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STANDARDIZED CATCH RATES FOR SIMULATED LONGLINE DATA SAM WG 2017

Mauricio Ortiz[1]

SUMMARY

*The Stock Assessment and Methods (SAM) working Group generated a simulated catch and effort data for an exercise of standardization of CPUE to compare results and different methods currently employ in ICCAT for CPUE analyses. This document describe and present the results of the exercise of an standardized indices of relative abundance for a billfish species (Makaira nigricans) estimated using Generalized Linear Mixed Models under a delta lognormal model approach. The standardization procedure included the explanatory factors; year, area, season, hook type, hook per basket, bait type, and surface temperature and dissolve oxygen as environmental covariates. Deviance analyses help to identify major explanatory and interactions variables, in the case of Year*factor interaction(s) these were considered random if included in the final model. Comparison with true population trends indicated a good performance of the standardization procedure, with confidence bounds always including the true trend in almost all cases. A systematic departure in all simulated datasets was identified for the last three years of the series.*

RÉSUMÉ

*Le groupe de travail sur les méthodes d'évaluation des stocks (WGSAM) a généré des données simulées de prise et d'effort pour un exercice de standardisation de la CPUE en comparant les résultats et les différentes méthodes actuellement utilisées à l'ICCAT pour des analyses de CPUE. Ce document décrit et présente les résultats de l'exercice avec des indices standardisés d'abondance relative d'une espèce d'istiophoridés (*Makaira nigricans*) estimés au moyen de modèles mixtes linéaires généralisés avec une approche delta-lognormale du modèle. La procédure de standardisation incluait les facteurs explicatifs suivants : année, zone, saison, type d'hameçon, hameçon par panier, type d'appât et température de surface et oxygène dissous en tant que covariables environnementales. Des analyses de l'écart contribuent à identifier les principales variables explicatives et d'interactions. Dans le cas de l'interaction année*facteur, celle-ci a été estimée être aléatoire si incluse dans le modèle final. La comparaison avec les tendances réelles de la population indiquait un bon niveau de performance de la procédure de standardisation, les limites de confiance incluant toujours la tendance réelle dans la plupart des cas. Un écart dans tous les jeux de données apparaissait systématiquement dans les trois dernières années de la série.*

RESUMEN

*El Grupo de trabajo sobre métodos de evaluación de stock generó unos datos simulados de captura y esfuerzo para un ejercicio de estandarización de la CPUE, para comparar los resultados y los diferentes métodos empleados actualmente en ICCAT para los análisis de CPUE. Este documento describe y presenta los resultados del ejercicio con índices de abundancia relativa estandarizada para una especie de marlín (*Makaira nigricans*) estimados utilizando modelos lineales mixtos generalizados con un enfoque de modelo delta lognormal. El procedimiento de estandarización incluía los factores explicativos año, zona, temporada, tipo de anzuelo, anzuelo por cesta, tipo de cebo, temperatura de la superficie y oxígeno disuelto como covariables medioambientales. Los análisis de desviación ayudan a identificar las variables explicativas y las interacciones. En el caso de interacciones año*factor, estas se consideraron aleatorias si se incluían en el modelo final. La comparación con tendencias reales de población indicaba un buen desempeño del procedimiento de estandarización, con*

[1] ICCAT Secretariat, C. Corazón de Maria 8, Madrid 28002, Spain

límites de confianza que incluían siempre la tendencia real en casi todos los casos. Se identificó una diferenciación que aparecía sistemáticamente en todos los conjuntos de datos simulados para los tres últimos años de la serie.

KEYWORDS

Standardizes CPUE, blue marlin, GLMM

Introduction

Relative indices of abundance are required for most assessment models in fisheries science (Maunder and Punt 2004, Campbell 2015). From simple biomass dynamics models to more complex statistical catch models, often they required relative indices of abundance to adjust observed catch, effort, size, age or other input data and the modelled population dynamics of the stock in evaluation. The relative indices should in theory reflect in time the fluctuations of the stock population in response to fishing and natural conditions within the biological limits imposed by the assumptions of the population model. In the ideal situation, these indices of relative abundance should be obtained from scientific sampling design surveys. However, for most fisheries and in particular for highly migratory species such tunas and billfish there are almost none fishery independent surveys with sufficient spatial temporal coverage that can be used exclusive as relative indices of abundance in stock assessments (Rodriguez-Marin et at 2003).

Hence, most current assessments of tunas and other highly migratory species relay primarily on the standardization of fisheries dependent catch and effort data (Maunder and Punt 2004). CPUE standardization is a common practice in fishery science, however the methodology and protocols for standardization of catch and effort data is far from been a standard protocol, and from an statistical point of view, with the advantage of computing power in recent times, a wide range of new statistical methods are been applied in many cases without a proper discern or reasons on the basis of their selection. In 2017, as part of their research work plant, the SCRS Stock Assessment and Methods working group (SAM WG) has distributed simulated catch and effort data (CPUE) to several scientist asking to perform a regular standardization analysis to compare results and protocols against known true trends.

Materials and methods

Four sets of simulated catch and effort data with several associated variables were provided with some indications of the type of data. All four datasets have the same number of observations simulated from the same fleet, and the same auxiliary variables. For this exercise, a detailed analysis for predictive variable(s) definition, model evaluation, selection of fixed effects e interactions and random effects are presented only for dataset 1, albeit all these steps were apply to each of the four datasets evaluated. Review of the other datasets indicated that the effect of each factor was similar, changing only in the trend of the population, e.g. the catch rates varied among datasets. Therefore, the first part of this document details the preliminary analysis of data, deviance table analysis, random interactions evaluation, model diagnostics and estimated standardized series output. Then the second part will compiled the results from the four datasets and compare the standardized trends. Finally, the SAM WG after the exercise was concluded, provided the “True” trend of the simulated population, and these were compared with the standardized results.

The data is simulated from a longline fishery operating in the Atlantic mostly in the northwestern, Gulf of Mexico and Caribbean areas with fewer fishing operations in the east and south Atlantic (**Figure 1**). The data covers 30 years from 1985 to 2015; catch is the number of caught blue marlin and effort is the number of hooks deployed per set observation. Nominal CPUE was estimated as the number of fish caught per thousand hooks, as expected the distribution of nominal CPUE is strong left-skewed, with a high proportion of zero catches; by year the proportion of sets with positive catches of blue marlin varies between 7% and 16%, in dataset 1 (**Figure 2**). Thus it was decided to use a statistical model that accounts for the zero catch observations, in this case the delta-lognormal model (Ortiz and Arocha, 2004, Christman 2013). For the positive catch sets, the dependent variable used was the natural log of CPUE. The auxiliary information provided included: year, month, bait type, hooks per basket, type of hook, number of light sticks per hook, latitude and longitude of set, sea surface temperature (SST) and surface dissolve oxygen (DO) estimates.

Each data includes 297,180 observations; it's assumed that each record represents a single longline set fishing operation. Some of the auxiliary information is provided as discrete variables, while the environmental variables SST and S_DO are continuous. In the initial step of the analyses was the review of the potential relationship between the auxiliary variables and the nominal catch rates; then based on this, continuous variables were categorized and discrete variables were re-categorized when necessary to have a more balance distribution of observations. Thereafter, a spatio-temporal analysis was performed to define geographical areas and seasonality of the fishery, evaluating also their relationship with nominal catch rates.

For the simulated longline data, relative indices of abundance for blue marlin were estimated by Generalized Linear Modeling approach assuming a delta lognormal model distribution following the same protocol as described in Arocha et al., 2010. A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. Deviance analysis tables were evaluated for the proportion of positive observations (i.e., positive sets/total sets), and for the positive catch rates to defined the single factors and interactions more important in the model. Final selection of explanatory factors was conditional to: a) the relative percent of deviance explained by adding the factor in evaluation (normally factors that explained more than 5% were included), and b) The χ^2 significance. In the CPUE standardization procedure, the goal is account for "all" other external factors that influence catch rates, leaving only the fish population fluctuations associated with the Year factor. Therefore, when an interaction of a given explanatory factor with Year is significant, then there are two options: a) to estimate a relative index of abundance for the year*Factor interaction and add the structure of the Factor to the assessment model (e.g. by area, or season) thus the model can fit to the year*Factor indices, or b) make an assumption on the interaction year*Factor (e.g. as random effect) and estimate some variance associated with this interaction such the assessment model dynamics can account for this variability in the index of relative abundance due to the Factor interaction and not exclusively as fluctuation of the population in that particular Year (Campbell 2015). In this analysis, it is assumed that significant interactions of Year*Factors are random, thus the model extend from a GLM to a generalized linear mixed model (GLMM).

Selection of the final mixed model was based on the Akaike's Information Criterion (AIC), the Bayesian Information Criterion (BIC), and a χ^2 test of the difference between the [–2 log likelihood] statistic of a successive model formulations (Littell et al., 1996). Relative indices for the delta model formulation were calculated as the product of the year effect least square means (LSmeans) from the binomial and the lognormal model components. The LSmeans estimates use a weighted factor of the proportional observed margins in the input data to account for the non-balance characteristics of the data. LSMeans of lognormal positive trips were bias corrected using Lo et al., (1992) algorithms. Diagnostics and influence point analyses were also performed on final models (Bentley et al, 2011, Little et al 1996) Analyses were done using the Glimmix and Mixed procedures from the SAS® statistical computer software (SAS Institute Inc. 1997).

Results and discussion

Blue marlin spatial distribution of the simulated fishing effort overall is presented in **Figure 1**. For the analysis, the Atlantic was distributed into eight areas; the Gulf of Mexico, the Caribbean Sea, the Atlantic Bight (US coast between 30° and 40° N and extending to 60° W), the Sargasso sea (US Florida coast and north of the Caribbean islands to 30° N and 60° W), north Atlantic (above 40°N), central Atlantic (between 15° and 40° N, and 60° W and the Africa coast), mid Atlantic (between 15° N and 20° S), and the south Atlantic (below 20° S). In the south Atlantic there were few observations in limited number of years (2000/01), thus this area was excluded from the standardization analyses.

