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BLUEFIN TUNA LARVAL INDICES IN THE BALEARIC ARCHIPELAGO FOR THE MANAGEMENT STRATEGY EVALUATION ("STRICT UPDATE" AND "REVISED VERSION" FOR 2001-2019 PERIOD)

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SUMMARY

*This document presents the update of the bluefin tuna larval indices from the Balearic Archipelago (Western Mediterranean). The two indices are the "strict updated" developed in 2019 (*SCRS/P/2019/055*) and the Revised Version, presented to the Group in May 2020 (SCRS/2020/067). The main differences between the two indices are the methods applied to compute the mean and dispersion of the two stage models, and the years included in each index. The revised version interpolates the larval indices for the years 2008 and 2011 for which some icthtipplanton surveys are available. The two indices are updated here with data from 2019 but excludes the 2018 year.*

RÉSUMÉ

Ce document présente la mise à jour des indices larvaires du thon rouge de l'archipel des Baléares (Méditerranée occidentale). Les deux indices sont la « mise à jour stricte » développée en 2019 (SCRS/P/2019/055) et la version révisée, présentée au Groupe en mai 2020 (SCRS/2020/067). Les principales différences entre les deux indices sont les méthodes appliquées pour calculer la moyenne et la dispersion des modèles à deux étapes, et les années incluses dans chaque indice. La version révisée interpole les indices larvaires pour les années 2008 et 2011 pour lesquelles quelques prospections d'ichtyoplancton sont disponibles. Les deux indices sont mis à jour ici avec les données de 2019 mais excluent l'année 2018.

RESUMEN

Este documento presenta la actualización de los índices larvales de atún rojo del archipiélago Balear (Mediterráneo occidental). Los dos índices son la «actualización estricta» desarrollada en 2019 (SCRS/P/2019/055) y la versión revisada, presentada al Grupo en mayo de 2020 (SCRS/2020/067). Las principales diferencias entre los dos índices son los métodos aplicados para calcular la media y la dispersión de los modelos de dos etapas, así como los años incluidos en cada índice. La versión revisada interpola los índices larvales para los años 2008 y 2011, para los que se dispone de algunas prospecciones de ictioplancton. Se actualizan los dos índices con datos de 2019, pero excluyendo el año 2018.

KEYWORDS

Standardization of CPUE, environmental variability, Balearic Sea, MSE, larval index strict update, Thunnus thynnus

1. Introduction

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Here we present the “strict update” and the “Revised Version” of the Bluefin tuna larval index in the Balearic Sea. The larval indices includes data from the systematic sampling campaigns from 2001 to 2005 and from 2012 to 2019 (not including data from 2018). The “Revised Version” includes also data for the 2008 and 2011, following specific interpolation methods taking advantage of smaller campaigns of ichthyoplankton surveys conducted those years.

The “strict update” is provided to minimize changes in relation to the current larval index integrated in the MSE and follows the same standardization of the larval index developed in 2019 (SCRS/P/2019/055). This index was updated in January 2020, including new data from 2017 and used for the MSE that year and in the VPA. The standardization of the CPUE is resolved with a two stage model combining a binomial and a log-normal submodel, both resolved with GAMs. Corrections for unbalanced factors and back-transformation of the errors are resolved through a grid of random combination of predicted factors.

The “Revised Version” follow a standardization approach develop for the May 2020 BFT group meeting, resolved using marginal means for specified factors EMMEANS (Searle *et al.*, 1980, Length R. 2020). This version provides also index values for the years 2008 and 2011, years for which smaller ichthyoplankton sampling campaigns are available. The adequacy of including those years in the index and detailed methodology for this version of the index is described in the document SCRS/2020/067 (See Alvarez-Berastegui *et al.,* 2020).

Both indices show lower values in 2019 than in 2017, but within the range of variability of that 2017 year. Nominal catches and both indices (stick update and revised version), confirms the increase trends along the whole time series.

2. Material & Methods

Biological data

Atlantic bluefin tuna (*Thunnus thynnus*) larvae were collected during twelve ichthyoplankton surveys around the Balearic Islands during summer (**Table 1**) in systematic ichthyoplankton surveys targeting the spawning peak of Atlantic bluefin tuna in the area. Systematic surveys were carried out in June–July in two periods, i.e. 2001–2005 and 2012-2019 (excluded 2018).Survey design consisted of a regular grid of 10 × 10 nautical miles covering the area between 37.858–40.358 N and 0.778–4.918 E, covering an area of 86,351 Km^2. The 2008 and 2011 campaigns covered smaller areas that the systematic campaigns (See table 1 and maps in Annex 4), these two campaigns were included in the “revised version” index but not included in the development of the “strict update” index. Fishing operations were conducted at around 2 knots, during 8–10 minutes and covered a linear distance of about 600 m. The volume of water filtered was measured with flowmeters located at the centre of the net. During the period 2001-2005, tows were performed using a bongo net of 60 cm mouth diameter, stepped obliquely to a depth of 70 m (deep oblique), or from 5 m above the bottom at coastal stations, to the surface maintaining the vessel speed at two knots. For the second period and for the years 2008 and 2011, the sampling was conducted using bongo 90 nets fitted with 500 microns meshes towed down to 20 – 30 meters (mixed layer oblique), covering the whole mixed layer depth in this area and season (Torres *et al.,* 2014).

