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STANDARDIZED CATCH RATES FOR BIGEYE TUNA (*THUNNUS OBESUS*) FROM THE UNITED STATES PELAGIC LONGLINE FISHERY

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SUMMARY

This paper presents two indices of abundance (CPUE in number and in biomass) of bigeye tuna from the United States pelagic longline fishery logbooks in the Atlantic Ocean for years 1986-2014. The standardization procedure included the following variables; year, area, season, gear characteristics (light sticks) and fishing characteristics (operations procedure, and target species calculated as the fraction of swordfish caught to the total catch which is used to identify trips that primarily target and catch swordfish. Spatial strata were defined by an adaptive area stratification methodology and observations that clearly were affected by fishing regulations (closed areas or bait restrictions) were excluded when these factors could not be accounted for in the modeling. Standardized indices were estimated using Generalized Linear Mixed Models with a delta binomial-lognormal approach. Both indices indicate an overall decline since the mid-1980s, a second decline in the late 2000s, and stable but low values since 2007 and slight increases in 2013 and 2014.

RÉSUMÉ

Le présent document fait état de deux indices d'abondance (CPUE en nombre et en biomasse) du thon obèse provenant des carnets de pêche des palangriers pélagiques des États-Unis dans l'océan Atlantique entre 1986 et 2014. La procédure de standardisation incluait les variables suivantes : année, zone, saison, caractéristiques des engins (baguettes lumineuses) et caractéristiques de la pêche (procédure opérationnelle et espèces-cibles calculées comme étant la fraction des espadons capturés par rapport à la prise totale qui est utilisée pour identifier les sorties qui ciblent et capturent essentiellement l'espadon). Des strates spatiales ont été définies au moyen d'une méthodologie souple de stratification spatiale et on a exclu les observations qui ont clairement été affectées par les réglementations en matière de pêche (fermetures de zones ou restrictions concernant les appâts) lorsque ces facteurs n'ont pas pu être pris en compte dans le modèle. Les indices standardisés ont été estimés à l'aide de modèles mixtes linéaires généralisés selon une approche delta binomiale-lognormale. Les deux indices font apparaître une chute générale depuis le milieu des années 80, une deuxième chute à la fin des années 2000 et des valeurs stables mais faibles depuis 2007 ainsi que de légères augmentations en 2013 et 2014.

RESUMEN

Este documento presenta dos índices de abundancia (CPUE en número y en biomasa) de patudo de los cuadernos de pesca de la pesquería de palangre pelágico estadounidense en el océano Atlántico para los años 1986-2014. El procedimiento de estandarización incluía las siguientes variables: año, área, temporada, características del arte (bastones de luz) y características de la pesca (procedimiento de operaciones y especie objetivo calculadas como la parte de pez espada capturado con respecto a la captura total que se utiliza para identificar las mareas que se dirigen y capturan principalmente pez espada). Se definieron los estratos espaciales mediante una metodología de estratificación del área adaptativa, y se excluyeron las observaciones claramente afectadas por reglamentaciones pesqueras (zonas vedadas o restricciones de cebo) cuando estos factores no podían tenerse en cuenta en la modelación. Los índices estandarizados se estimaron utilizando modelos lineales mixtos generalizados con el enfoque del modelo delta binomial-lognormal. Ambos índices indicaron un descenso global desde mediados de los 80, un segundo descenso a finales de los 2000, valores estables pero bajos desde 2007 y ligeros aumentos en 2013 y 2014.

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KEYWORDS

*Bigeye tuna, Abundance indices, Catch/effort,
Catch rate standardization, Generalized linear model, Pelagic longline fisheries*

1. Introduction

The report presents standardized CPUE estimates in numbers of bigeye tuna and in weight by assigning an average weight to each fish from observer data. Data are obtained from pelagic longline logbooks for years 1986 to 2014. We use a delta lognormal approach implemented as a generalized linear mixed model in SAS (SAS Institute Inc. 1997) using methodology similar to Ortiz and Diaz (2003) and Ortiz (2004) and Ortiz and Calay 2012.

2. Materials and Methods

Data

Data for this analysis comes from the United States Atlantic and Gulf of Mexico pelagic longline fishery described in detail by Hoey and Bertolino (1988). Swordfish, Yellowfin and Bigeye Tuna (BET) are the predominant target species. The pelagic longline fishing grounds of the US fleet extends from the Grand Banks in the North Atlantic to 5-10° south of the Equator, mainly in the Western Atlantic including the Caribbean Sea and the Gulf of Mexico (**Figure 1**).The fishery has operated under several time-area restrictions since 2000 due to management regulations related to swordfish and other species (U.S. Federal Register 2000, **Figure 1**). These restrictions included two permanent closures to pelagic longline fishing, one in the Gulf of Mexico known as the Desoto Canyon, effective since November 1st 2000, and the second permanent closure on the Florida East Coast effective since March 1st 2001. In addition, three time-area restrictions were also imposed for the pelagic longline gear in the US Atlantic coast: the Charleston Bump, an area off the South Carolina coast closed from February 1st to April 30th starting in 2001 year, The Bluefin Tuna Protection Area off the South New England coast closed from June 1st to June 30th starting in 1999, and the Grand Banks area that was closed from July 17 2001 to January 9 2002 as a result of an emergency rule implementation (Cramer 2002). Further restrictions involved the Northeast Distant Waters area where, starting in 2004, all vessels were required to use circle hooks with mackerel bait.

Catch and effort data are available from pelagic logbooks reported daily by vessel captains (Scott et al. 1993, Cramer and Bertolino 1998). US pelagic logbook data are available since 1986, however from 1986 to 1991, submission of logbooks was voluntary, and became mandatory in 1992. In this paper we use both vessel logbook reports for the CPUE in number. Fishing effort is reported as number of hooks per set, and nominal catch rates were calculated as number of BET caught per 1,000 hooks for each observation. Data are also available from the Observer program but logbook data was used for this analysis due to the more comprehensive spatial and temporal coverage and the lack of a reporting bias for bigeye which are almost always retained and sold.

To obtain CPUE in weight we assign an average weight to the landed fish by year, area and season from observer data. For years with no observer data, the average weights by season and area were applied.

The pelagic longline logbook data (**Figure 2**) comprises a total of 342,998 recorded sets from 1986 through 2014. **Figure 2** presents the geographic distribution of total catch in number of bigeye from the pelagic logbooks for summed by approximately 40x40 nautical mile grid cell for the years 1987 through 2014.

Each record contains information of catch by set, including: date-time, geographical location, catch in numbers of targeted and bycatch species, number of hooks, light stick and various other gear parameters for each set, as well as environmental conditions such as temperature.