Figure 3 shows the trends of nominal lnCPUE and the auxiliary discrete variables of area, month, hooks per basket (hbf), and light-sticks per hook (lights). Areas were defined in function of ecological regions and distribution of fishing effort, about 80% of the sets were in the northwest Atlantic off the US coast (NATL, BIGHT, SARG) with some operations in the Gulf of Mexico and Caribbean and much less in the central, equatorial and south Atlantic. Although there is high variance in catch rates, it appears that in the SARG and BIGHT areas consistently there are higher CPUE for blue marlin, in contrast low CPUE were in the SATL and GMEX. By month, there is also large variability, but some trend was observed with slight higher CPUE in the first trimester (Jan-Mar), low in May-Aug and average for the rest of the year. Thus, it was decided to use trimesters as temporal factor (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Nov). The number of light sticks per hooks also show some trend with lnCPUE, with 1 or 2 light showing lower catch rates compared to 3 lights (albeit, is the more common configuration of the gear), and drop again when 4 lights were used. For the standardization because the number of observations with 1 light is limited, the factor lights included the levels: 1or 2 lights, 3 light and 4 lights. Hooks per basket (hbf) is another gear configuration factor, which in principle determines the depth of the longline set, lower hbf correspond to shallower sets, a feature that in principle will increase the probability of encounter blue marlins. In the data five categories were found, however the distribution by year has varied substantially (**Figure 5**), indicating a shift in the fishing operations of the fleet. In the early years, 2 and 3 hbf were predominant, but in the 1990's the fleet shifted toward higher hbf number, with 4 or more being almost the norm after 2000. The lnCPUE shows a clear trend in the data, with higher catch rates on shallow sets (e.g. low hbf) and decreasing trend when the set are deeper (**Figure 2**). Because the unbalance distribution of the hbf observations by years, the data was categorized as; shallow set (2 o 3 hbf), deep set (4 or 5 hbf) and deepest sets (6 hbf). The data also provided information on hook type (levels 1 to 5), however two hook types; 4 (62%) and 1 (31%) account for 90% of the data, very few observations from hook types 2 and 5. Thus, the hook type factor was categorized into 3 levels; Type 1 (hook types 1 and 2), Type 3 (hook type 3), and Type 4 (hook type 4 and 5). These categories were chosen based only in balancing data distribution. Other information provided with the data was the variable gear; with over 125 levels and no particular useful description or characterization for the standardization analyses, thus it was ignored.

Two environmental variables were provided for each observation; sea surface temperature (SST) and surface dissolve oxygen (DO). **Figure 4** presents the bivariate plot of these variables with the nominal catch rates for blue marlin. Two features are clear; i) there is a lot of variability in the both cases with no clear trend in the data as indicated by the smoother functions. ii) The range of both SST and DO is rather narrow, most catches occurring within 18° to 30° C range, and 4.4 to 5.3 ml/l. However, the smoother functions indicated a non-linear relationship between catch rates and SST and DO, thus it will be not advisable to include them as continuous variables in the standardization model, neither use GAMs, or nonlinear functions as predictions outside the range of most values will be extremely variable. In this case it was, decide to use the smoother functions as indicators of the cutoff values to categorize these environmental variables when the linear trends changed. Thus for SST, 3 levels were defined; 1 = SST < 18° C, 2 = 18° ≤ SST < 25°, and 3 = SST ≥ 25° C. And, for DO, 4 levels were defined; 1 = DO < 4.5 ml/l, 2 = 4.5 ≤ DO < 4.8, 3 = 4.8 ≤ DO < 5.3, and 4 = DO ≥ 5.3.

The deviance tables for blue marlin from the simulated longline dataset 1 analyses are presented in T**able 1.** For the mean catch rate given that it is a positive set, the factors: Year, Area, hpb, Htype and lights; and the interactions Year×area, Year×season, Year×hpb, and Area×hpb were the major factors that explained whether or not a set caught at least one fish. For the proportion of positive/total sets; Year, Area, Season, hpb, Htype, Lights, Bait, surface temperature (ST), and dissolve oxygen (DOx); and the interactions Year×season, Year×hpb, Year×bait, Area×Season, Area×Htype, season×Htype and Area×lights were more significant. Once a set of fixed factors were selected, we evaluated first level random interaction between the year and other effects.

As expected several of the interactions with the Year factor were significant and explained important percent of the variance observed in the data. Thus, these Year*factor interactions were considered as random effects in each of the delta model subcomponents, their statistical effect were evaluated using the AIC, BIC, and likelihood test (**Table 2**). Once a final model was identified, model diagnostics were revised to identify potential departure from the GLMM assumptions or observations with large influence in the model results.

Model diagnostics for the proportion of positive binomial sub-model include plots (**Figure 7a-d**) for a check of the link function, the variance function, the check for the error distribution of the model, and the qq-plot (normalized cumulative quartile plot) of the standardized deviance residuals. All diagnostic plots show no indication of departure from the expected or null pattern, the linear trend fit (broken line) and smother (loess) trend (solid line) for all plots fall within the expected pattern. The next set of plots (**Figure 7e-i**), check for the scale of fixed factors and covariates in the model. Results indicate no strong departures from the expected pattern (i.e., a constant range about the zero line).

In **Figure 8** presents a series of plots that check for influential observations in the proportion of positive binomial sub-model. The first plot (**8a**) is the deviance residuals of each observation, the second plot is the estimates of leverage (diagonal elements of the 'hat' matrix), and they represent the influence of a given observation in the fit. The third plot shows observations with Cook's distances estimated that have greater influence. The next plot is the estimated restricted likelihood distances (RDL) (SAS, 2008), a global measure of the influence of the observations on all parameters. The greater the RLD, the greater their influence in the model overall fit. The fifth plot is a combination of the leverage and Cook's distance estimates, on this plot observations within the upper-right region delimited by the broken lines (cut-off values of leverage and Cook's distance) represent data with high influence and high leverage overall.

In GLMM models, like the one presented here, with random components in the model fit, the following plots (**Figure 8**) provide information on the influence of given observations on the overall unconditional predicted values (fixed factor expectation and random assumption influence). First, is the PRESS residuals plot (SAS, 2008), PRESS residual measure influences as the difference between the observed value and the predicted (marginal) mean, where the predicted value is obtained without the observations in question. High PRESS residuals indicate observations with large influence in model fit. Another measure of influence for GLM mixed models is the DFFITS, which is similar to Cook's distances, large values indicate greater changes in the parameter estimates relative to the variability of the variability of the parameter. Finally, the Covariance ratio estimates measure the impact of an observation in the precision of a vector of estimates (SAS, 2008). In general, most observations were within the expected pattern, the several observations that appeared to be influential did not affect the overall model fit.

Model diagnostics for the positive catch of the lognormal sub-model, are the same as for the binomial sub-model; that is, checks for the link function, variance function, error distribution, the normalized cumulative quartile, and check for the scale of fixed factors and covariates in the model (**Figure 9a-i**). Similarly, checks for indication of influential observations for the positive observations of the lognormal sub-model (**Figure 10**) included, deviance residuals, Leverage, Cook's distance, RLD, PRESS residuals, DFFITS and Covariance ratio plot. No strong variations were observed, thus we can conclude that the model is not grossly wrong.

Standardized CPUE series for blue marlin from the dataset 1are shown in **Table 3** and **Figure 11**. Coefficients of variation ranged from 30 to 51% for the selected model fit. The standardized CPUE series show that the relative abundance of blue marlin caught by the longline fleet reflects a rather stable trend from 1986 through 2012; thereafter the index shows an increasing trend. The trends from the nominal and standardized index differed substantially; indeed the nominal CPUE (**Figure 11**) shows a rather declining trend through the whole period, while the standardized index presents a more stable trend with a rapid increase in the latest 3 years. Up to this point will be what a "regular" standardization procedure will cover. Next the results from the four datasets are presented and compared.

Figure 12 presents the nominal CPUE trends for each of the provided simulated datasets; case 4 shows the overall highest catch rates (1.4 fish per thousand hooks) but also the more drastic decline, cases 1 and 6 present a rather similar trend with some decline initially until 2005, and a rather more stable trend afterwards. Case 5 differs in that the catch rates declined initially for 5 years, and after 1990 there is an increase up to 2000, follow by some years of oscillations but with stable trend overall. The changes in catch rates are also reflected in the proportion of sets with catches of blue marlin (e.g. positive sets) (**Figure 12**), although in general less than 20% of the sets caught blue marlin, each case shows a different pattern, with only cases 1 and 6 following similar trends. Case 4 shows a reduction in the proportion of positive sets from 30% in the early period (1986 -1997) to about 5% in the 2004-2015 years.

As indicated before, for each dataset, a deviance table and random effect analysis were performed and the final model in each case was selected. **Figure 13 and Table 4** presents the standardized series for the four cases; case 4 shows a decreasing trend overall with some recovery in the latest years (2012-2015), case 5 instead shows an increasing trend since 1990 until 2004, in 2005 forward the trend continuous to increase but more abruptly with some peaks in 2005 and 2013-14. The nominal catch rates for the last 3 years (2012-15) are actually well below and outside of the confidence bounds of the standardized index. For case 6, it follows a similar trend of the case 1, with continuous decline since 1986 until 2005, follow by a period of stable trend (2006-2012), and then a rapid increase in the latest 3 years. It is noted that dataset 6 was updated by the SAM WG after it were identified incongruent patterns during the standardization analysis. Overall the standardized indices have a coefficient of variance (CV) between 20% and 60% (**Figure 14**), being greater I the latest years (2012-2015) and in the initial year when the number of observations was low.

The final section, correspond to the comparison of the standardized trends with the actual true blue marlin population trends, for this the SAM WG provided afterwards the annual true trends. **Figure 14** shows the comparison of the relative index of abundance estimated from the standardization of the CPUE data for each data set including the 95% confidence bounds and the true population trends. Overall, the standardization of catch and effort data produced reliable indices of abundance; in all cases but 4 points (Cases 5 and 6 years 2013/14) the true values were outside of the 95% bounds of the relative index estimates. In case 1 the true population was constant (no change at all), the estimated relative index show similar pattern except for the latest years 2012/15, when the relative index indicates a rapid increase. In case 4, the relative index follows the true trend of decline closely, with again departure in the last 3 years, when it predicts an increase greater than the true trend. In case 5, the relative index follows closely the true trend in the first part of the time period (1986-2000), then it oscillates about the true trend with more significant departure also in 2013-15. For case 6, the relative index follows closely the true trend, with some departure after 2006, but again more significantly in 2013-15 when the index indicates a substantial increase that is not the case of the true population (**Figure 14**).

Looking in more detailed, **Table 5** and **Figures 15** and **16** shows the deviations of the estimated relative indices from the true values for each case. The sum of square residuals indicated that case 4 was the best estimate of the true trend (1.25), follow by cases 1 and 6 (2.43 and 3.14, respectively). The worst scenario was with case 5 (7.48) were the SSQ is about twice the other cases. However, it is clear that the most "deviant" trend in all four cases were for the last 3 years (2013-2015). Comparatively to prior years, in 2013-15, the SSQ is 10 times higher (see bubble plots in **Figure 15** and deviates in **Figure 16**), and not only divergent but also in the same direction, e.g. the relative indices predicting rapid increases in population while the true trends show relative small changes. The residual patterns also indicates some trend in the relative indices of abundance, negative residuals are seen in the early period (1986-1992) and later period (2013-2015), while positive residuals are almost constant in the intermedia years (1994-2012) with a single exception in 2005.

It is not clear yet what is the source of the deviations particularly in the 2013-15 years, it noticeable that in 2012, for the Caribbean area, the proportion of sets with positive catch was 100%, albeit the number of set in this area is low compared to the rest of all areas. If the 2013-15 years were excluded from the standardization, the relative indices are roughly 3 times closer to the true trends comparing the SSQ fits.