In all surveys, plankton samples were preserved with 4% formalin buffered with borax. Tuna larvae were identified to the species level and measured in standard length. Once in the laboratory, the number of larvae were counted and standardised at each hauling station, following Álvarez-Berastegui *et al.,* (2017).

Correction for the larvae length decay in numbers

The abundance of Atlantic bluefin tuna are standardised to larvae at reference length of 2 mm to avoid the exponential decay due to natural mortality and changes on catchability of older larvae (Alvarez-Berastegui et al. 2017). In order to maintain the index as much similar to previous versions, the retrocalculation model has not been re-adjusted with new catch distributions from 2017 and 2019, therefore we used the following the equation developed for previous versions of the index.

$$N_{2mm} = 1092944e^{-0.722\,L_i}, \qquad \text{(Eq. 1)}$$

where N_{2mm} is the number of larvae at 2 millimetres and L_i total length of larvae, in mm. Second, the catch per unit area (CPUA, in N larvae / m^2) is computed following the equation:

$$CPUA = \frac{N\ larvae}{V_{filtered}} D_{tow} \quad \text{(Eq. 2)}$$

where $V_{filtered}$ is the volume of water filtered by the net (in m^3) and D_{tow} is the towing depth (in m). Finally, CPUA is standardised or the two nets used following an exponential relationship between B60 deep oblique and B90 mixed layer oblique of the form:

$$CPUA_{B90} = 0.58\ CPUA_{B60}\ e^{0.00115\ CPUA_{B60}},\ R^2 = 0.998 \quad \text{(Eq. 3)}$$

Environmental and fishing operation data exploration.

In-situ environmental data driving larval habitats, mean temperature and salinity of the water column down to the mixed layer depth were retrieved during the surveys using a CTD. In order to assess potential variability of sampling and environmental conditions among years that could affect the standardization of the catches we explore boxplots of the following variables: volume filtered by nets per year, Tmezcla, Smezcla, Oxygen concentration in the mixed layer depth (OMEZCLA), day of the year (DY) and hour of the fishing operation (hournorm).

Larval index standardization models for the "Strict update" and "Revised Version".

The standardization of larval abundances retrocalculated to 2mm was conducted using two step models combining a binomial submodel for the probabilities of larvae presence and a log transformed submodel for the positive abundances. Both submodels are resolved with GAMs.

For the "Strict Update". The index cover the period 2001-2005 and 2012-2019, (excluding 2018), using only extensive systematic ichthyoplankton surveys. Both submodels were fitted using the same variables than in the previous version of the MSE strict update index (SCRS/P/2019/055). The presence probability (binomial) submodel performance was checked with plots of Area Under the Curve (AUC) and density plot of real positive and negative estimates. The log transformed positive abundance submodel was checked with the deviance of the residual versus theoretical quantiles , residuals versus linear predictor, histogram of the residuals and the response versus fitted values. To compensate for changes in factors among years, mean values and associated deviations were calculated from a grid obtained from the prediction of a random combinations of explanatory variables among the "year" factor. Deviations from the mean where computed as the dispersion of the outputs of that grid.

For the "Revised Version". The index cover the period 2001-2019, (excluding 2018), including data from the extensive systematic ichthyoplankton surveys and from smaller campaigns in 2008 and 2011. Both submodels were fitted using the same variables than in the previous version of the MSE revised index The presence probability (binomial) submodel performance and the log transformed positive abundance submodel was checked with the deviance of the residual versus theoretical quantiles, residuals versus linear predictor, histogram of the residuals and the response versus fitted values. Mean were calculated accounting for compensation for changes in factors among years using EMMEANS (Searle *et al*., 1980, Lenth R. 2020). Error distribution was computed also within EMMEANS. The approach for integrating the data from the years 2008 and 2011 (years with lower number of samples), and a sensitive analyses of including smaller campaigns, together with the methodological details of this index is described in the document SCRS/2020/067 (Alvarez-Berastegui *et al*., 2020).

3. Results

- The larval indices are presented in **Table 2, Figure 1 and Figure 2**.
- Model performance plots for the binomial and lognormal model for both indices are presented in ANNEX 1 (Strict U`pdate index) and ANNEX 2 ("Revised Version").
- Internal variability of explanatory variables and additional environmental parameters are presented in Box Plots in ANNEX 2: Tmezcla, Smezcla, Oxygen concentration in the mixed layer depth OMEZCLA), hour of the day (hournum) and day of the year (DY)
- Maps of the sampling campaigns are presented in ANNEX 3.
- Model descriptive outputs, with variables included, significances and deviances explained are presented in ANNEX 4 (for the strict update submodels) and in Annex 5 (for the Revised Version submodels)

4. Concussions

- The levels of larvae abundances in 2019 are below those of 2017 but within the same confidence intervals.
- With the inclusion of new data some of the variables (hour of the day) become not significant, what would explain small changes with previous versions of the indices.
- EMMEANS applied for the Revised Version seems a more realistic approach for calculation of the errors associated to the two-stage model with log transformed data. The strict updated index, may underestimate coefficients of variation.