Data exclusions

Various data restrictions were necessary to eliminate incomplete or erroneous records or records that were non-standard, such as very short sets of fewer than 100 hooks, weight of fish incorrectly recorded as number, vessels with op code 1 or 3 as there were very few sets from these, or sets with zero fish of any species captured. Restricting the logbook data only to sets from 1986 onward, those with greater than 100 hooks per set, and with complete catch, effort, location and date information and with the regulatory restrictions defined below, resulted in a total of 290,995 sets, of which ~29% were positive for BET with the observed proportion positive increasing in recent years. As noted below, sets in closed areas were excluded before and after the closure, sets that occurred in the Northeast Distant waters after 2003 were excluded and sets in the FEC at latitudes lower than 28ºN latitude were removed as the closures of the Florida straits shifted effort away from the Florida Straits towards the area north of the Bahamas (not shown due to data confidentiality). This spatial shift in effort clearly impacted the CPUE in the FEC as a whole, creating a spurious year*area interaction that was mitigated by removing FEC at latitudes lower than 28ºN latitude.

Adaptive area partitioning

We employed the algorithm of Ichinokawa and Brodziak (2010) to partition the spatial domain into homogeneous areas. This algorithm iteratively tested spatial partitions of the dataset and determining the improvement in fit. We used the Bayesian Information criterion to determine fit and successively partitioned the dataset into 20 splits. We chose the final number of splits based upon a criterion where we stopped partitioning after a split failed to account for greater than 10% of the explained deviance (**Figure 3**). We chose this reduction in explained deviance rather than reduction in BIC as the structure of the data (repeated and clustered observation) rather than independent and identically distributed data and the high sample size means that conventional hypothesis testing metrics will tend towards type I errors of finding spurious significance. Hence we chose a % of deviance which avoids having a very large number of likely spurious spatial partitions. The spatial partitions determined by this algorithm were called the variable NewArea and are shown in **Figure 4**.

Model factors

Model factors evaluated included: year, Area (old area definitions shown in **Figure 1**, used for the continuity model), NewArea, Season, Target species defined as the fraction of SWO/total catch in number, OP- or operations code which is a code that is classifies vessels based on their fishing configuration, type and size of vessel, main target species, and area of operation(s). In recent years the OP codes have not been updated so recent entrants to the fishery have been assigned a code of '9'.). Other factors included in the analyses of catch rates included the use and number of light-sticks (lightc) expressed as the ratio of light-sticks per hook. We defined targeting (Target) as a categorical variable with four levels based on the proportion of the number of Swordfish caught to the total number of fish per set, with four discrete target categories corresponding to the ranges 0-25%, 25-50%, 50-75%, and 75-100%.

Eleven geographical areas (NewArea) were determined on the basis of the adaptive partitioning algorithm. These were: the Caribbean, Gulf of Mexico, Florida East Coast, South Atlantic Bight, Mid-Atlantic Bight, New England Coastal, Northeast Distant Waters, the Sargasso Sea, and the offshore area (**Figure 1**). Calendar quarters (SEASON) were used to account for seasonal fishery distribution through the year (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec.

Factors related to BET-specific fishing strategy such as longer gangions, more hooks between floats and longer floatlines were examined. Due to changes in the units with which gangion length were recorded, this variable proved impossible to use at this time and no clear relationship between floatline length or number of hooks between floats was observed (**Figures 5 and 6**). Other variables include Sea Surface temperature (SST), time of set in the am or pm (BSPM), target species (TBET), a variable recorded by fishers on the logbook which was divided into the following categories and hook type (circle or J). While hook type appeared to be influential it was also only recorded late in the time series and the catch rates for unknown types (likely mostly J hooks) was similar to the catch rate of circle hooks, despite the apparent decrease catch rate between circle and J hooks (**Figure 6**). Unfortunately most of the other variables were only recorded starting in 1992 so it would limit the model to 1992-2014 and bait used was only recorded starting in 2005 so it could not be used as a model factor in the full time series.

Dependent variables

Two dependent variables were used for the analysis, catch per unit effort (1000 hooks) in number (CPUEN) and in weight (CPUEW). CPUEN was obtained from the logbook data as the number of bigeye caught per 1,000 hooks for each longline set. This number included kept as well as live and dead discarded bigeye, however discarded bigeye represented less than 5% of the total number of caught tuna. CPUEW was obtained from the DLS weigh-out database as the total dressed carcass weight of bigeye landed for an entire trip, divided by the total number of hooks set for the trip. For comparison, nominal catch rates of bigeye caught per 1,000 hooks was also obtained from the DLS database. Note that the DLS recorded tuna did not include discarded fish.

Distributional assumptions

Distributional assumptions were evaluated using methods in Lauretta et al 2015. Goodness of fit tests favored the negative binomial over the Poisson distribution (**Tables 1 and 2**) where the chi-square distribution statistic rejected a Poisson distribution in all 30 years but failed to reject the Negative binomial in 7/30 years. A Kolmogorov-Smirnov tests for the log (positive CPUE) rejected a lognormal distribution in all 30 years. Nonetheless when negative binomial models were estimated with year*factor random effects, the models did solve after many hours so we are only presenting the delta-lognormal model results.

Statistical modeling

Continuity (Model 1). The first model was a continuity model which used the exact same model as Ortiz and Calay (2011) without re-estimating model factors. We do not recommend this model for advice, but show it only for continuity purposes.

Best-practices full time series (Model 2, and closed areas removed (Model 3)). The second and third models apply a best-practices approach of full evaluation of error distribution assumptions, re-evaluation of model factors and factor levels and particular attention to the spatial area partitioning with an application of the Ichinokawa and Brodziak (2010) adaptive area partitioning. This model was estimated for the entire time series (1986-2014).

Initial Models:

Success ~ year + NewArea+Season+ lightc+Target+op + all 2-way interactions

Log(CPUE) ~ year + NewArea+Season+lightc+Target+op + all 2-way interactions

Final Model

Success ~ year + NewArea+Season +Target+ *year*area*

Log(CPUE) ~ year + NewArea+Season+op +area:season+*year:season*+ *year*area*

Where year*factor interactions were modeled as random effects. Model selection was performed according to the reduction in explained deviance, with factors being retained if they result in greater than a 1% reduction. First main factors were chosen, and then all two-way interactions were tested. Subsequently all random effects were included only if they indicated improved model fit based upon a reduction in AIC (**Table 3**). Model selection was performed in R and final model estimation was performed in SAS with proc GLIMMIX.

Dealing with management measures and spatial/temporal closures.

Due to the differing effects of spatial/temporal closures in different areas e.g., any “closure” effect would be likely to be unique to the particular area and not constant across the dataset, it was not straightforward to estimate a single open/closed effect to account for spatial closures. Furthermore, the NED area (**Figure 1**) had a restriction the allowed only mackerel bait after 2004, which appeared to severely impact BET catch rates (**Figure 7**). Thus the most parsimonious approach was to exclude data from the entire time series before and after the closure, in which case the abundance signal comes only from the continuously open areas or area-time combinations.

This differs from the approach used in prior versions of this index where area closures were dealt with by estimating an open/closed effect which was found not to be significant in the model (Ortiz and Calay 2011). The problem with this approach is that the effects of area closures are not the same across all closures – in the FEC management measures increased CPUE, in the NED they decreased CPUE. Hence any open/closed term is not the same across all areas. By excluding observations before and after the closures, we reduce the influence of spurious year*area interactions (**Figure 8**).