In summary, after the standardization exercise it can be concluded the following:

- Catch and effort data from fishery dependent sources can be used to estimate relative indices of abundance.
- Standardization of nominal CPUE requires a thoroughly analysis of all associated factors and variables that can affect catch rates.
- Zero catch and positive fishing effort should be considered within the standardization, in particular when this proportion of zeros is high and or when the proportion of zero catches varies annually.
- It is important to define the factor(s) and the appropriate levels for each factor in function of the response variable relationship and the balance or distribution of observations in the model.
- Deviance table allows to identify the main factors and interactions that explains the observed variability in the catch rates, it is important to consider the percent of deviance explained by each factor/interaction and not only statistical test indicators (F, chi-square) for the selection of the final model, following the "principle of parsimony" to avoid over-parameterization.
- Interactions including the Year factor should be evaluated and if consider in the final model, included as random effect interaction.
- Diagnostics are important component of the standardization analyses; they should be performed and presented.
- As important as the point estimates of the relative index of abundance are the estimate of variability for each year, they must be calculated within the appropriate model.

Other more particular recommendations:

- Continuous variables should be evaluated and their relationship with the dependent variable review. If this relationship is not clearly linear, they should be included as categorical variables or in a functional form that allows proper variance estimation, predictability and interactions with other factors.
- It is important to strike for at least a balance distribution of observations within and between factors.
- It is not necessary that the nominal and standardized trends follow the same trend. The standardized index for the Year factor show in theory the trend of the population, while the nominal catch rates should represent the combined trends of all other factors and its interactions.

References

Bentley, N., T.H. Kendrick, P.J. Starr and P.A. Breen. 2011. Influence plots and metrics: tools for better understanding fisheries catch-per-unit-effort standardizations. ICES J. Mar. Sci. doi:10:1093.

Campbell, R. A. 2015. Constructing stock abundance indices from catch and effort data: some nuts and bolts. Fish. Res. 161:109-130.

Christman, M. C. 2013. A review of estimation methods for parameters of the delta-lognormal distribution. Interim Report to the Fisheries Statistics Division, NOAA/NMFS/SEFSC Miami, FL 29 Jan 2013.

Littell, R.G., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS® System for Mixed Models, Cary. NC. SAS Institute Inc., 1996 663 pp.

Lo, N.C., 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. 49:2515-2526.

Maunder, M.N. and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70:141-159.

Ortiz, M., F. Arocha. 2004. Alternative error distribution models for standardization of catch rates of non-target species from pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fish. Res., 70:275-297.

Rodriguez-Marin, E., H. Arrizabalaga, M. Ortiz, C. Rodriguez-Cabello, G. Moreno and L.T. Kell. 2003. Standardisation of bluefin tuna, Thunnus thynnus, catch per unit effort in the bait-boat fishery of the Bay of Biscay (Eastern Atlantic). ICES J. Mar. Sci. 60:1216:1231.

SAS Institute Inc. 2008, SAS/STAT® 9.2. Cary, NC: SAS Institute Inc.

SAS Institute Inc. 1997, SAS/STAT® Software: Changes and Enhancements through Release 6.12. Cary, NC: SAS Institute Inc. 1167 pp.

Table 1. Deviance analysis tables for explanatory variables in the delta lognormal model for blue marlin catch rates from the simulated longline dataset 1. Percent of total deviance refers to the deviance explained by the full model; *p* value refers to the probability Chi-square test between two nested models. The mean catch rate for positive observations assumed a lognormal error distribution.

Billfish PLL CPUE Index Case 1

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	9862.4857			
Year	29	7665.8751	2196.61	38.8%	< 0.001
Year Area	6	6087.5111	1578.36	27.9%	< 0.001
Year Area Season	3	6070.9058	16.61	0.3%	< 0.001
Year Area Season Hpb	2	5266.802	804.10	14.2%	< 0.001
Year Area Season Hpb Htype	2	5181.4541	85.35	1.5%	< 0.001
Year Area Season Hpb Htype Lights	2	4837.2621	344.19	6.1%	< 0.001
Year Area Season Hpb Htype Lights Bait	3	4825.3341	11.93	0.2%	0.008
Year Area Season Hpb Htype Lights Bait St	2	4821.3488	3.99	0.1%	0.136
Year Area Season Hpb Htype Lights Bait St Dox	3	4816.7651	4.58	0.1%	0.205
Year Area Season Hpb Htype Lights Bait St Dox Year*Area	172	4717.2277	99.54	1.8%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... Year*Season	85	4684.7709	32.46	0.6%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... Area*Season	17	4671.099	13.67	0.2%	0.690
Year Area Season Hpb Htype Lights Bait St Dox ... Year*Hpb	57	4616.1428	54.96	1.0%	0.552
Year Area Season Hpb Htype Lights Bait St Dox ... Area*Hpb	12	4538.7823	77.36	1.4%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox ... Season*Hpb	6	4527.9548	10.83	0.2%	0.094
Year Area Season Hpb Htype Lights Bait St Dox ... Year*Htype	21	4521.2346	6.72	0.1%	0.999
Year Area Season Hpb Htype Lights Bait St Dox ... Area*Htype	10	4517.4309	3.80	0.1%	0.956
Year Area Season Hpb Htype Lights Bait St Dox ... Season*Lights	6	4371.0381	1.78	0.0%	0.939
Year Area Season Hpb Htype Lights Bait St Dox ... Hpb*Lights	4	4342.0378	29.00	0.5%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox ... Htype*Lights	3	4339.1552	2.88	0.1%	0.410
Year Area Season Hpb Htype Lights Bait St Dox ... Year*Bait	61	4319.3438	19.81	0.4%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... Area*Bait	16	4311.1703	8.17	0.1%	0.944
Year Area Season Hpb Htype Lights Bait St Dox ... Season*Bait	9	4305.1641	6.01	0.1%	0.739
Year Area Season Hpb Htype Lights Bait St Dox ... Hpb*Bait	4	4300.9775	4.19	0.1%	0.381
Year Area Season Hpb Htype Lights Bait St Dox ... Htype*Bait	1	4300.7851	0.19	0.0%	0.661
Year Area Season Hpb Htype Lights Bait St Dox ... Lights*Bait	5	4295.1218	5.66	0.1%	0.340
Year Area Season Hpb Htype Lights Bait St Dox ... Year*St	52	4281.7756	13.35	0.2%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... Area*St	10	4252.6851	29.09	0.5%	0.001
Year Area Season Hpb Htype Lights Bait St Dox ... Season*St	6	4247.3592	5.33	0.1%	0.503
Year Area Season Hpb Htype Lights Bait St Dox ... Hpb*St	4	4245.2954	2.06	0.0%	0.724
Year Area Season Hpb Htype Lights Bait St Dox ... Htype*St	3	4241.6439	3.65	0.1%	0.302
Year Area Season Hpb Htype Lights Bait St Dox ... Lights*St	4	4240.7926	0.85	0.0%	0.931
Year Area Season Hpb Htype Lights Bait St Dox ... Bait*St	4	4238.4465	2.35	0.0%	0.672
Year Area Season Hpb Htype Lights Bait St Dox ... Year*Dox	77	4225.5741	12.87	0.2%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... Area*Dox	14	4212.9413	12.63	0.2%	0.556
Year Area Season Hpb Htype Lights Bait St Dox ... Season*Dox	9	4208.8325	4.11	0.1%	0.904
Year Area Season Hpb Htype Lights Bait St Dox ... Hpb*Dox	6	4207.0043	1.83	0.0%	0.935
Year Area Season Hpb Htype Lights Bait St Dox ... Htype*Dox	6	4206.2556	0.75	0.0%	0.993
Year Area Season Hpb Htype Lights Bait St Dox ... Lights*Dox	6	4205.0196	1.24	0.0%	0.975
Year Area Season Hpb Htype Lights Bait St Dox ... Bait*Dox	9	4204.1809	0.84	0.0%	1.000
Year Area Season Hpb Htype Lights Bait St Dox ... St*Dox	2	4203.9906	0.19	0.0%	0.909

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	42899.540			
Year	29	40971.592	1927.95	6%	< 0.001
Year Area	6	22349.925	18621.67	60%	< 0.001
Year Area Season	3	21508.155	841.77	3%	< 0.001
Year Area Season Hpb	2	21355.352	152.80	0%	< 0.001
Year Area Season Hpb Htype	2	21215.963	139.39	0%	< 0.001
Year Area Season Hpb Htype Lights	2	20833.018	382.94	1%	< 0.001
Year Area Season Hpb Htype Lights Bait	3	19728.378	1104.64	4%	< 0.001
Year Area Season Hpb Htype Lights Bait St	2	18331.850	1396.53	4%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox	3	17773.639	558.21	2%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area	173	16412.653	1360.99	4%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Season	85	15957.298	455.36	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Season	18	15302.285	655.01	2%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Hpb	58	14866.848	435.44	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Hpb	12	14776.166	90.68	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*Hpb	6	14723.462	52.70	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Htype	25	14678.715	44.75	0%	0.009
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Htype	12	14546.094	132.62	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*Htype	6	13981.757	564.34	2%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Hpb*Htype	4	13950.668	31.09	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Lights	58	13774.127	176.54	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Lights	12	13255.862	518.26	2%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*Lights	6	13098.528	157.33	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Hpb*Lights	4	13030.968	67.56	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Htype*Lights	3	13008.524	22.44	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Bait	65	12787.702	220.82	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Bait	17	12670.694	117.01	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*Bait	9	12644.641	26.05	0%	0.002
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Hpb*Bait	6	12489.609	155.03	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Htype*Bait	1	12486.101	3.51	0%	0.061
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Lights*Bait	5	12440.693	45.41	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*St	52	12325.039	115.65	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*St	10	12304.781	20.26	0%	0.027
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*St	6	12090.829	213.95	1%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Hpb*St	4	12081.831	9.00	0%	0.061
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Htype*St	4	12072.403	9.43	0%	0.051
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Lights*St	4	12051.198	21.21	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Bait*St	6	12041.671	9.53	0%	0.146
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Year*Dox	78	11892.759	148.91	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Area*Dox	14	11858.231	34.53	0%	0.002
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Season*Dox	9	11795.737	62.49	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Hpb*Dox	6	11792.225	3.51	0%	0.742
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Htype*Dox	6	11787.751	4.47	0%	0.613
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Lights*Dox	6	11759.818	27.93	0%	< 0.001
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... Bait*Dox	9	11740.782	19.04	0%	0.025
Year Area Season Hpb Htype Lights Bait St Dox Year*Area ... St*Dox	3	11715.773	25.01	0%	< 0.001

Table 2. Analysis of delta lognormal mixed model formulations for blue marlin catch rates from the simulated longline dataset 1. Likelihood ratio tests the difference of –2 REM log likelihood between two nested models. The asterisk * indicates the selected model for each component of the delta mixed model.