Acknowledgements

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Table 1. Dataset used in the analysis of bluefin tuna larval index and characteristics of the surveys.

Year	*Gear*	*Tow depth*	*No. samples*	*Survey dates*
2001	B60	70	162	16/06 - 07/07
2002	B60	70	171	07/06 - 28/06
2003	B60	70	198	03/07 - 29/07
2004	B60	70	166	18/06 - 08/07
2005	B60	70	186	27/06 - 23/07
2008	B90	30	41	29/07 – 11/08
2011	B90	30	84	14/05 – 17/07
2012	B90	30	153	21/06 – 08/07
2013	B90	30	124	20/06 – 10/07
2014	B90	30	92	13/06 – 30/06
2015	B90	30	94	23/06 – 09/07
2016	B90	30	95	21/06 – 07/07
2017	B90	30	92	26/06 – 12/07
2019	B90	30	108	19/06 - 05/07

Table 2. Nominal CPAU and larval indices re expressed in retro-calculated number of larvae per 10m^2.

			Strict Update (as in SCRS/P/2019/055, and updated in January 2020)					***Revised Version (as in SCRS/2020/067, presented in May 2020)***				
year	**No. samples**	**Nominal CPUA**	**Strict update index**	**se_i**	**cv_i**	**UCI**	**LCI**	**Revised version index**	**se_i**	**cv_i**	**UCI**	**LCI**
2001	162	6,64	**3,404**	0,267	0,079	3,93	2,87	**4,106**	1,72	0,42	9,2	1,8
2002	171	4,23	**8,888**	0,680	0,076	10,44	7,69	**9,209**	4,49	0,49	23,2	3,7
2003	198	8,19	**3,573**	0,254	0,071	4,22	3,17	**2,129**	1,15	0,54	5,9	0,8
2004	166	28,87	**6,433**	0,499	0,078	7,46	5,47	**10,448**	4,37	0,42	23,3	4,7
2005	186	8,21	**1,954**	0,143	0,073	2,26	1,69	**1,997**	0,80	0,40	4,3	0,9
2008	41	0,35						**2,001**	1,57	0,79	8,0	0,5
2011	85	39,27						**9,191**	3,67	0,40	19,8	4,3
2012	153	212,99	**21,397**	1,730	0,081	25,28	18,30	**24,984**	5,45	0,22	38,4	16,2
2013	124	178,00	**31,409**	2,821	0,090	36,99	25,84	**39,828**	12,06	0,30	72,0	22,0
2014	92	85,15	**15,728**	1,640	0,104	19,31	12,74	**18,378**	5,44	0,30	32,8	10,3
2015	94	196,26	**25,991**	2,681	0,103	31,97	21,18	**34,441**	8,44	0,25	55,8	21,2
2016	95	185,38	**21,027**	2,157	0,103	25,83	17,15	**30,764**	8,52	0,28	53,0	17,9
2017	92	521,10	**55,382**	5,774	0,104	67,98	44,85	**67,460**	16,87	0,25	110,4	41,2
2019	108	478,57	**49,244**	4,738	0,096	59,44	40,48	**44,888**	10,41	0,23	71,0	28,4

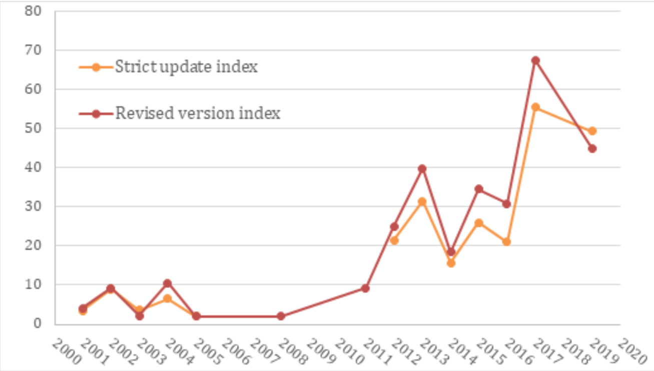


Figure 1. Larval index (MSE strict update and Revised Version), (retrocalculated number of larvae per 10m^2), note that 2018 year is not included.