Variance estimation

Variance estimates of the index were obtained as the product of two uncorrelated random variables (Goodman 1960).

3. Results and Discussion

This paper presents some extensive analysis of the spatial distribution of catches (**Figures 2-3**) and applies the adaptive spatial partitioning algorithm of Ichinokawa and Brodziak (2010) to create more homogenous spatial areas. These, more spatial areas improve model fit over the prior, non-BET specific spatial partitioning by creating more homogenous spatial areas. The decision to limit to the number of partitions to only those that accounted for up to 10% of the explained deviance was a practical consideration so as to not have a very large number of areas. This also was the level of deviance reduction where the BIC started to reach a plateau (**Figure 4**). Choosing the number of spatial areas based solely on AIC or BIC reduction, as recommended in Ichinokawa and Brodziak (2010) would likely have produced >20 different spatial partitions, as all 20 explored in this paper resulted in significant reductions BIC. It is likely that, due to the clustered nature of the data, further spatial partitioning would simply be splitting out similar fishing trips, rather than unique spatial areas. Hence the decision to limit the number of partitions was made for parsimony. The final distribution of spatial areas generally resembles the previous areas, with some slight shifting of borders (**Figure 4**).

This paper also presents an evaluation of model factors that might influence BET CPUE (**Figure 5, 6**). Unfortunately very few of the factors that might clearly differentiate targeting of BET versus other species appear to be influential- note that lack of contrast between Hooks between floats, gangion length or float-line length. Furthermore, variables such as sea surface temperature, time of day of set and bait used have not been recorded over the full time series so they cannot be used for the longer model. It would be possible to use some of these factors in a reduced time series model (1992-2014), if this was deemed of important. While the factor of hook type appears important, this is likely due to the combined influence of hook type, bait and location of where paired both J and circle hooks were used. The fact that the pre-circle hook time period when mainly J hooks were used (denoted in **Figure 6** as no hook type noted) has the same mean CPUE as circle hooks indicates that hook type, alone, would not be a useful model factor.

The greatest overall factor explaining differences in catch rates appears to be area (**Figure 5**) with mean catch rates varying substantially by area, and some evidence of year*area interactions (**Figure 7**). These interactions reduced by using the new adaptive areas, which lead to more homogenous mean catch rates and by excluding closed areas or areas such as the NED which was still open but highly affected by regulations (**Figure 8**). Alternatively it would have been possible to model the NED post 2003 as another area, but this could have potentially confounded the effect of time.

Overall model fit was acceptable for the binomial and lognormal components (**Figure 9**). While the negative binomial model appeared to provide a better fit than the lognormal model and much better than a Poisson model (**Tables 1** and **2**) the lognormal fits were adequate (**Figure 9**), despite the departure from lognormality. The negative binomial model had difficulty estimating random effect interactions and did not find a solution after several hours of runtime. Hence, for practical purposes we employ the delta lognormal model. When we compared the estimated means from both lognormal and the negative binomial model (without random effect interactions) the R^2 was 0.85 indicating that both would likely give a fairly similar trend.

Model performance as measured by the overall amount of deviance reduction indicated that the binomial model only accounted for 31% and the lognormal only 24% of the total deviance, indicating that much of the variability remained unexplained (**Tables 2 and 3**). The most important model factor was area with year and season of lesser importance. Factors related to targeting of bigeye (OP) and (Targeting) were relatively unimportant. A sensitivity run was conducted (not shown) of the effects of removing either OP or targeting and the R^2 were both 0.99 with model 3, chosen as the best model. Year*factor interactions deemed significant by deviance reduction were also significant by the added inclusion criteria of reduction in AIC (**Table 3**). Fixed factor estimates (**Tables 4** and **5**) indicate the effects of each model component and largely reflect patterns observed in **Figures 5** and **6** except that there are some differences when each model component is examined in isolation. As the season*area interactions were likely to be real, and fixed- e.g. certain seasons operate differently in certain areas, they were retained as fixed effects in the models. The estimated index in number (**Tables 6, Figure 10**) indicates a sharp decline from the late 1980s, then relatively high catch rates in the late 1990s with a second decline in the early 2000s with stable and low values up until 2012. Since 2012 there has been a two-year increase in CPUE. The model shows a clear divergence from nominal values in recent years with the standardized estimates being lower than the nominal (**Figure 10**).

The models estimated in both weight and number show very high correlation (**Figure 11**, r^2=0.94). Furthermore, Prager and Goodyear (2001) found little difference in estimating production models in weight or number under a range of simulation scenarios, so it may be likely that these can be considered interchangeable for some modeling platforms. For constructing seasonal models the index is also calculated by year and season (**Table 9**).

The three models; 1. continuity, model 2 with no closed area restrictions and model 3 with closed areas removed before and after all show quite similar patterns of relative abundance (**Table 8, Figure 12**). When scaled to a common mean the indices area also quite similar to the index in Ortiz and Calay (2011), (orange line in **Figure 12**). However there is a noticeable divergence between models 1 and 2 and index 3 in the recent years as the estimated index is higher and shows a greater increasing trend since 2004. This is clearly due to the removal of the spurious NED observations post-2003 where catch rates were extremely low (**Figure 7**) due to management restrictions. Hence index 3 is an improvement over previous treatments.

For input into seasonal analyses, estimates using Model 3 were calculated by year and season: 1(Jan-Mar), 2(Apr-Jun), 3(July-Sep), 4(Oct-Dec), (**Figure 13, Table 11**) and show seasonal variation with the highest catch rates in the last quarter of the year.

This analysis differed in several ways from previous treatments of this data. First we did not use the dealer weigh-out data as the information was not reported at the set by set level and as this dataset is largely duplicative with the logbook. Hence we felt that it was simpler to use a single dataset. Second we have revised the spatial area definitions and made data exclusions due to the un-modeled effects of management regulations. Nonetheless the overall model is similar to the previously used CPUE indices (Ortiz and Calay 2011).

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Table 1. Goodness of fit testing for poisson and negative binomial models by year.