	GLMixed Model	-2 REM Log likelihood	Akaike's Information Criterion	Bayesian Information Criterion	Likelihood Ratio Test		Dispersion
	Proportion Positives						
	Year Area Season HpB Htype lights bait ST DOx	43414.6	443416.6	43423.9			1.7602
	Year Area Season HpB Htype lights bait ST Dox *Year*Area*	43149.3	43153.3	443160	265.3	0.0000	1.6572
	Year Area Season HpB Htype lights bait ST Dox *Year*Area Year*Season*	43111.5	43117.5	443127.6	37.8	0.0000	1.6309
	Year Area Season HpB Htype lights bait ST Dox *Year*Area Year*Season Year*HpB*	42780	42788	42801.4	331.5	0.0000	1.5719
	Year Area Season HpB Htype lights bait ST Dox *Year*Area Year*Season Year*HpB Year*bait*	42633.2	42643.2	42659.9	146.8	0.0000	1.5461
	Year Area Season HpB Htype lights bait ST Dox *Year*Area Year*Season Year*HpB Year*bait season*Htype*	42222.2	42234.2	42254.3	411	0.0000	1.4827
*	Year Area Season HpB Htype lights bait ST Dox *Year*Area Year*Season Year*HpB Year*bait Year*lights season*Htype*	42168.2	42182.2	42205.6	54	0.0000	1.4717
	Positives catch rates Vessel Size Category						
	Year Area Season HpB Htype lights bait ST DOx	30196.8	30198.8	30207.3			
	Year Area Season HpB Htype lights bait ST DOx *Year*Area*	29849.1	29853.1	29859.8	347.7	0.0000	
	Year Area Season HpB Htype lights bait ST DOx *Year*Area Year*Season*	29766.6	29772.6	29782.7	82.5	0.0000	
	Year Area Season HpB Htype lights bait ST DOx *Year*Area Year*Season Year*HpB*	29521.9	29529.9	29543.3	244.7	0.0000	
*	Year Area Season HpB Htype lights bait ST DOx *Year*Area Year*Season Year*HpB Year*Bait*	29483.1	29493.1	29509.8	38.8	0.0000	

Table 3. Nominal and standardized (Delta lognormal mixed model) CPUE for blue marlin catch rates from the simulated longline dataset 1.

Year	N Obs	Nominal CPUE	Standard CPUE	Low	Upp	coeff var	std error
1986	1352	0.611	0.252	0.097	0.654	51%	0.1274
1987	10526	0.447	0.232	0.096	0.559	46%	0.1072
1988	12270	0.426	0.249	0.103	0.602	46%	0.1155
1989	13783	0.455	0.224	0.119	0.421	32%	0.0725
1990	12963	0.452	0.274	0.149	0.503	31%	0.0852
1991	12641	0.439	0.302	0.167	0.548	30%	0.0920
1992	12316	0.393	0.270	0.150	0.485	30%	0.0808
1993	12036	0.365	0.259	0.138	0.485	32%	0.0833
1994	12884	0.367	0.202	0.110	0.369	31%	0.0624
1995	13745	0.321	0.188	0.102	0.347	31%	0.0590
1996	13890	0.343	0.248	0.138	0.445	30%	0.0741
1997	12934	0.325	0.202	0.110	0.369	31%	0.0623
1998	10875	0.263	0.208	0.114	0.382	31%	0.0646
1999	10279	0.281	0.194	0.106	0.356	31%	0.0602
2000	10108	0.282	0.244	0.134	0.446	31%	0.0753
2001	9638	0.218	0.175	0.088	0.346	35%	0.0615
2002	8665	0.243	0.156	0.074	0.327	38%	0.0597
2003	8446	0.219	0.185	0.087	0.395	39%	0.0728
2004	8781	0.216	0.232	0.102	0.525	43%	0.0990
2005	7115	0.133	0.241	0.122	0.475	35%	0.0842
2006	6957	0.115	0.190	0.095	0.378	36%	0.0674
2007	7700	0.139	0.174	0.080	0.379	40%	0.0704
2008	8245	0.161	0.241	0.115	0.505	38%	0.0923
2009	8427	0.128	0.184	0.085	0.399	40%	0.0739
2010	7200	0.120	0.182	0.083	0.397	41%	0.0739
2011	7601	0.126	0.160	0.077	0.335	38%	0.0612
2012	9810	0.150	0.218	0.107	0.445	37%	0.0801
2013	9555	0.171	0.434	0.228	0.824	33%	0.1429
2014	9181	0.155	0.421	0.213	0.832	35%	0.1478
2015	7190	0.146	0.366	0.177	0.759	38%	0.1381

Table 4. True relative abundance and estimated relative index (standardized) for each of the four datasets of blue marlin from a simulated longline catch and effort data. LCI and UCI indicate estimated 95% confidence bounds.

	Case															
	C1				C4				C5				C6			
Year	TRUE	STDCPUE	LCI	UCI	TRUE	STDCPUE	LCI	UCI	TRUE	STDCPUE	LCI	UCI	TRUE	STDCPUE	LCI	UCI
1986	1	1.064026	0.409783	2.762808	1.518835	1.753322	0.909006	3.381867	0.446354	0.575188	0.20825	1.588672	1.139705	1.219442	0.583209	2.549754
1987	1	0.978908	0.406005	2.360219	1.584302	1.773603	1.009863	3.114942	0.417025	0.345781	0.1268	0.942941	1.121764	1.127199	0.572823	2.218098
1988	1	1.052169	0.43544	2.542391	1.636675	1.732259	0.977579	3.069546	0.382589	0.365363	0.134562	0.992032	1.094194	1.128396	0.571734	2.227044
1989	1	0.943605	0.501122	1.776791	1.702143	1.928877	1.239544	3.001559	0.31686	0.339583	0.155227	0.742889	0.994074	1.150478	0.715341	1.850306
1990	1	1.155949	0.629295	2.123357	1.649769	1.62408	1.031907	2.55608	0.281639	0.239785	0.102382	0.561595	0.912078	0.925606	0.566283	1.512927
1991	1	1.275526	0.703094	2.314011	1.662862	1.879512	1.223893	2.886336	0.278235	0.262321	0.114888	0.598951	0.866385	0.981626	0.60355	1.596535
1992	1	1.138512	0.63347	2.046206	1.675956	1.841766	1.209647	2.804208	0.33781	0.343561	0.162762	0.725196	0.811793	0.983859	0.609828	1.587297
1993	1	1.093973	0.58447	2.047625	1.728329	1.851513	1.179899	2.905418	0.403277	0.364091	0.167743	0.790269	0.774925	0.826481	0.482442	1.415859
1994	1	0.851531	0.465013	1.559322	1.610489	1.360465	0.862754	2.1453	0.473457	0.354125	0.171844	0.729755	0.820637	0.742624	0.450403	1.224437
1995	1	0.794536	0.430649	1.4659	1.529964	1.513812	0.981062	2.335862	0.530283	0.411424	0.204899	0.826115	0.875465	0.785879	0.479381	1.288341
1996	1	1.047561	0.584086	1.878807	1.402304	1.381519	0.880025	2.168798	0.582656	0.48281	0.247117	0.943302	0.957443	0.991534	0.622455	1.579455
1997	1	0.851465	0.465548	1.557288	1.27988	1.132584	0.705057	1.819352	0.612117	0.449145	0.227842	0.885401	1.021297	0.955994	0.597563	1.529419
1998	1	0.879886	0.480062	1.612707	1.257621	0.924791	0.552589	1.547692	0.722756	0.49744	0.254457	0.972451	1.048538	0.99385	0.62003	1.593049
1999	1	0.81797	0.445723	1.501102	1.162694	0.894381	0.537512	1.488184	0.817028	0.60981	0.323815	1.148398	1.09414	0.926664	0.577457	1.48705
2000	1	1.032034	0.565229	1.884359	1.070386	0.929453	0.554365	1.558327	0.925704	0.773013	0.4202	1.422059	1.121527	1.130777	0.713502	1.792086
2001	1	0.736627	0.37175	1.459638	0.925704	0.613727	0.323789	1.163291	1.070386	0.786287	0.410559	1.505866	1.185307	1.052154	0.627517	1.764139
2002	1	0.656829	0.312959	1.378534	0.817028	0.632982	0.327119	1.224836	1.162694	0.751237	0.374721	1.506075	1.203559	1.133568	0.659925	1.947157
2003	1	0.782868	0.367247	1.668857	0.722756	0.498942	0.241688	1.030018	1.257621	0.647007	0.308961	1.35492	1.167019	0.897662	0.498269	1.617193
2004	1	0.977576	0.430836	2.218142	0.612117	0.518782	0.235961	1.14059	1.27988	1.172456	0.576881	2.382902	1.103439	1.040046	0.544119	1.987976
2005	1	1.015844	0.514792	2.004574	0.582656	0.810824	0.439284	1.496605	1.402304	2.277527	1.410386	3.677806	0.966669	1.061336	0.617168	1.825168
2006	1	0.801609	0.402442	1.596692	0.530283	0.379186	0.172801	0.832066	1.529964	1.077092	0.591564	1.961118	0.930166	0.666276	0.372437	1.191946
2007	1	0.736222	0.338537	1.601074	0.473457	0.327195	0.135674	0.789074	1.610489	1.305687	0.691862	2.464102	0.893534	0.515915	0.25736	1.034222
2008	1	1.017212	0.485366	2.131835	0.403277	0.386771	0.170816	0.875748	1.728329	1.630673	0.905882	2.935365	0.866111	0.533064	0.268141	1.059733
2009	1	0.776897	0.358514	1.683529	0.33781	0.292147	0.114597	0.744782	1.675956	1.129534	0.591835	2.155747	0.811429	0.54962	0.275886	1.094952
2010	1	0.766637	0.350544	1.67663	0.278235	0.184007	0.059816	0.566047	1.662862	1.28832	0.691106	2.401613	0.875246	0.539919	0.271355	1.074283
2011	1	0.677387	0.324001	1.41621	0.281639	0.176235	0.058467	0.531213	1.649769	1.283668	0.717066	2.297981	0.94818	0.533642	0.277231	1.027208
2012	1	0.922133	0.45303	1.876983	0.31686	0.297795	0.122518	0.723829	1.702143	1.7243	1.002754	2.965045	1.030559	0.729073	0.395202	1.345001
2013	1	1.831506	0.963877	3.480126	0.382589	0.749337	0.372769	1.506309	1.636675	3.176223	2.078482	4.85373	1.085041	1.918961	1.147622	3.208735
2014	1	1.775889	0.897536	3.513821	0.417025	0.785397	0.387949	1.590021	1.584302	2.951692	1.94234	4.485561	1.121654	2.083768	1.242596	3.494369
2015	1	1.547115	0.746618	3.205873	0.446354	0.824738	0.41141	1.653319	1.518835	2.384856	1.427536	3.984164	1.158121	1.874587	1.081319	3.249806

Table 5. Sum of square differences and residuals of the true relative blue marlin populations and the estimated relative index of abundance from the catch and effort standardization models. Colored shades indicate largest departure values; blue = positive, red = negative.