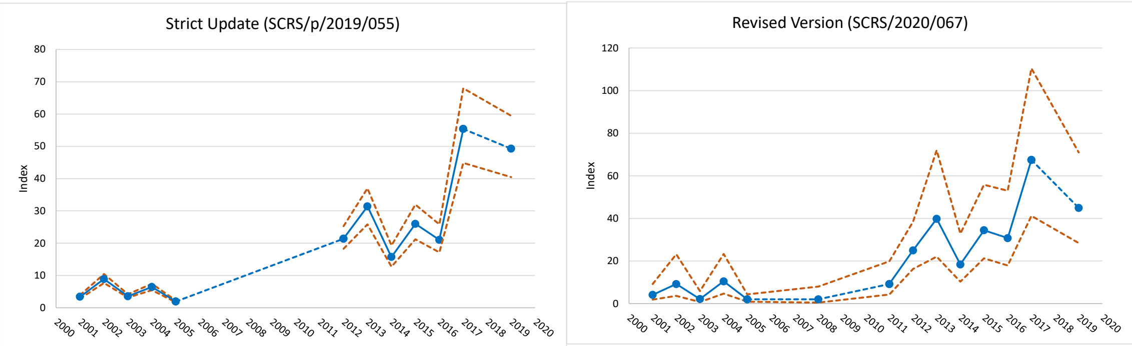


Figure 2. Left: Strict update index with UCI and LCI. Right: Revised version of UCI and LCI (upper and lower confidence limits calculated assuming non-normal distribution of errors). The differences in CVs due to different methods applied in the back transformation of the logarithmic scales (see methods).

Model Check Plots for The Strict Update Index

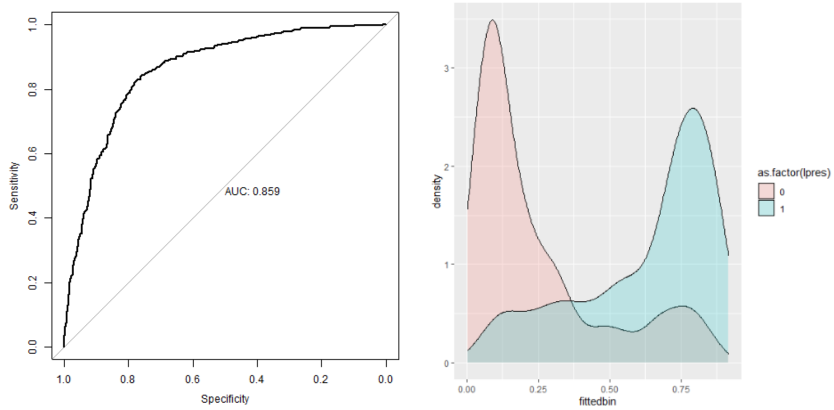


Figure. Model check for the binomial submodel. Plots of Area Under the Curve (AUC) (left) and density plot of real positive and negative estimates (right).

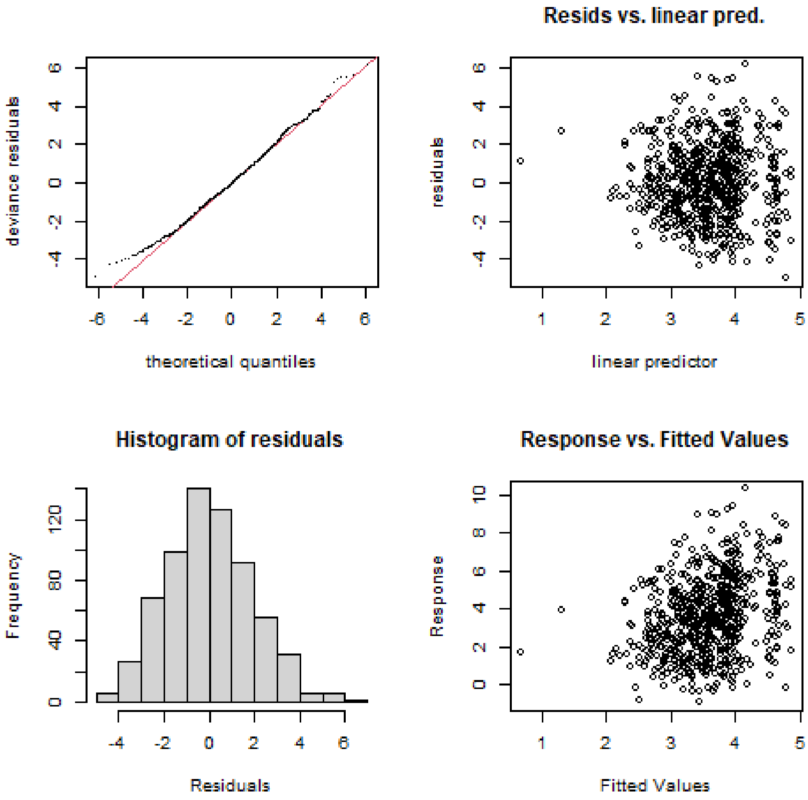


Figure. Model check for the log transformed positive abundance submodel. Deviance of the residual versus theoretical quantiles, residuals versus linear predictor, histogram of the residuals, response versus fitted values.