Discrete Model Goodness-of-Fit Tests									
Year	Prop Positive	Mean catch	Var Catch	Var Mean Ratio	Var>>Mean	Prop Pos Threshold	Obs Prop<Expected	Poisson Chisq Pr	Neg Binomial Chisq Pr
1986	0.32	1.60	12.8	8.0	YES	0.20	NO	**<0.005**	**0.020**
1987	0.29	1.10	8.4	7.7	YES	0.33	**YES**	**<0.005**	**<0.005**
1988	0.29	0.97	9.6	9.9	YES	0.38	**YES**	**<0.005**	**<0.005**
1989	0.33	1.12	8.0	7.2	YES	0.33	NO	**<0.005**	**<0.005**
1990	0.30	1.07	10.3	9.6	YES	0.34	**YES**	**<0.005**	**<0.005**
1991	0.32	1.29	11.4	8.9	YES	0.28	NO	**<0.005**	**<0.005**
1992	0.27	1.00	9.6	9.6	YES	0.37	**YES**	**<0.005**	**<0.005**
1993	0.30	1.48	15.7	10.6	YES	0.23	NO	**<0.005**	0.072
1994	0.29	1.41	14.1	10.0	YES	0.24	NO	**<0.005**	**<0.005**
1995	0.31	1.40	16.1	11.5	YES	0.25	NO	**<0.005**	**<0.005**
1996	0.25	1.13	13.7	12.1	YES	0.32	**YES**	**<0.005**	**<0.005**
1997	0.28	1.50	19.3	12.9	YES	0.22	NO	**<0.005**	**<0.005**
1998	0.30	1.61	18.6	11.5	YES	0.20	NO	**<0.005**	**0.026**
1999	0.29	1.92	24.9	13.0	YES	0.15	NO	**<0.005**	**<0.005**
2000	0.26	1.10	11.0	10.0	YES	0.33	**YES**	**<0.005**	**<0.005**
2001	0.28	1.58	21.4	13.5	YES	0.21	NO	**<0.005**	**<0.005**
2002	0.28	1.24	11.8	9.5	YES	0.29	**YES**	**<0.005**	0.281
2003	0.19	0.73	7.0	9.6	YES	0.48	**YES**	**<0.005**	**<0.005**
2004	0.16	0.82	10.0	12.3	YES	0.44	**YES**	**<0.005**	0.417
2005	0.23	1.08	12.8	11.9	YES	0.34	**YES**	**<0.005**	**<0.005**
2006	0.31	1.65	17.8	10.8	YES	0.19	NO	**<0.005**	**0.040**
2007	0.26	1.03	8.5	8.3	YES	0.36	**YES**	**<0.005**	0.401
2008	0.29	1.30	11.2	8.7	YES	0.27	NO	**<0.005**	0.120
2009	0.27	1.15	8.9	7.7	YES	0.32	**YES**	**<0.005**	**<0.005**
2010	0.39	1.73	14.7	8.5	YES	0.18	NO	**<0.005**	**<0.005**
2011	0.39	2.07	17.7	8.6	YES	0.13	NO	**<0.005**	**<0.005**
2012	0.34	1.41	9.9	7.0	YES	0.24	NO	**<0.005**	**<0.005**
2013	0.35	1.54	10.2	6.6	YES	0.22	NO	**<0.005**	**<0.005**
2014	0.38	1.74	12.9	7.4	YES	0.18	NO	**<0.005**	**<0.005**
2015	0.45	2.03	12.3	6.1	YES	0.13	NO	**<0.005**	**0.022**

Table 2. Goodness of fit testing for lognormal models by year.

Positive CPUE Log-normal Model Goodness-of-fit Test				
Year	Mean_LogCPUE	Var_LogCPUE	Shapiro_Wilks_Test_Pr	KS_Test_Pr
1986	2.31	0.85	**<0.005**	**<0.005**
1987	1.91	0.82	**<0.005**	**<0.005**
1988	1.73	0.72	**<0.005**	**<0.005**
1989	1.75	0.78	NA	**<0.005**
1990	1.70	0.76	**<0.005**	**<0.005**
1991	1.64	0.83	**<0.005**	**<0.005**
1992	1.51	0.85	**<0.005**	**<0.005**
1993	1.58	0.90	**<0.005**	**<0.005**
1994	1.55	0.85	**<0.005**	**<0.005**
1995	1.38	0.87	NA	**<0.005**
1996	1.38	0.89	**<0.005**	**<0.005**
1997	1.53	1.01	**<0.005**	**<0.005**
1998	1.55	0.99	**<0.005**	**<0.005**
1999	1.72	1.07	**<0.005**	**<0.005**
2000	1.41	0.95	**<0.005**	**<0.005**
2001	1.62	1.03	**<0.005**	**<0.005**
2002	1.39	0.93	**<0.005**	**<0.005**
2003	1.22	0.91	**<0.005**	**<0.005**
2004	1.40	1.15	**<0.005**	**<0.005**
2005	1.35	1.11	**<0.005**	**<0.005**
2006	1.56	1.15	**<0.005**	**<0.005**
2007	1.35	1.07	**<0.005**	**<0.005**
2008	1.46	0.94	**<0.005**	**<0.005**
2009	1.42	0.90	**<0.005**	**<0.005**
2010	1.37	0.83	**<0.005**	**<0.005**
2011	1.58	0.86	**<0.005**	**<0.005**
2012	1.33	0.73	**<0.005**	**<0.005**
2013	1.47	0.82	**<0.005**	**<0.005**
2014	1.51	0.77	**<0.005**	**<0.005**
2015	1.45	0.75	**<0.005**	**<0.005**

Table 3. Deviance table for proportion positive

Proportion Positive Sets

Model	Df	Resid. Dev	Dev Reduction	% Dev Reduction
Intercept only	342997	414952		
year	342968	411356	3596	0.9
season	342994	404093	10859	2.6
area	342987	318022	96930	23.4
target	342994	409586	5366	1.3
lights	342994	412510	2442	0.6
op	342990	374509	40443	9.7
area+year	342958	316049	1973	0.5
area+season	342984	313281	4741	1.1
area+lights	342984	317665	357	0.1
area+target	342984	314240	3783	0.9
area+op	342980	315875	2147	0.5
area+season+year	342955	311353	1929	0.5
area+season+target	342981	308838	4444	1.1
area+season+lights	342981	312899	383	0.1
area+season+op	342977	310960	2322	0.6
year+area+season+target+year:area	342674	287832	19314	4.7
year+area+season+target+year:season	342869	304476	2670	0.6
year+area+season+target+year:target	342865	305848	1299	0.3
year+area+season+target+area:season	342922	303159	3988	1.0
year+area+season+target+area:target	342922	301873	5273	1.3
year+area+season+target+season:target	342943	306807	339	0.1

Table 4. Deviance table for log CPUE.

Positive Catch Rates

Model	Df	Resid. Dev	Dev Reduction	*% Dev Reduction*
NULL	100526	91822		
year	100497	89102	2719	*3.0*
season	100523	90910	912	*1.0*
area	100516	82102	9719	*10.6*
target	100523	91782	40	*0.0*
lights	100523	89941	1880	*2.0*
op	100519	82764	9057	*9.9*
area+year	100487	78040	4062	4.4
area+season	100513	80598	1505	1.6
area+lights	100513	81200	903	1.0
area+target	100513	82018	85	0.1
area+op	100509	80153	1949	2.1
area+year+season	100484	76436	1605	1.7
area+year+lights	100484	77229	811	0.9
area+year+target	100484	77656	385	0.4
area+year+op	100480	76744	1296	1.4
area+year+season+lights	100481	75706	730	0.8
area+year+season+target	100481	75942	493	0.5
area+year+season+op	100477	75261	1175	1.3
area+year+season+op+target	100474	74664	597	0.7
area+year+season+op+lights	100474	74699	562	0.6
area+year+season+op+area:year	100209	72070	3191	3.5
area+year+season+op+area:season	100448	74107	1155	1.3
area+year+season+op+area:op	100419	74576	685	0.7
area+year+season+op+year:season	100394	74063	1199	1.3
area+year+season+op+year:op	100274	73692	1569	1.7
area+year+season+op+season:op	100456	74874	387	0.4
area+year+season+op+area:year+area:season	100180	70974	1096	1.2

area+year+season+op+area:year+area:op	100152	71559	512	0.6
area+year+season+op+area:year+year:season	100126	71026	1044	1.1
area+year+season+op+area:year+year:op	100006	71273	797	0.9
area+year+season+op+area:year+season:op	100188	71725	345	0.4
area+year+season+op+area:year+area:season+area:op	100123	70584	390	0.4
area+year+season+op+area:year+area:season+year:season	100097	70044	930	1.0
area+year+season+op+area:year+area:season+year:op	99977	70227	747	0.8
area+year+season+op+area:year+area:season+season:op	100159	70797	177	0.2

Table 5. Fit information criteria for random effects. All random effects estimated as significant by reduction in deviance were also significant by AIC.