	Estimated error squared of point Estimate				Residuals distribution			
Year	Pop 1	Pop 4	Pop 5	Pop 6	Pop 1	Pop 4	Pop 5	Pop 6
1986	0.004099	0.054984	0.016598	0.006358	-0.06403	-0.23449	-0.12883	-0.07974
1987	0.000445	0.035835	0.005076	2.95E-05	0.021092	-0.1893	0.071243	-0.00544
1988	0.002722	0.009136	0.000297	0.00117	-0.05217	-0.09558	0.017226	-0.0342
1989	0.00318	0.051408	0.000516	0.024462	0.056395	-0.22673	-0.02272	-0.1564
1990	0.02432	0.00066	0.001752	0.000183	-0.15595	0.025689	0.041854	-0.01353
1991	0.075915	0.046937	0.000253	0.013281	-0.27553	-0.21665	0.015914	-0.11524
1992	0.019186	0.027493	3.31E-05	0.029607	-0.13851	-0.16581	-0.00575	-0.17207
1993	0.008831	0.015174	0.001536	0.002658	-0.09397	-0.12318	0.039186	-0.05156
1994	0.022043	0.062512	0.01424	0.006086	0.148469	0.250023	0.119333	0.078013
1995	0.042215	0.000261	0.014127	0.008026	0.205464	0.016153	0.118859	0.089586
1996	0.002262	0.000432	0.009969	0.001162	-0.04756	0.020784	0.099847	-0.03409
1997	0.022063	0.021696	0.02656	0.004264	0.148535	0.147296	0.162971	0.065303
1998	0.014427	0.110776	0.050767	0.002991	0.120114	0.33283	0.225316	0.054688
1999	0.033135	0.071992	0.042939	0.028048	0.18203	0.268313	0.207218	0.167476
2000	0.001026	0.019862	0.023315	8.56E-05	-0.03203	0.140933	0.152691	-0.00925
2001	0.069365	0.09733	0.080712	0.01773	0.263373	0.311977	0.284099	0.133154
2002	0.117766	0.033873	0.169297	0.004899	0.343171	0.184046	0.411457	0.069991
2003	0.047146	0.050093	0.37285	0.072553	0.217132	0.223814	0.610614	0.269357
2004	0.000503	0.008711	0.01154	0.004019	0.022424	0.093335	0.107425	0.063393
2005	0.000251	0.05206	0.766015	0.008962	-0.01584	-0.22817	-0.87522	-0.09467
2006	0.039359	0.02283	0.205093	0.069637	0.198391	0.151097	0.452872	0.263889
2007	0.069579	0.021393	0.092904	0.142597	0.263778	0.146262	0.304802	0.37762
2008	0.000296	0.000272	0.009537	0.11092	-0.01721	0.016506	0.097656	0.333047
2009	0.049775	0.002085	0.298577	0.068544	0.223103	0.045663	0.546422	0.261809
2010	0.054458	0.008879	0.140282	0.112445	0.233363	0.094228	0.374542	0.335327
2011	0.104079	0.01111	0.13403	0.171842	0.322613	0.105405	0.366101	0.414538
2012	0.006063	0.000363	0.000491	0.090894	0.077867	0.019065	-0.02216	0.301487
2013	0.691402	0.134504	2.370206	0.695423	-0.83151	-0.36675	-1.53955	-0.83392
2014	0.602003	0.135698	1.869754	0.925662	-0.77589	-0.36837	-1.36739	-0.96211
2015	0.299334	0.143174	0.749992	0.513324	-0.54711	-0.37838	-0.86602	-0.71647
	SSQ							
	2.42725	**1.251534**	**7.479258**	**3.137861**				
	0.83451	0.838159	2.489306	1.003452				
	2.908593	1.493195	3.004556	3.127067				

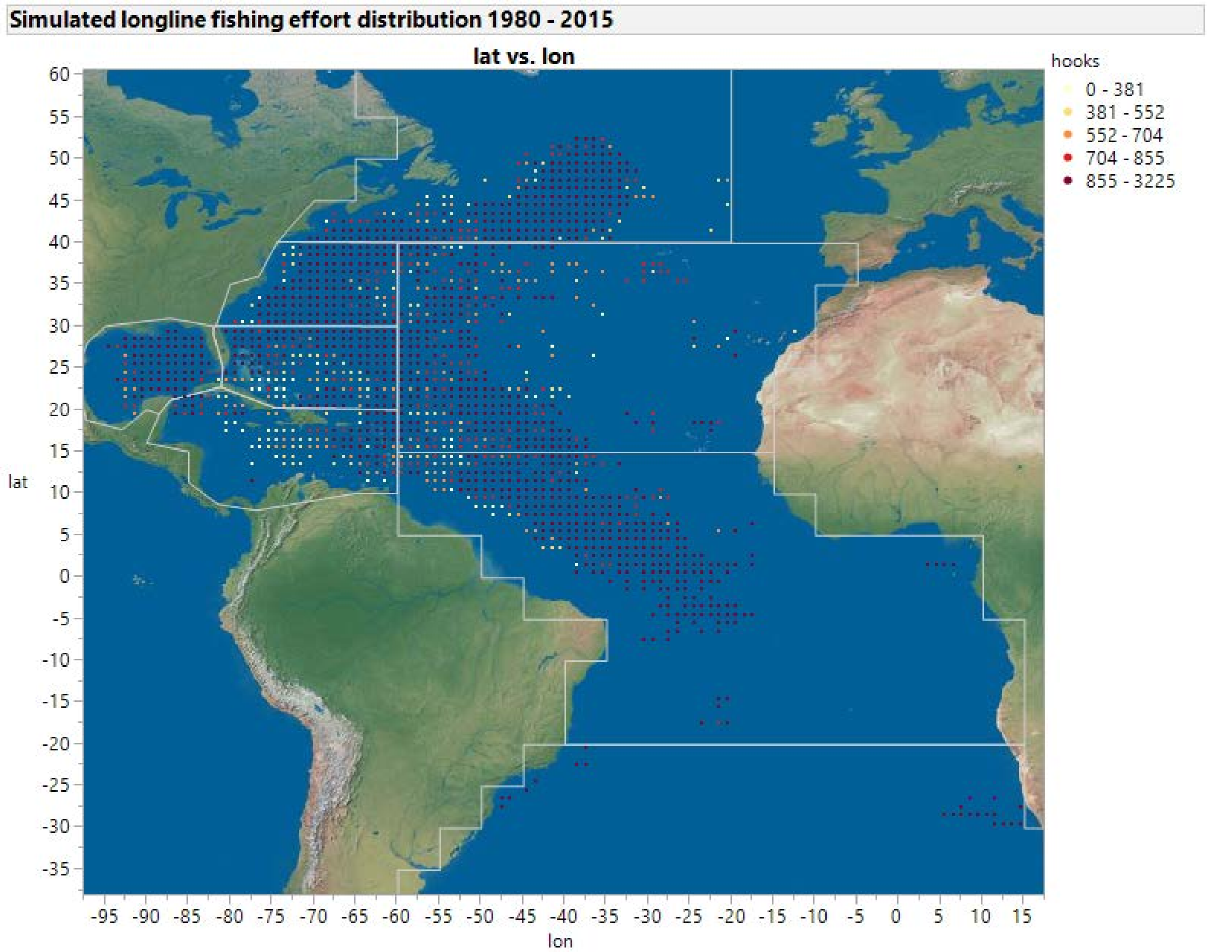
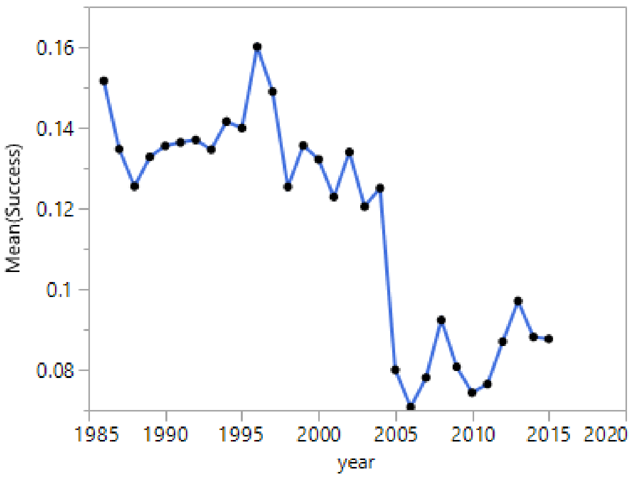


Figure 1. Spatial distribution of simulated catch-effort data for longline fishery 1980 – 2015. The points represent the number of set per lat-lon location, the areas correspond to the spatial assumed distribution.



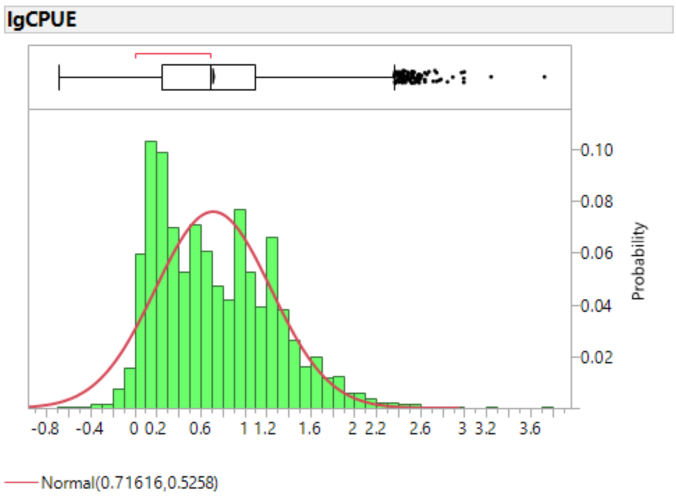


Figure 2. Proportion of positive blue marlin catch sets (left plot) by year, and distribution of the lnCPUE positive catch sets (right plot) from the simulated longlined catch effort dataset 1.