Annex 2

Model check plots for the revised version index

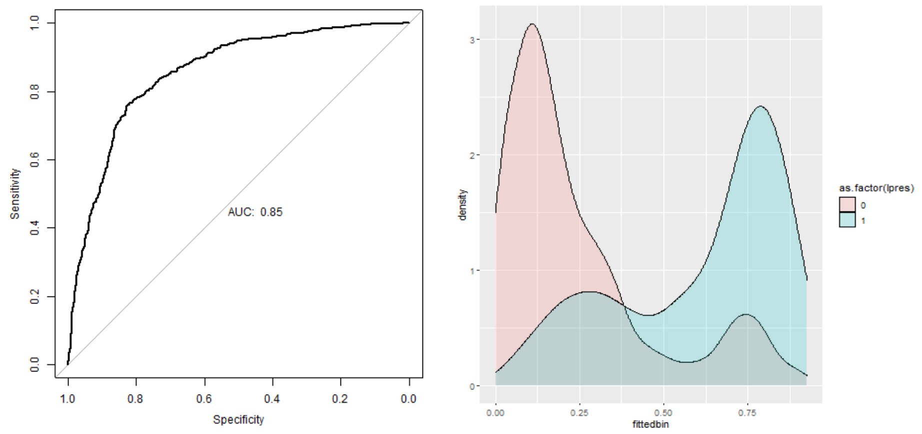


Figure. Model check for the binomial submodel. Plots of Area Under the Curve (AUC) (left) and density plot of real positive and negative estimates (right).

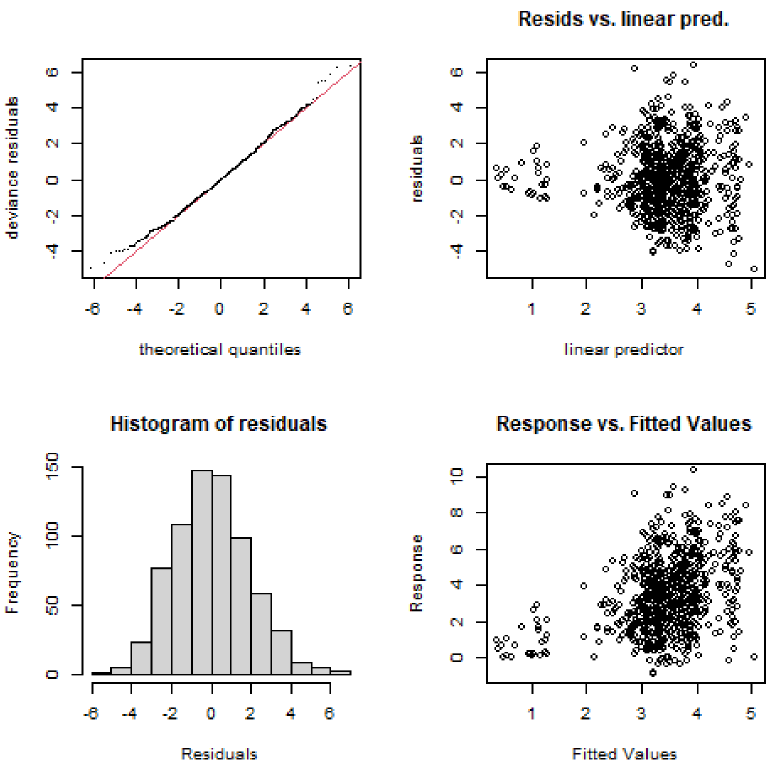


Figure. Model check for the log transformed positive abundance submodel. Deviance of the residual versus theoretical quantiles, residuals versus linear predictor, histogram of the residuals, response versus fitted values.

Input data exploration

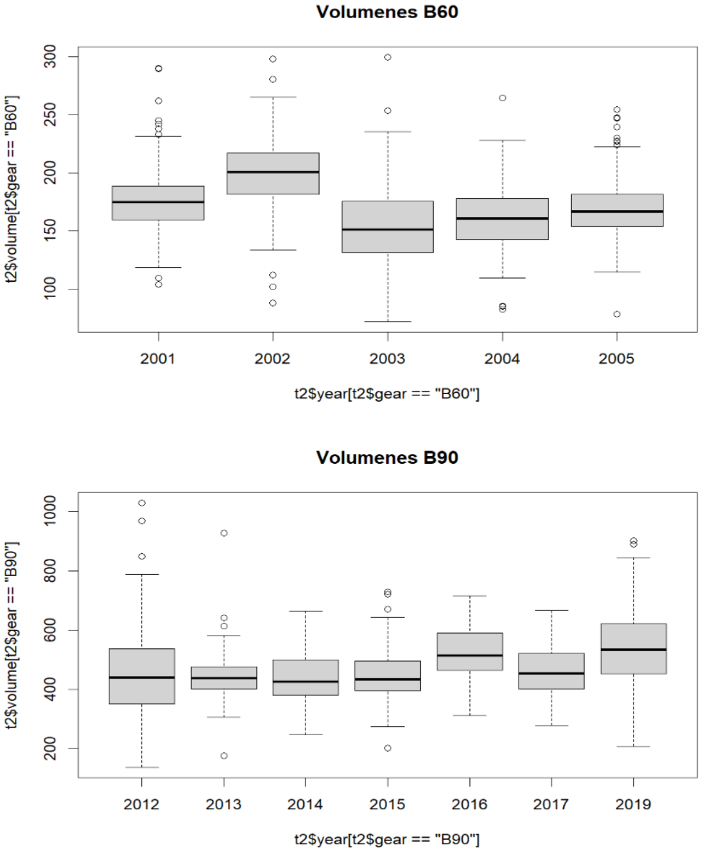


Figure. Boxplot of volumenes filtered per year.