Proportion positive model			
Fixed effects	Random effects	Neg2LogLike	AIC
positv/total= year area season targ2	no Random effects	14237.1	14239
positv/total= year area season targ2	year*area	13644.7	13649
Lognormal model			
Fixed effects	Random effects	Neg2LogLike	AIC
lgcpuen = year area season op area*season	none	242233	242235
lgcpuen = year area season op area*season	year*area	239442	239446
lgcpuen = year area season op area*season	year*area year*season	238645	238651

Table 6. Fixed factor estimates for proportion positive submodel, the areas are the new areas.

Effect	area	SEASON	YEAR	TARG2	est	SE	DF	Pr > |t|	Lower	Upper
Intercept					0.06772	0.2937	268	0.8178	-0.5106	0.646
YEAR			1986		-0.6792	0.3712	268	0.0684	-1.41	0.05165
YEAR			1987		0.1657	0.3228	268	0.6082	-0.4699	0.8013
YEAR			1988		-0.2286	0.322	268	0.4784	-0.8626	0.4054
YEAR			1989		-0.1189	0.3197	268	0.7104	-0.7483	0.5106
YEAR			1990		-0.0864	0.3201	268	0.7875	-0.7167	0.5439
YEAR			1991		-0.1456	0.3232	268	0.6527	-0.7819	0.4907
YEAR			1992		-0.3416	0.322	268	0.2897	-0.9755	0.2924
YEAR			1993		-0.2988	0.3223	268	0.3546	-0.9334	0.3357
YEAR			1994		-0.4231	0.3217	268	0.1896	-1.0566	0.2103
YEAR			1995		-0.2539	0.3229	268	0.4323	-0.8896	0.3817
YEAR			1996		-0.1641	0.3205	268	0.609	-0.7952	0.4669
YEAR			1997		-0.2806	0.3198	268	0.381	-0.9102	0.349
YEAR			1998		-0.1086	0.3195	268	0.7343	-0.7376	0.5205
YEAR			1999		0.07012	0.3234	268	0.8285	-0.5666	0.7069
YEAR			2000		-0.1423	0.3246	268	0.6615	-0.7814	0.4968
YEAR			2001		-0.0614	0.3237	268	0.8497	-0.6987	0.5759
YEAR			2002		-0.2077	0.322	268	0.5196	-0.8417	0.4264
YEAR			2003		-0.6041	0.3255	268	0.0646	-1.2449	0.03684
YEAR			2004		-0.7647	0.3323	268	0.0221	-1.4189	-0.1105
YEAR			2005		-0.3305	0.3318	268	0.3202	-0.9838	0.3229
YEAR			2006		-0.0207	0.3322	268	0.9503	-0.6748	0.6333
YEAR			2007		-0.4041	0.3313	268	0.2236	-1.0563	0.2482
YEAR			2008		-0.3586	0.3301	268	0.2783	-1.0085	0.2913
YEAR			2009		-0.4008	0.3305	268	0.2264	-1.0515	0.25
YEAR			2010		-0.3575	0.3294	268	0.2787	-1.0059	0.291
YEAR			2011		-0.508	0.3315	268	0.1266	-1.1606	0.1447
YEAR			2012		-0.3895	0.3278	268	0.2359	-1.035	0.256
YEAR			2013		-0.2302	0.3267	268	0.4817	-0.8734	0.4131
YEAR			2014		0.06398	0.3278	268	0.8454	-0.5813	0.7093
YEAR			2015		0	.	.	.	.	.
area	FEC				1.1919	0.1314	268	<.0001	0.9331	1.4507
area	GOM				-2.3256	0.1284	268	<.0001	-2.5785	-2.0728
area	MAB				-0.3801	0.1305	268	0.0039	-0.637	-0.1232
area	NCA				0.3048	0.1315	268	0.0212	0.04592	0.5637
area	NCAR				-1.4253	0.2109	268	<.0001	-1.8406	-1.01
area	NEC				0.7244	0.1284	268	<.0001	0.4717	0.9771
area	NED				0.2118	0.1518	268	0.1641	-0.0871	0.5107
area	SAB				-3.0908	0.1593	268	<.0001	-3.4045	-2.7771
area	SAR				2.2484	0.2427	268	<.0001	1.7705	2.7262
area	SCA				1.683	0.1405	268	<.0001	1.4065	1.9596
area	SCAR				0	.	.	.	.	.
SEASON		Apr-Jun			-1.1436	0.03414	3662	<.0001	-1.2105	-1.0766
SEASON		Jan-Mar			-0.7486	0.03579	3662	<.0001	-0.8188	-0.6785
SEASON		Jul-Sep			-0.6025	0.02914	3662	<.0001	-0.6597	-0.5454
SEASON		Oct-Dec			0	.	.	.	.	.
TARG2				1	0.4627	0.03791	3662	<.0001	0.3884	0.5371
TARG2				2	0.5325	0.03932	3662	<.0001	0.4554	0.6096
TARG2				3	0.3191	0.04035	3662	<.0001	0.24	0.3982
TARG2				4	0	.	.	.	.	.

Table 7. Fixed factor estimates for lognormal submodel.