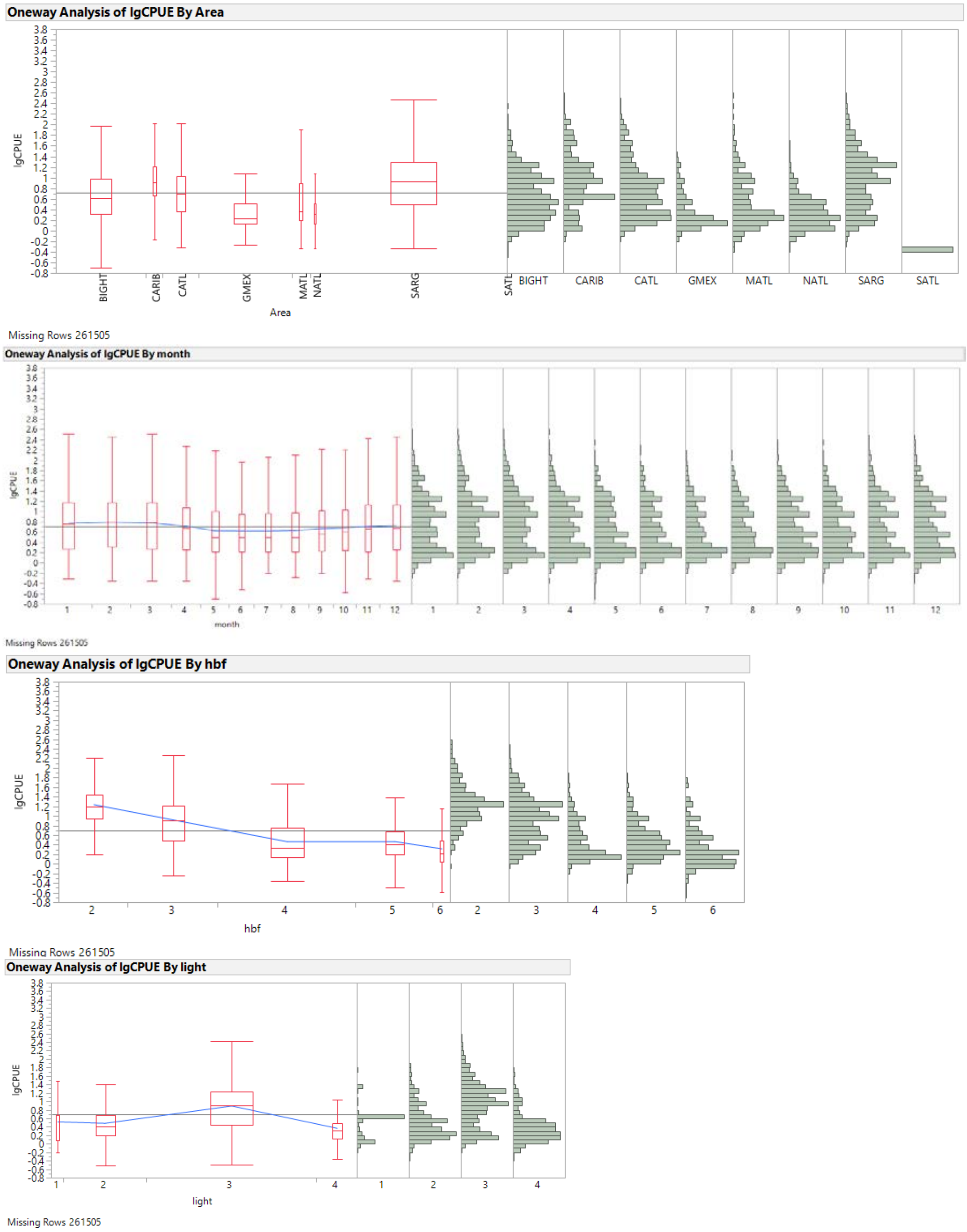


Figure 3. Analysis of the factors: area, month, hooks per basket (hbf) and number of light sticks per hook (lights) and their relationship with the nominal lnCPUE rates of blue marlin (positive catch sets) of the simulated dataset 1. Each plot shows the boxplot of each level with the width proportional to the number of observations.

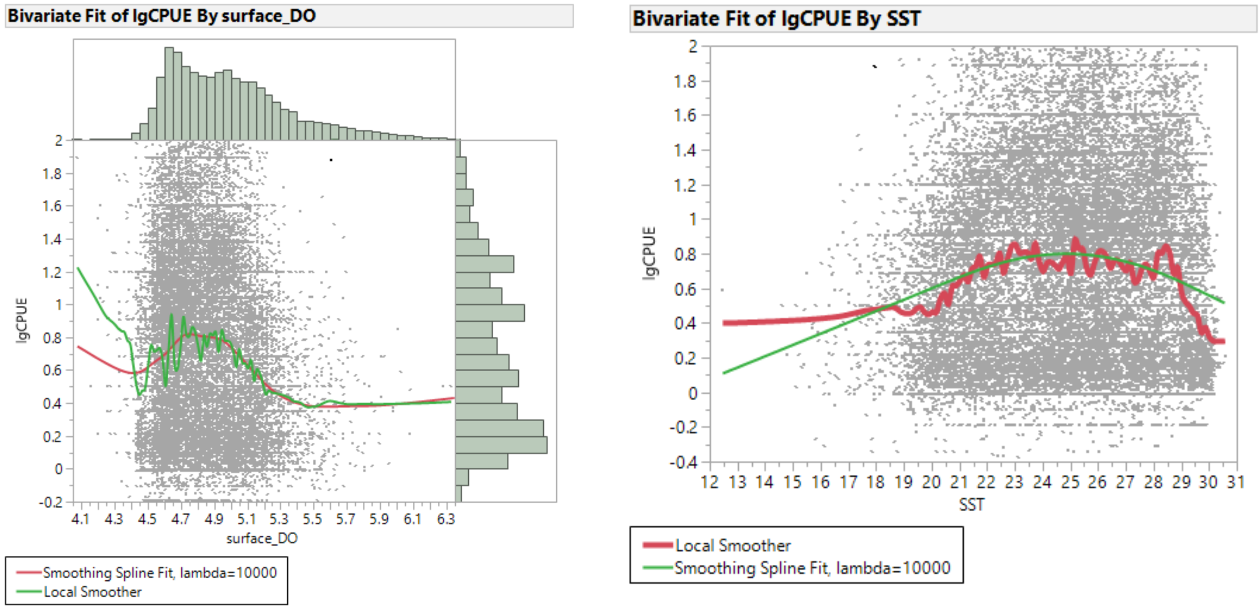


Figure 4. Bivariate plots of the lnCPUE blue marlin and the environmental variables surface dissolve oxygen (DO) and sea surface temperature (SST). The lines represent two smoother fits to the data.

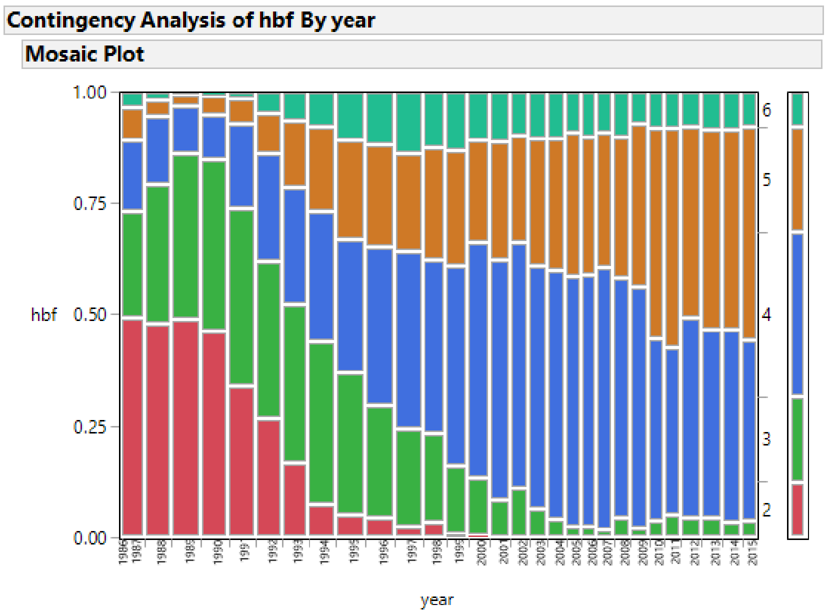


Figure 5. Mosaic plot of the distribution by year of hook per basket (hbf) categories in the simulated longline dataset 1.

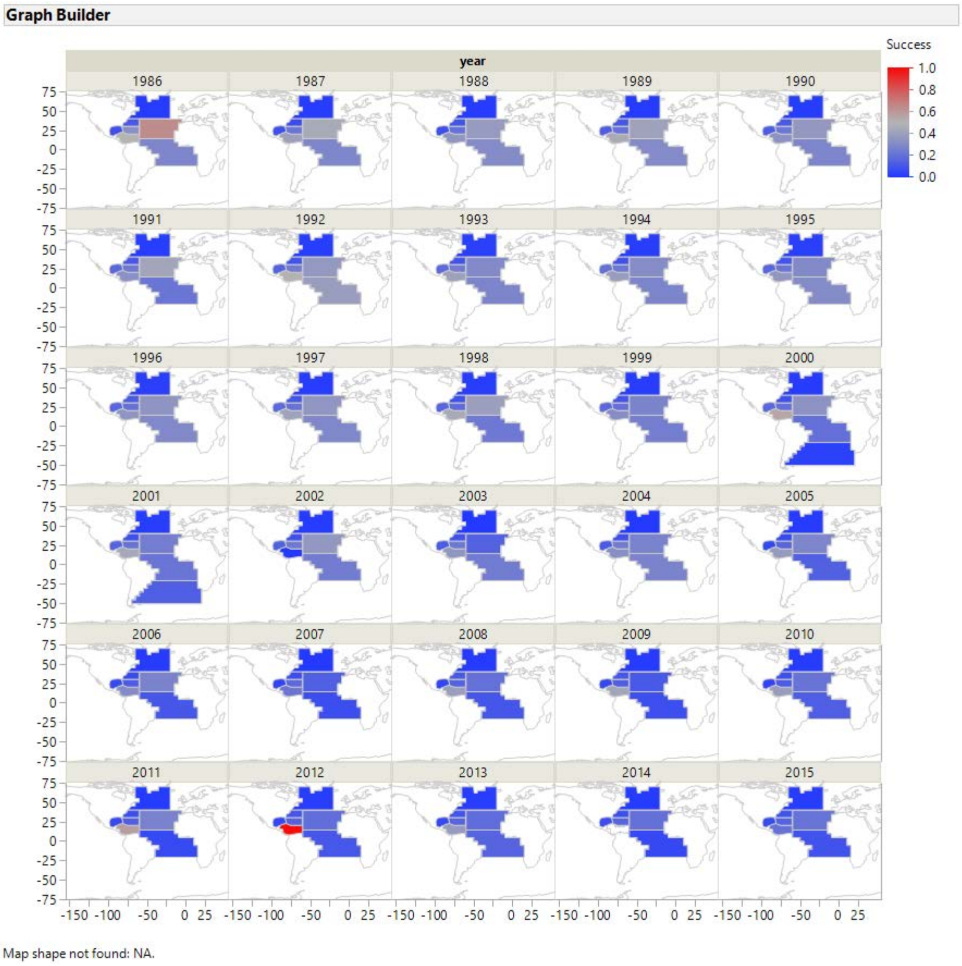


Figure 6. Annual distribution of the mean proportion of positive sets (Success) by area for blue marlin dataset 1. Color scale indicates the mean proportions with blue a low proportion and red as high proportion.

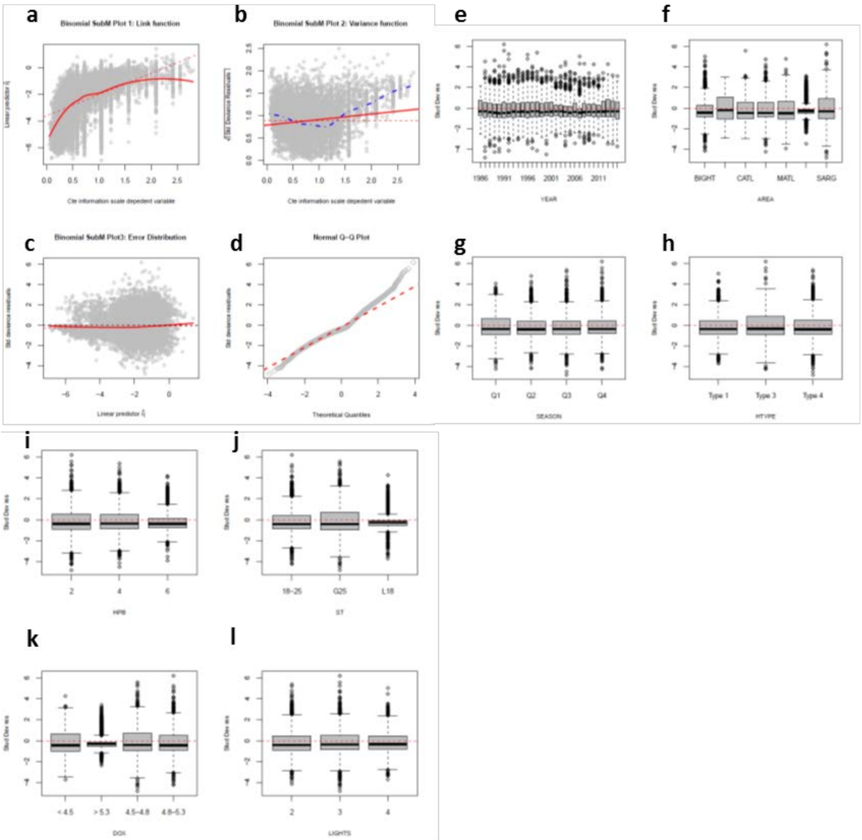


Figure 7. Diagnostic plots for the binomial proportion of the positive sub-model; a) check of the link function, b) the variance function, c) error distribution of the model, d) qq-plot of the standardized residuals, e – l) check for the scale of fixed factors in the model.