Figure. Boxplot of Temperature in the mixed layer depth per year.

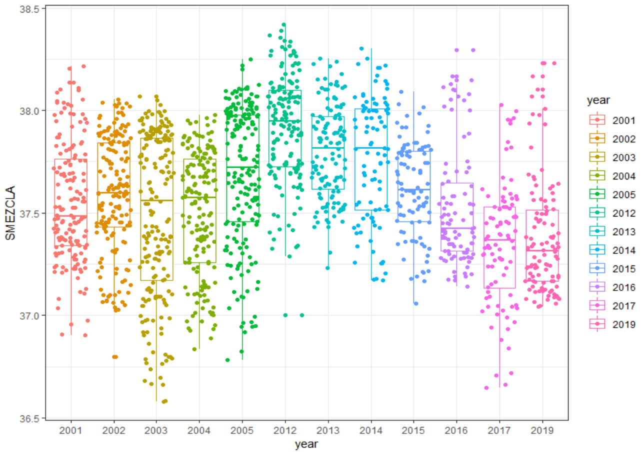


Figure. Boxplot of Salinity in the mixed layer depth per year.

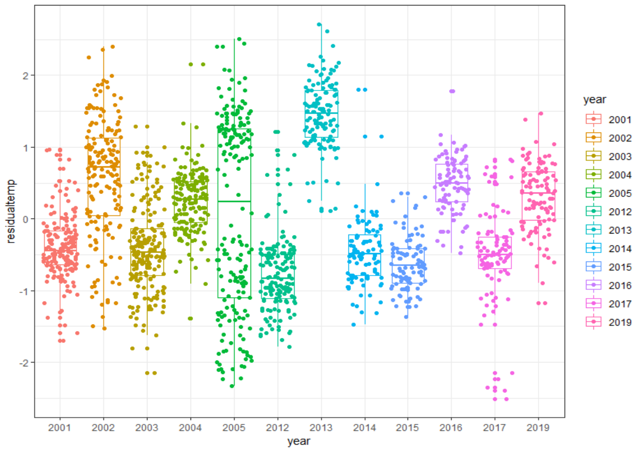


Figure. Boxplot of residual temperature in the mixed layer depth per year (extracted the effect of the day of the year).

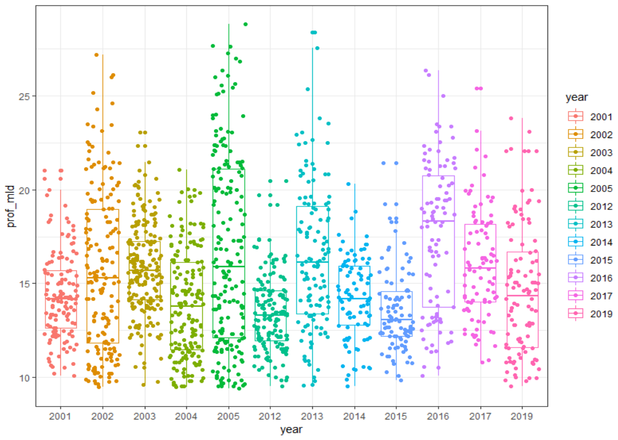


Figure. Boxplot of the depth of the mixed layer depth per year.

Figure. Boxplot of the oxygen concentration in the mixed layer depth per year.