Effect	AREA	SEASON	YEAR	OP	Est	SE	DF	Pr > |t|	Lower	Upper
Intercept					1.2329	0.1658	8.2E+01	<.0001	0.9031	1.5628
YEAR			1986		0.6131	0.2146	8.2E+01	0.0054	0.1862	1.04
YEAR			1987		0.6341	0.1829	8.2E+01	0.0008	0.2702	0.998
YEAR			1988		0.4066	0.1831	8.2E+01	0.0291	0.0424	0.7708
YEAR			1989		0.3447	0.1827	8.2E+01	0.0627	-0.019	0.7081
YEAR			1990		0.2923	0.183	8.2E+01	0.114	-0.072	0.6563
YEAR			1991		0.358	0.1837	8.2E+01	0.0548	-0.007	0.7234
YEAR			1992		0.2021	0.1838	8.2E+01	0.2746	-0.163	0.5677
YEAR			1993		0.1978	0.1842	8.2E+01	0.2859	-0.169	0.5642
YEAR			1994		0.1279	0.184	8.2E+01	0.489	-0.238	0.4939
YEAR			1995		0.0317	0.1838	8.2E+01	0.8634	-0.334	0.3974
YEAR			1996		0.1371	0.1826	8.2E+01	0.455	-0.226	0.5003
YEAR			1997		0.0782	0.1827	8.2E+01	0.6699	-0.285	0.4416
YEAR			1998		0.0804	0.1823	8.2E+01	0.6603	-0.282	0.443
YEAR			1999		0.3186	0.1829	8.2E+01	0.0853	-0.045	0.6824
YEAR			2000		0.1502	0.1833	8.2E+01	0.415	-0.215	0.5149
YEAR			2001		0.1151	0.183	8.2E+01	0.531	-0.249	0.4792
YEAR			2002		0.0273	0.1825	8.2E+01	0.8814	-0.336	0.3904
YEAR			2003		-0.132	0.1838	8.2E+01	0.4735	-0.498	0.2333
YEAR			2004		-0.152	0.1873	8.2E+01	0.4204	-0.524	0.2209
YEAR			2005		0.0083	0.1866	8.2E+01	0.9645	-0.363	0.3795
YEAR			2006		0.0909	0.1863	8.2E+01	0.6269	-0.28	0.4614
YEAR			2007		-0.169	0.1866	8.2E+01	0.3675	-0.54	0.2021
YEAR			2008		-0.124	0.1862	8.2E+01	0.5059	-0.495	0.246
YEAR			2009		-0.241	0.1861	8.2E+01	0.1991	-0.611	0.1293
YEAR			2010		-0.301	0.1856	8.2E+01	0.1092	-0.67	0.0687
YEAR			2011		-0.185	0.1876	8.2E+01	0.3277	-0.558	0.1884
YEAR			2012		-0.284	0.186	8.2E+01	0.1311	-0.654	0.0863
YEAR			2013		-0.111	0.1856	8.2E+01	0.5514	-0.48	0.2582
YEAR			2014		-0.06	0.1854	8.2E+01	0.7487	-0.429	0.3093
YEAR			2015		0	.	.	.	.	.
area	FEC				1.0079	0.0613	2.5E+02	<.0001	0.8872	1.1285
area	GOM				-0.287	0.0618	2.5E+02	<.0001	-0.408	-0.165
area	MAB				0.544	0.0615	2.5E+02	<.0001	0.4229	0.6651
area	NCA				0.4695	0.0595	2.5E+02	<.0001	0.3523	0.5867
area	NCAR				0.2342	0.1772	2.5E+02	0.1875	-0.115	0.5833
area	NEC				0.5388	0.0583	2.5E+02	<.0001	0.4241	0.6536
area	NED				0.1714	0.0694	2.5E+02	0.0142	0.0346	0.3082
area	SAB				0.2025	0.0972	2.5E+02	0.0383	0.011	0.3939
area	SAR				0.5508	0.1345	2.5E+02	<.0001	0.2859	0.8157
area	SCA				0.5616	0.0621	2.5E+02	<.0001	0.4393	0.6839
area	SCAR				0	.	.	.	.	.
SEASON		Apr-Jun			-0.067	0.0422	8.2E+01	0.1183	-0.15	0.0173
SEASON		Jan-Mar			-0.178	0.0398	8.2E+01	<.0001	-0.257	-0.099
SEASON		Jul-Sep			-0.032	0.0513	8.2E+01	0.5392	-0.134	0.0704
SEASON		Oct-Dec			0	.	.	.	.	.
OP				0	-0.019	0.0123	9.5E+04	0.1235	-0.043	0.0052
OP				2	-0.235	0.0109	9.5E+04	<.0001	-0.256	-0.213
OP				4	-0.132	0.0099	9.5E+04	<.0001	-0.151	-0.113
OP				5	-0.042	0.0117	9.5E+04	0.0003	-0.065	-0.019
OP				6	0.0773	0.0139	9.5E+04	<.0001	0.0501	0.1045
OP				7	-0.385	0.0283	9.5E+04	<.0001	-0.441	-0.33
OP				8	-0.427	0.025	9.5E+04	<.0001	-0.476	-0.378
OP				9	0	.	.	.	.	.
area*SEASON	FEC	Apr-Jun			-0.311	0.0388	9.5E+04	<.0001	-0.387	-0.235
area*SEASON	FEC	Jan-Mar			-0.087	0.035	9.5E+04	0.0128	-0.156	-0.018
area*SEASON	FEC	Jul-Sep			0.0519	0.0478	9.5E+04	0.2782	-0.042	0.1456

area*SEASON	FEC	Oct-Dec	0	.	.	.	.	.
area*SEASON	GOM	Apr-Jun	-0.014	0.044	9.5E+04	0.7458	-0.1	0.0719
area*SEASON	GOM	Jan-Mar	0.1187	0.0342	9.5E+04	0.0005	0.0517	0.1858
area*SEASON	GOM	Jul-Sep	-0.069	0.0497	9.5E+04	0.1644	-0.167	0.0283
area*SEASON	GOM	Oct-Dec	0	.	.	.	.	.
area*SEASON	MAB	Apr-Jun	-0.551	0.0409	9.5E+04	<.0001	-0.632	-0.471
area*SEASON	MAB	Jan-Mar	-0.356	0.0421	9.5E+04	<.0001	-0.438	-0.273
area*SEASON	MAB	Jul-Sep	0.0332	0.049	9.5E+04	0.4984	-0.063	0.1292
area*SEASON	MAB	Oct-Dec	0	.	.	.	.	.
area*SEASON	NCA	Apr-Jun	-0.518	0.0386	9.5E+04	<.0001	-0.593	-0.442
area*SEASON	NCA	Jan-Mar	-0.315	0.0404	9.5E+04	<.0001	-0.394	-0.235
area*SEASON	NCA	Jul-Sep	0.0017	0.0471	9.5E+04	0.972	-0.091	0.094
area*SEASON	NCA	Oct-Dec	0	.	.	.	.	.
area*SEASON	NCAR	Apr-Jun	-0.363	0.1911	9.5E+04	0.0575	-0.738	0.0116
area*SEASON	NCAR	Jan-Mar	0.0841	0.1971	9.5E+04	0.6697	-0.302	0.4705
area*SEASON	NCAR	Jul-Sep	-0.293	0.2181	9.5E+04	0.1791	-0.72	0.1345
area*SEASON	NCAR	Oct-Dec	0	.	.	.	.	.
area*SEASON	NEC	Apr-Jun	-0.458	0.0326	9.5E+04	<.0001	-0.522	-0.394
area*SEASON	NEC	Jan-Mar	-0.155	0.0841	9.5E+04	0.065	-0.32	0.0097
area*SEASON	NEC	Jul-Sep	-0.29	0.0413	9.5E+04	<.0001	-0.371	-0.209
area*SEASON	NEC	Oct-Dec	0	.	.	.	.	.
area*SEASON	NED	Apr-Jun	0.3463	0.059	9.5E+04	<.0001	0.2307	0.4618
area*SEASON	NED	Jul-Sep	-0.132	0.0471	9.5E+04	0.0051	-0.224	-0.04
area*SEASON	NED	Oct-Dec	0	.	.	.	.	.
area*SEASON	SAB	Apr-Jun	-0.282	0.1044	9.5E+04	0.0069	-0.487	-0.078
area*SEASON	SAB	Jan-Mar	-0.063	0.1368	9.5E+04	0.6474	-0.331	0.2056
area*SEASON	SAB	Jul-Sep	0.0508	0.107	9.5E+04	0.6347	-0.159	0.2605
area*SEASON	SAB	Oct-Dec	0	.	.	.	.	.
area*SEASON	SAR	Apr-Jun	-0.01	0.1151	9.5E+04	0.9334	-0.235	0.2161
area*SEASON	SAR	Jan-Mar	0.692	0.1184	9.5E+04	<.0001	0.4599	0.924
area*SEASON	SAR	Jul-Sep	-0.157	0.1345	9.5E+04	0.2443	-0.42	0.107
area*SEASON	SAR	Oct-Dec	0	.	.	.	.	.
area*SEASON	SCA	Apr-Jun	-0.173	0.0546	9.5E+04	0.0015	-0.28	-0.066
area*SEASON	SCA	Jan-Mar	0.1064	0.0355	9.5E+04	0.0027	0.0369	0.1759
area*SEASON	SCA	Jul-Sep	0.3191	0.0646	9.5E+04	<.0001	0.1925	0.4456
area*SEASON	SCA	Oct-Dec	0	.	.	.	.	.
area*SEASON	SCAR	Apr-Jun	0	.	.	.	.	.
area*SEASON	SCAR	Jan-Mar	0	.	.	.	.	.
area*SEASON	SCAR	Jul-Sep	0	.	.	.	.	.
area*SEASON	SCAR	Oct-Dec	0	.	.	.	.	.

