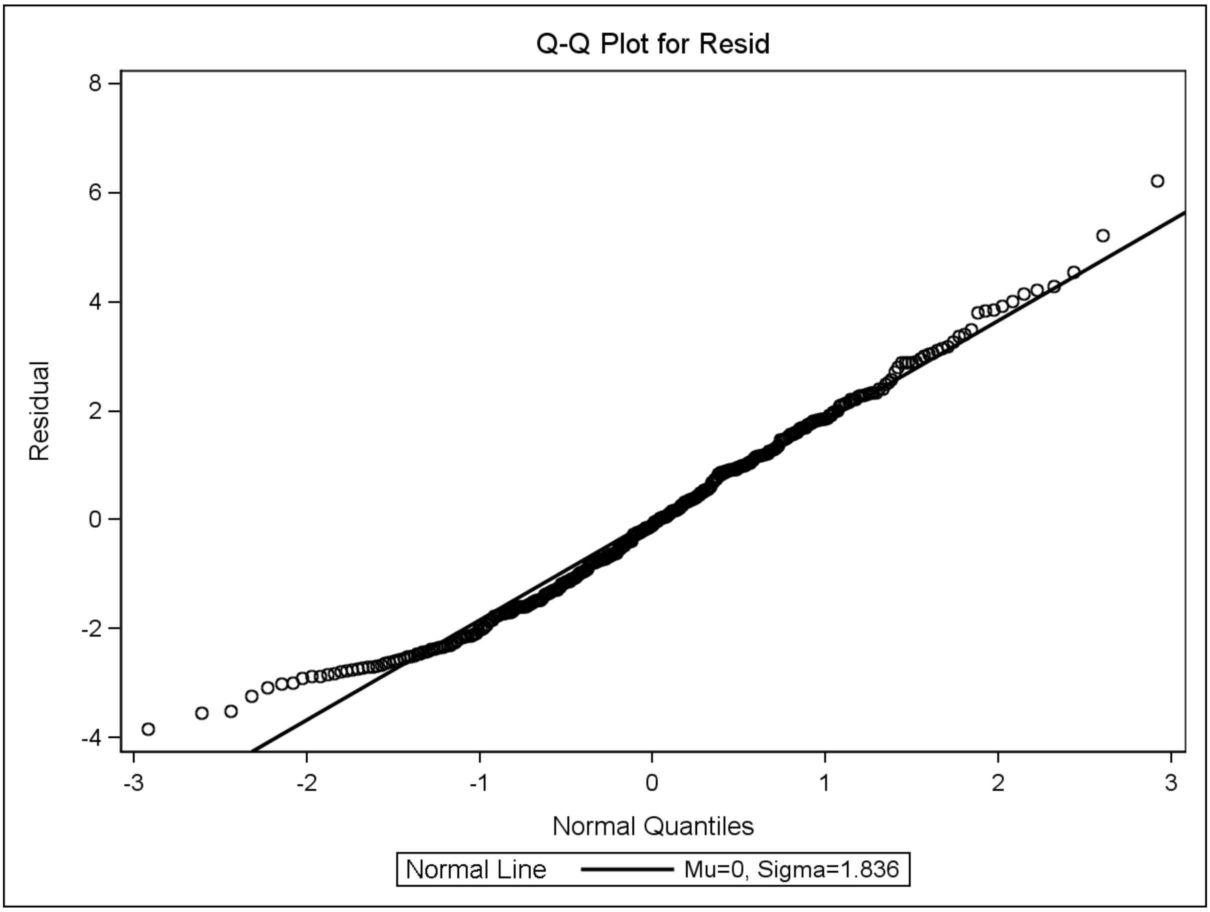


Figure 7. QQplot of chi-square residuals of the lognormal submodel for the SLI in the western Mediterranean Sea.