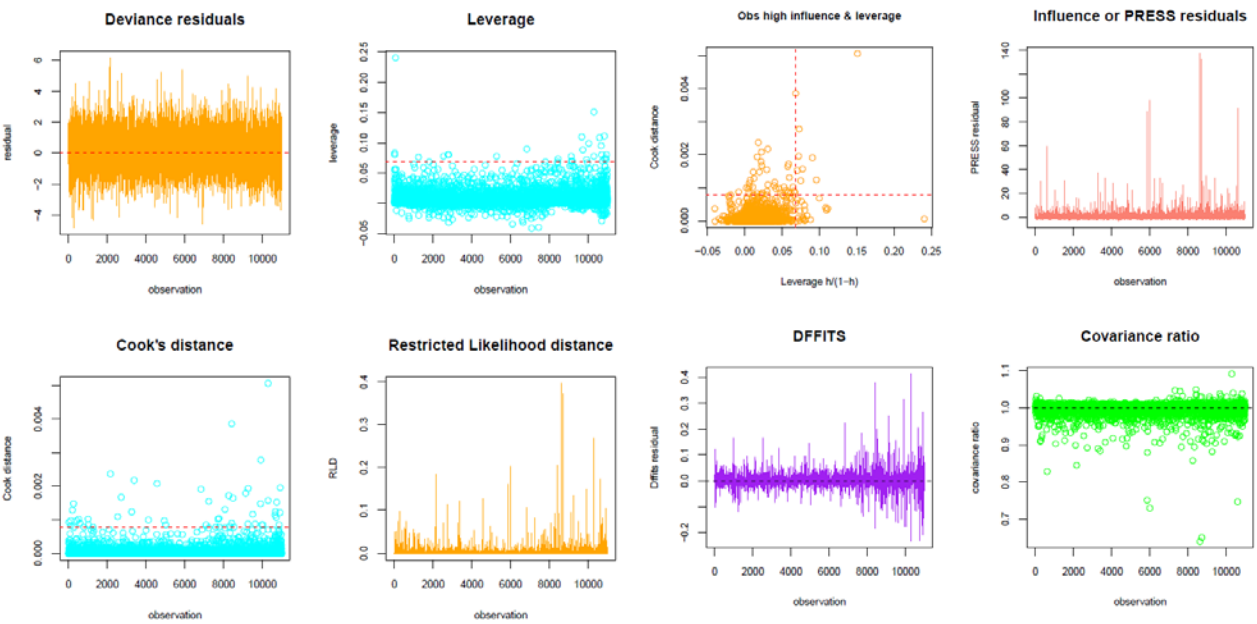


Figure 8. Diagnostic plots for influential observations in the binomial proportion of positives sub-model: Deviance residuals, leverage, Cook's distance, restricted likelihood distance, high influence-leverage, PRESS residuals, DFFITs and covariance ratio plot.

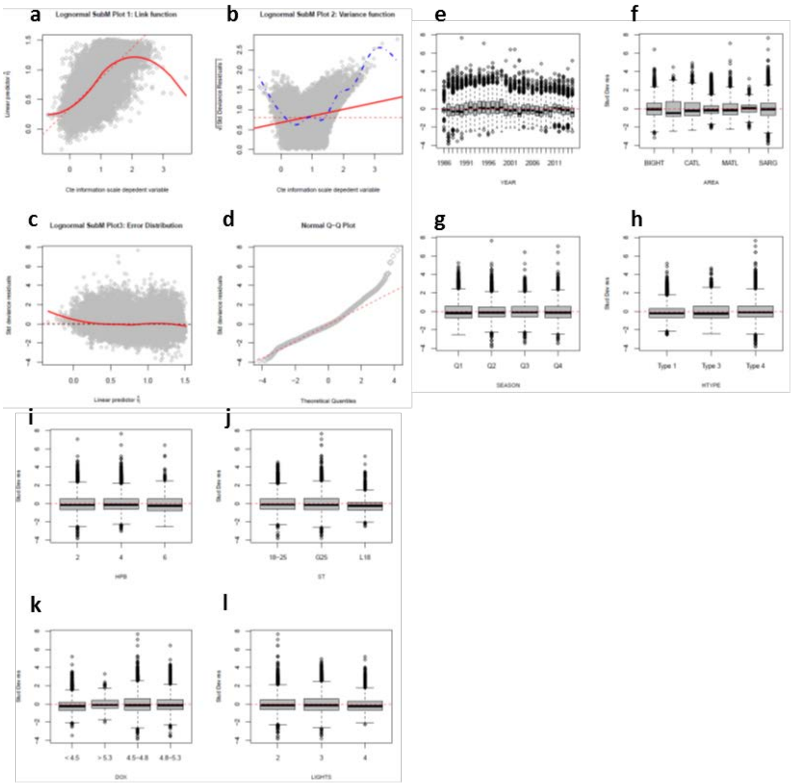


Figure 9. Diagnostic plots for the positive catch lognormal sub-model; a) check of the link function, b) the variance function, c) error distribution of the model, d) qq-plot of the standardized residuals, and e – l) check for the scale of fixed factors in the model.

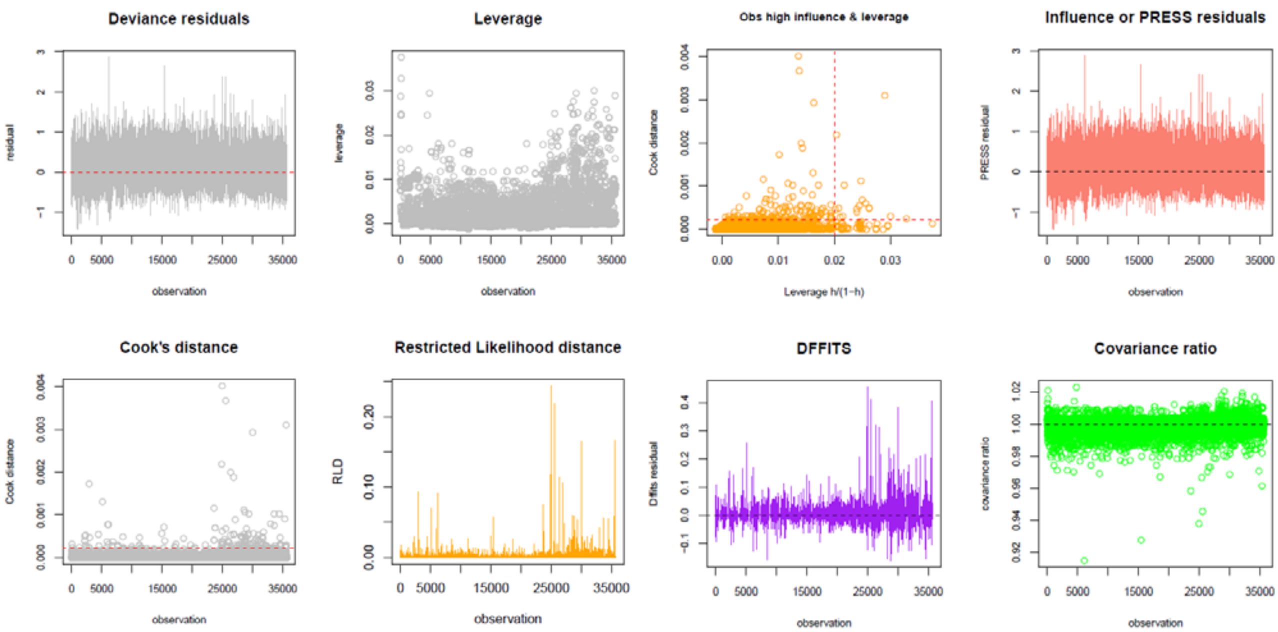


Figure 10. Diagnostic plots for influential observations in the positives catch lognormal sub-model: Deviance residuals, leverage, Cook's distance, restricted likelihood distance, high influence-leverage, PRESS residuals, DFFITs and covariance ratio plot.

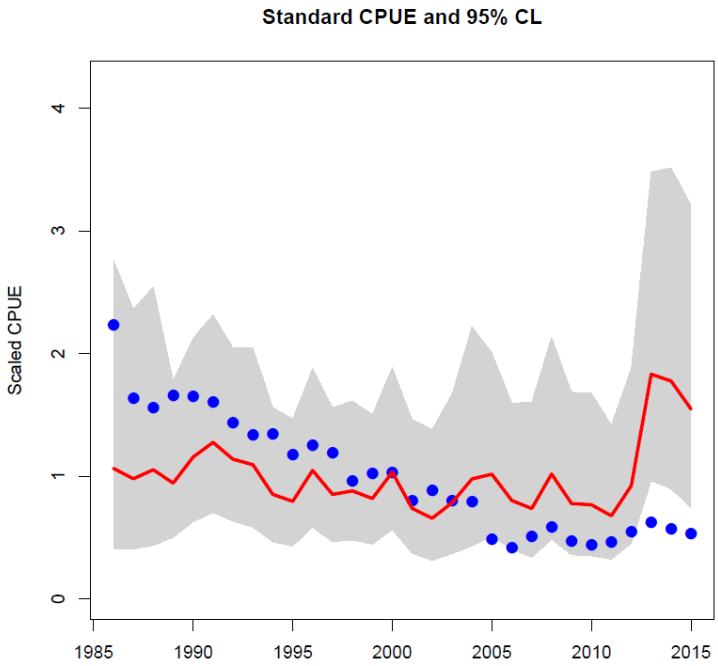


Figure 11. Estimated nominal (blue circles) and standardized (red line) CPUE of blue marlin from the simulated longline dataset 1.