Table 8. Nominal and standardized catch rates of bigeye tuna in #/1000 hooks (CPUEN) from the pelagic logbook data for model 2 with restrictions. Note that the nominal CPUE includes zero catches.

year	nobs	obcpue	obppos	estcpue	STDCPUE	cv_i	LCI	UCI
1986	1456	5.333	0.365	2.891	1.209	0.197	0.819	1.785
1987	10862	3.631	0.341	5.079	2.124	0.122	1.666	2.709
1988	11613	2.973	0.346	3.215	1.344	0.128	1.042	1.734
1989	12728	3.354	0.391	3.234	1.352	0.125	1.055	1.734
1990	11868	3.200	0.377	3.129	1.309	0.125	1.020	1.679
1991	11278	3.201	0.395	3.224	1.348	0.128	1.044	1.741
1992	12151	2.257	0.313	2.436	1.019	0.131	0.785	1.323
1993	11559	2.912	0.369	2.494	1.043	0.131	0.803	1.354
1994	12648	2.623	0.359	2.142	0.896	0.133	0.688	1.167
1995	13774	2.342	0.366	2.174	0.909	0.130	0.702	1.178
1996	12870	2.038	0.304	2.556	1.069	0.125	0.833	1.372
1997	12406	2.452	0.320	2.240	0.937	0.127	0.728	1.205
1998	12020	2.752	0.351	2.498	1.045	0.124	0.817	1.336
1999	9672	3.323	0.352	3.516	1.471	0.123	1.150	1.880
2000	9513	2.054	0.299	2.624	1.098	0.128	0.851	1.416
2001	10056	2.357	0.285	2.660	1.112	0.126	0.866	1.430
2002	9719	1.773	0.276	2.229	0.932	0.127	0.724	1.200
2003	9565	1.081	0.193	1.457	0.609	0.137	0.464	0.800
2004	9251	1.274	0.164	1.270	0.531	0.149	0.395	0.714
2005	7519	1.777	0.238	2.020	0.845	0.140	0.639	1.117
2006	7166	2.732	0.319	2.657	1.111	0.134	0.851	1.451
2007	8756	1.806	0.259	1.612	0.674	0.141	0.509	0.892
2008	8507	2.037	0.292	1.737	0.726	0.139	0.551	0.958
2009	8822	1.698	0.267	1.503	0.629	0.140	0.476	0.831
2010	7220	2.423	0.399	1.458	0.610	0.138	0.463	0.802
2011	7830	2.964	0.403	1.478	0.618	0.144	0.464	0.824
2012	10366	1.947	0.354	1.451	0.607	0.138	0.461	0.799
2013	9934	2.399	0.366	1.913	0.800	0.135	0.612	1.046
2014	8835	2.683	0.397	2.400	1.004	0.130	0.775	1.300

Table 9. Nominal and standardized catch rates of bigeye tuna in kg/1000 hooks (CPUEW).

year	nobs	obcpue	obppos	estcpue	STDCPUE	cv_i	LCI	UCI
1986	1456	5.333	0.365	143.876	1.448	0.213	0.951	2.207
1987	10862	3.631	0.341	245.308	2.470	0.135	1.886	3.233
1988	11613	2.973	0.346	154.089	1.551	0.141	1.172	2.053
1989	12728	3.354	0.391	155.301	1.564	0.138	1.188	2.057
1990	11868	3.200	0.377	148.979	1.500	0.138	1.139	1.975
1991	11278	3.201	0.395	155.272	1.563	0.142	1.179	2.072
1992	12151	2.257	0.313	117.720	1.185	0.144	0.890	1.578
1993	11559	2.912	0.369	98.492	0.992	0.144	0.744	1.321
1994	12648	2.623	0.359	88.436	0.890	0.146	0.666	1.190
1995	13774	2.342	0.366	85.090	0.857	0.143	0.644	1.139
1996	12870	2.038	0.304	98.725	0.994	0.138	0.755	1.309
1997	12406	2.452	0.320	82.675	0.832	0.140	0.630	1.099
1998	12020	2.752	0.351	91.343	0.920	0.137	0.701	1.207
1999	9672	3.323	0.352	145.431	1.464	0.137	1.115	1.922
2000	9513	2.054	0.299	105.722	1.064	0.141	0.804	1.408
2001	10056	2.357	0.285	113.428	1.142	0.139	0.866	1.506
2002	9719	1.773	0.276	70.739	0.712	0.139	0.540	0.940
2003	9565	1.081	0.193	52.383	0.527	0.149	0.392	0.709
2004	9251	1.274	0.164	49.090	0.494	0.161	0.359	0.681
2005	7519	1.777	0.238	78.650	0.792	0.153	0.584	1.074
2006	7166	2.732	0.319	99.742	1.004	0.148	0.748	1.347
2007	8756	1.806	0.259	72.836	0.733	0.154	0.540	0.997
2008	8507	2.037	0.292	74.275	0.748	0.153	0.552	1.013
2009	8822	1.698	0.267	58.270	0.587	0.153	0.433	0.795
2010	7220	2.423	0.399	53.466	0.538	0.151	0.399	0.727
2011	7830	2.964	0.403	51.875	0.522	0.157	0.382	0.714
2012	10366	1.947	0.354	55.791	0.562	0.152	0.415	0.759
2013	9934	2.399	0.366	66.871	0.673	0.148	0.501	0.904
2014	8835	2.683	0.397	83.982	0.846	0.144	0.635	1.126

Table 10. Standardized catch rates of bigeye tuna in kg/1000 hooks (CPUEN) for the four models.