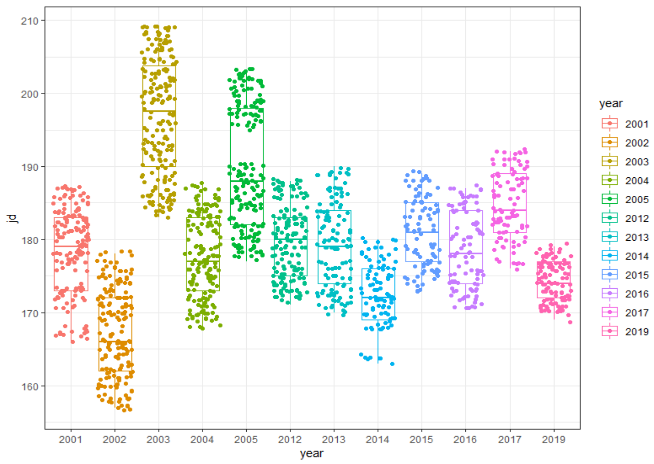
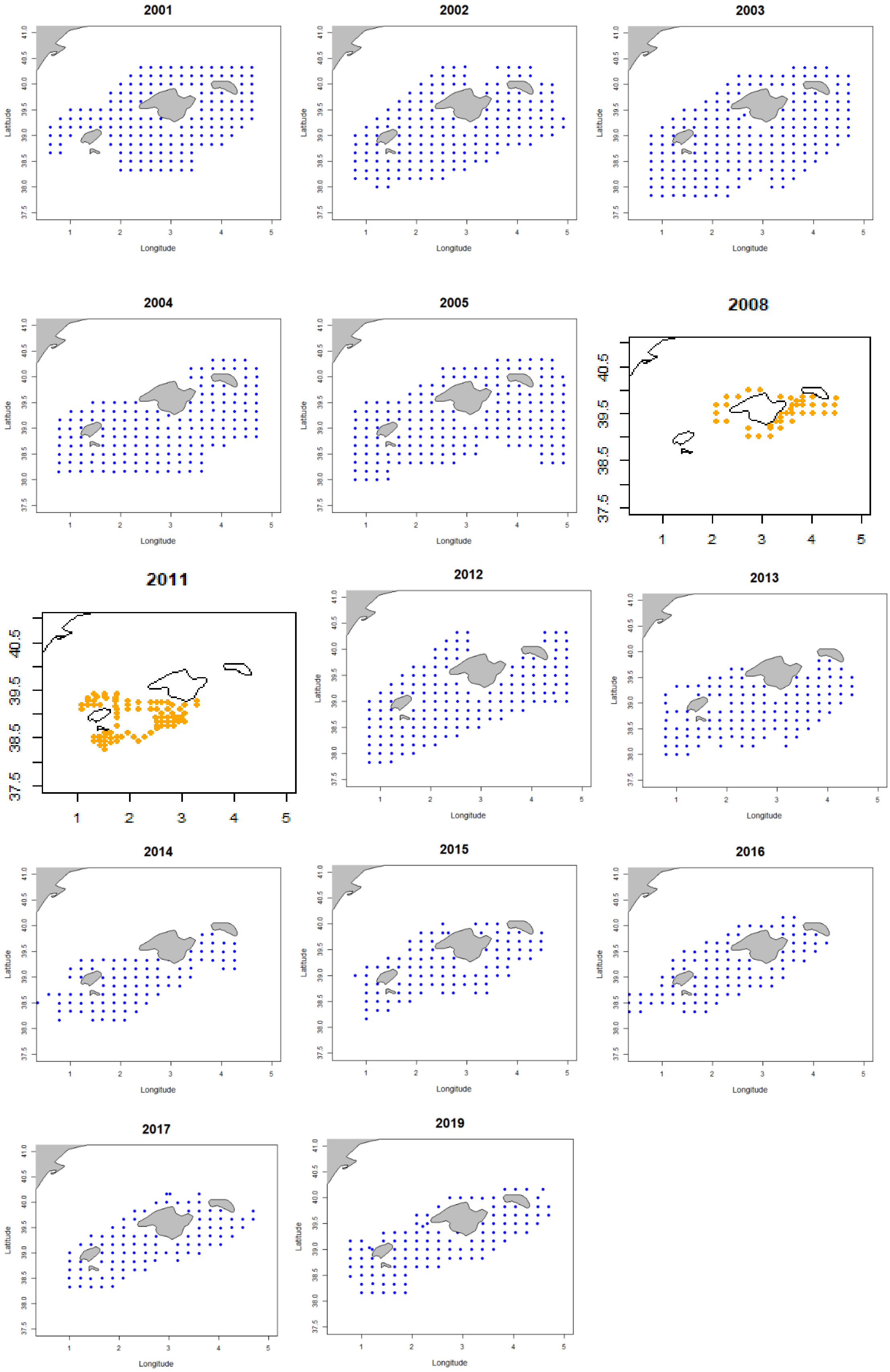


Figure. Boxplot of the day of the year of the samples.

Location of samples for each year



Annex 5

Gam model outputs, Strict update index

```
Link function: logit

Formula:
lpres ~ as.factor(year) + s(lat, lon, k = 9) + s(jd, k = 3) +
    s(SMEZCLA, k = 3) + s(residualtemp, k = 3)

Parametric coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)         -1.98702    0.23597  -8.420  < 2e-16 ***
as.factor(year)2002  0.68390    0.43444   1.574    0.115
as.factor(year)2003 -0.75080    0.50630  -1.483    0.138
as.factor(year)2004  0.15981    0.32712   0.489    0.625
as.factor(year)2005 -0.04876    0.36940  -0.132    0.895
as.factor(year)2012  2.59788    0.32567   7.977 1.50e-15 ***
as.factor(year)2013  3.14776    0.41908   7.511 5.87e-14 ***
as.factor(year)2014  2.59915    0.36003   7.219 5.23e-13 ***
as.factor(year)2015  2.74442    0.35409   7.751 9.15e-15 ***
as.factor(year)2016  2.51813    0.34583   7.281 3.30e-13 ***
as.factor(year)2017  2.75977    0.40457   6.822 9.01e-12 ***
as.factor(year)2019  3.20040    0.35164   9.101  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                  edf Ref.df Chi.sq  p-value
s(lat,lon)      6.830  7.702  11.84 0.089975 .
s(jd)           1.966  1.998  28.39 5.33e-07 ***
s(SMEZCLA)      1.866  1.981  15.62 0.000995 ***
s(residualtemp) 1.502  1.751  10.81 0.002018 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.375   Deviance explained =   32%
UBRE = -0.055789  Scale est. = 1         n = 1641
```