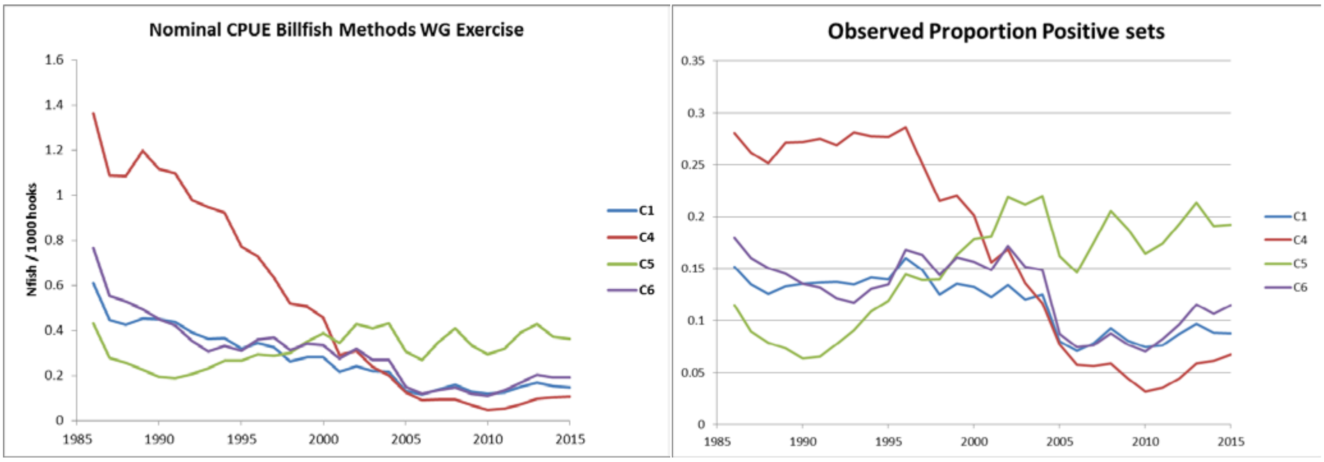


Figure 12. Nominal CPUE annual trends of the four datasets provided for the SAM WG standardization exercise (left plot) and observed proportion of positive catch (blue marlin) within each dataset (right plot).

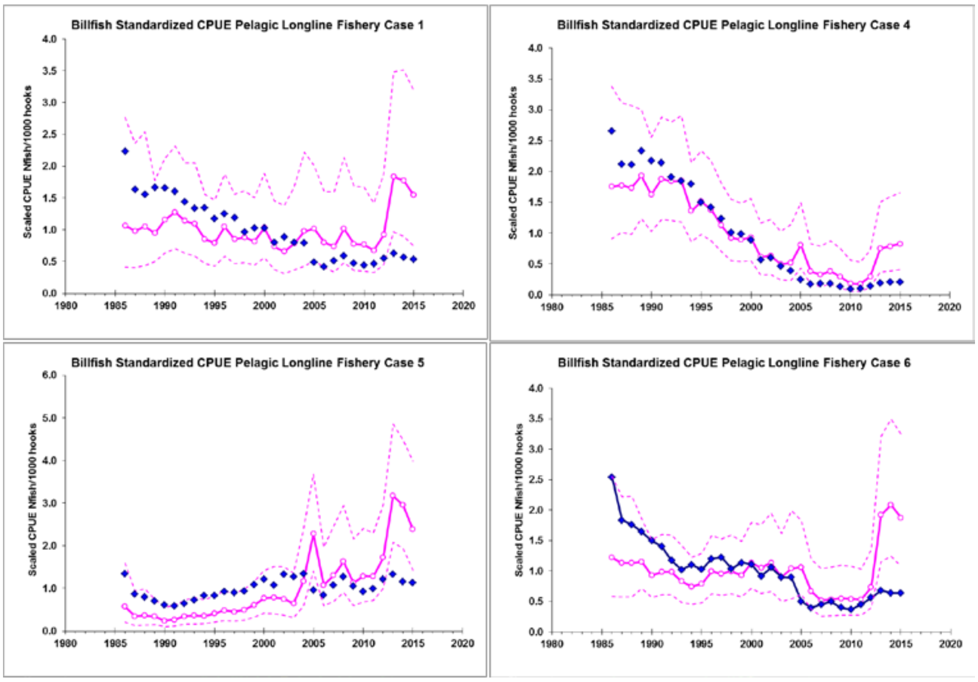


Figure 13. Nominal (diamonds) and standardized (line) CPUE blue marlin simulated longline datasets with 95% confidence intervals.

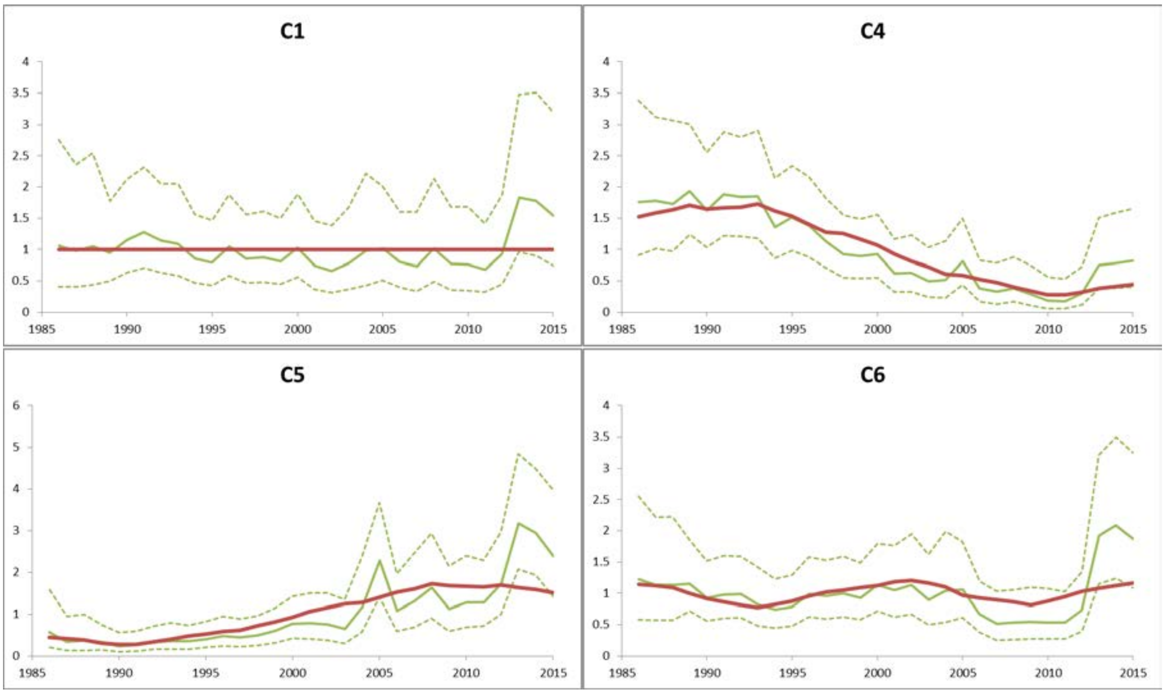


Figure 14. Comparison of the blue marlin "True" annual trends (red line) and relative index of abundance (green) with 95% confidence bounds for the four datasets provided by the SAM WG.

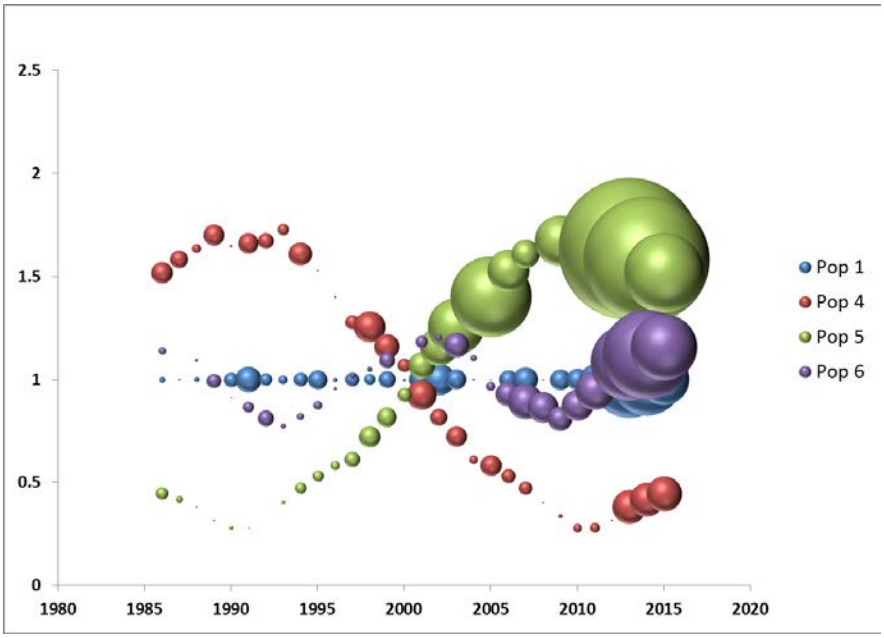


Figure 15. Plot of residuals between the True blue marlin and the estimated relative index of abundance for each of the four datasets (Pop 1 – 4). The size of the bubble indicates the square difference between true and estimated value, the overall trend of each series is the population trend in reference to the overall mean (e.g. 1).

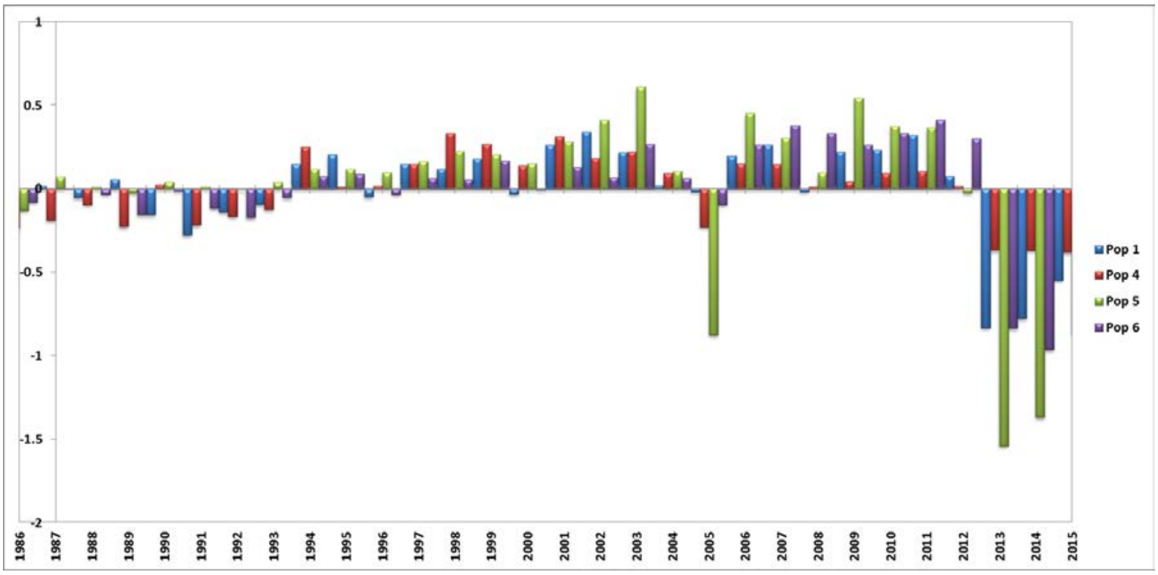


Figure 16. Annual distribution of residuals (True-estimate) of the relative abundance index for the blue marlin simulated datasets.