2- Gaussian submodel

```
Link function: identity
Formula:
log(target) ~ as.factor(year) + s(lat, lon, k = 9) + s(TMEZCLA,
    k = 3) + s(SMEZCLA, k = 3) + s(hournorm, bs = "cc", k = 7)

Parametric coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)           2.8975     0.3820   7.585 1.19e-13 ***
as.factor(year)2002   0.4970     0.6415   0.775  0.43873
as.factor(year)2003   0.6745     0.7650   0.882  0.37828
as.factor(year)2004   0.5242     0.5558   0.943  0.34595
as.factor(year)2005  -0.5015     0.5536  -0.906  0.36534
as.factor(year)2012   0.5398     0.4615   1.170  0.24251
as.factor(year)2013   0.7940     0.5203   1.526  0.12750
as.factor(year)2014   0.2192     0.4958   0.442  0.65848
as.factor(year)2015   0.6969     0.4464   1.561  0.11894
as.factor(year)2016   0.5319     0.4628   1.149  0.25088
as.factor(year)2017   1.4448     0.4640   3.113  0.00193 **
as.factor(year)2019   1.2401     0.4724   2.625  0.00887 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                  edf Ref.df     F p-value
s(lat,lon)  2.789e+00  3.395 0.696 0.63521
s(TMEZCLA)  1.888e+00  1.987 6.611 0.00251 **
s(SMEZCLA)  1.756e+00  1.939 1.505 0.18014
s(hournorm) 1.047e-09  5.000 0.000 0.65105
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0634   Deviance explained = 8.84%
GCV = 3.8414  Scale est. = 3.7331    n = 654
```

Annex 6

Gam model outputs, Revised version index

```
Family: binomial
Link function: logit
Formula:
lpres ~ as.factor(year) + s(jd, k = 3) + s(SALanom, k = 3) +
    s(tempres2, k = 3)

Parametric coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)          -2.0192     0.2361  -8.552  < 2e-16 ***
as.factor(year)2002   1.1368     0.3762   3.022 0.002511 **
as.factor(year)2003  -1.2664     0.4029  -3.143 0.001671 **
as.factor(year)2004   0.3017     0.3190   0.946 0.344382
as.factor(year)2005  -0.3159     0.3158  -1.000 0.317100
as.factor(year)2006  -0.2391     0.4294  -0.557 0.577615
as.factor(year)2008   1.5069     0.8861   1.701 0.089008 .
as.factor(year)2010   2.5024     0.6104   4.100 4.14e-05 ***
as.factor(year)2011   1.1711     0.3467   3.378 0.000731 ***
as.factor(year)2012   2.1482     0.2857   7.518 5.55e-14 ***
as.factor(year)2013   3.0825     0.3827   8.054 7.99e-16 ***
as.factor(year)2014   2.6428     0.3346   7.898 2.83e-15 ***
as.factor(year)2015   2.7042     0.3457   7.822 5.19e-15 ***
as.factor(year)2016   2.6399     0.3357   7.865 3.70e-15 ***
as.factor(year)2017   2.7456     0.3719   7.383 1.55e-13 ***
as.factor(year)2019   3.5499     0.3433  10.340  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Ref.df Chi.sq  p-value
s(jd)       1.947      2  76.56  < 2e-16 ***
s(SALanom)  1.791      2  21.17 7.18e-06 ***
s(tempres2) 1.407      2  23.99 3.80e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.363   Deviance explained = 30.8%
-REML = 865.02  Scale est. = 1         n = 1837

Family: gaussian
Link function: identity
Formula:
log(BFTab_gs) ~ as.factor(year) + s(lon, lat, k = 9) + s(SALanom,
    k = 3) + s(tempres2, k = 3)

Parametric coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)          2.918529   0.372917   7.826  1.9e-14 ***
as.factor(year)2002  0.029368   0.590007   0.050 0.960316
as.factor(year)2003  0.451434   0.551807   0.818 0.413583
as.factor(year)2004  0.701496   0.539815   1.300 0.194204
as.factor(year)2005 -0.461903   0.489744  -0.943 0.345936
as.factor(year)2006 -2.214194   0.668188  -3.314 0.000969 ***
as.factor(year)2008 -1.685959   0.842831  -2.000 0.045855 *
as.factor(year)2010 -1.456623   0.952089  -1.530 0.126496
as.factor(year)2011  0.008405   0.530120   0.016 0.987355
as.factor(year)2012  0.590302   0.415248   1.422 0.155606
as.factor(year)2013  0.845650   0.501579   1.686 0.092254 .
as.factor(year)2014  0.152860   0.462921   0.330 0.741344
as.factor(year)2015  0.767890   0.431460   1.780 0.075559 .
as.factor(year)2016  0.668656   0.467164   1.431 0.152796
as.factor(year)2017  1.431734   0.428217   3.343 0.000872 ***
as.factor(year)2019  0.906818   0.444327   2.041 0.041644 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(lon,lat)  1.2967      8 0.345 0.11979
s(SALanom)  0.7251      2 1.319 0.05621 .
s(tempres2) 0.8910      2 4.077 0.00241 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
R-sq.(adj) =  0.111   Deviance explained = 13.3%
-REML = 1456.6  Scale est. = 3.6512    n = 706
```