YEAR	Continuity	cv	Model2 all areas	cv_i	Model3 restricted	cv_i
1986	3.466	0.250	2.551	0.231	2.891	0.197
1987	5.270	0.160	4.442	0.146	5.079	0.122
1988	3.730	0.170	2.790	0.157	3.215	0.128
1989	3.730	0.166	2.903	0.153	3.234	0.125
1990	2.466	0.180	2.760	0.155	3.129	0.125
1991	2.409	0.180	2.595	0.160	3.224	0.128
1992	2.160	0.185	2.104	0.165	2.436	0.131
1993	2.295	0.182	1.895	0.169	2.494	0.131
1994	2.213	0.182	1.644	0.173	2.142	0.133
1995	2.165	0.180	1.577	0.170	2.174	0.130
1996	2.184	0.177	1.980	0.160	2.556	0.125
1997	2.169	0.177	1.843	0.160	2.240	0.127
1998	2.485	0.172	2.118	0.156	2.498	0.124
1999	2.665	0.180	2.874	0.153	3.516	0.123
2000	2.377	0.181	2.119	0.162	2.624	0.128
2001	2.927	0.170	2.506	0.155	2.660	0.126
2002	2.798	0.166	2.241	0.154	2.229	0.127
2003	1.408	0.199	1.475	0.170	1.457	0.137
2004	0.956	0.215	1.009	0.184	1.270	0.149
2005	1.650	0.195	1.611	0.172	2.020	0.140
2006	1.997	0.188	1.960	0.167	2.657	0.134
2007	1.426	0.199	1.372	0.174	1.612	0.141
2008	1.316	0.198	1.403	0.173	1.737	0.139
2009	1.257	0.205	1.251	0.174	1.503	0.140
2010	1.191	0.194	1.156	0.173	1.458	0.138
2011	1.278	0.205	1.167	0.181	1.478	0.144
2012	1.281	0.197	1.094	0.177	1.451	0.138
2013	1.728	0.184	1.577	0.168	1.913	0.135
2014	1.964	0.177	1.849	0.162	2.400	0.130

Table 11. Standardized catch rates of bigeye tuna in number by year and season, where seasons are: 1(Jan-Mar), 2(Apr-Jun), 3(July-Sep), 4(Oct-Dec).

year_season	nobs	obcpue	obppos	estcpue	STDCPUE	cv_i	LCI	UCI
19863	33	8.295	0.545	7.124	2.575	0.240	1.605	4.133
19864	1421	5.272	0.362	6.601	2.386	0.045	2.179	2.613
19871	2453	3.527	0.329	3.856	1.394	0.038	1.292	1.504
19872	2734	2.231	0.257	3.723	1.346	0.039	1.244	1.456
19873	3411	3.923	0.382	4.328	1.564	0.029	1.476	1.658
19874	2264	4.996	0.394	7.206	2.605	0.033	2.437	2.784
19881	2897	1.979	0.274	4.047	1.463	0.037	1.359	1.575
19882	2503	2.147	0.284	4.192	1.515	0.039	1.402	1.637
19883	3438	2.556	0.365	2.858	1.033	0.030	0.972	1.098
19884	2775	5.271	0.452	6.165	2.229	0.029	2.104	2.360
19891	3401	2.180	0.303	3.886	1.405	0.032	1.316	1.499
19892	2587	1.762	0.305	2.553	0.923	0.038	0.856	0.996
19893	3728	4.096	0.456	3.897	1.409	0.026	1.337	1.484
19894	3012	5.129	0.484	5.158	1.864	0.027	1.766	1.969
19901	3293	2.571	0.325	3.422	1.237	0.032	1.159	1.320
19902	2286	1.242	0.248	1.699	0.614	0.046	0.560	0.673
19903	3698	2.523	0.4	2.399	0.867	0.029	0.819	0.918
19904	2591	6.693	0.525	6.458	2.334	0.028	2.209	2.467
19911	2642	2.319	0.282	2.354	0.851	0.040	0.785	0.922
19912	2160	1.503	0.217	1.807	0.653	0.050	0.591	0.722
19913	3753	3.882	0.493	4.193	1.516	0.025	1.443	1.592
19914	2723	4.465	0.512	4.661	1.685	0.028	1.594	1.780
19921	2977	1.666	0.268	2.169	0.784	0.038	0.726	0.846
19922	2701	0.927	0.174	1.376	0.497	0.050	0.450	0.550
19923	3957	2.996	0.362	2.380	0.860	0.029	0.811	0.912
19924	2516	3.221	0.435	3.354	1.212	0.032	1.137	1.292
19931	2539	1.672	0.269	1.915	0.692	0.042	0.636	0.753
19932	2371	0.812	0.17	1.411	0.510	0.054	0.458	0.568
19933	4152	3.984	0.459	3.715	1.343	0.025	1.278	1.411
19934	2497	4.383	0.508	4.741	1.714	0.029	1.618	1.815
19941	2611	2.106	0.265	1.567	0.566	0.043	0.520	0.617
19942	2864	1.005	0.188	1.260	0.456	0.047	0.415	0.500
19943	4010	2.892	0.41	2.841	1.027	0.027	0.974	1.083
19944	3163	4.176	0.526	4.838	1.749	0.025	1.663	1.839
19951	3153	1.415	0.275	2.032	0.734	0.037	0.683	0.790
19952	3227	0.976	0.22	1.497	0.541	0.041	0.499	0.587
19953	4879	2.702	0.43	2.728	0.986	0.023	0.941	1.034
19954	2515	4.557	0.543	4.715	1.705	0.027	1.613	1.801
19961	2573	1.433	0.272	2.226	0.805	0.040	0.742	0.872
19962	3229	1.216	0.222	1.807	0.653	0.041	0.603	0.708
19963	4449	2.409	0.373	2.382	0.861	0.027	0.816	0.909
19964	2619	3.015	0.321	4.009	1.449	0.035	1.350	1.555
19971	3100	1.563	0.25	1.961	0.709	0.040	0.655	0.767

19972	2388	1.864	0.252	1.553	0.561	0.047	0.511	0.617
19973	4458	2.763	0.332	2.565	0.927	0.029	0.876	0.982
19974	2460	3.582	0.451	4.152	1.501	0.030	1.412	1.595
19981	2637	1.894	0.267	1.869	0.676	0.041	0.622	0.734
19982	2410	1.462	0.23	1.271	0.460	0.049	0.417	0.507
19983	3822	2.675	0.378	2.374	0.858	0.029	0.810	0.909
19984	3151	4.552	0.481	5.729	2.071	0.025	1.968	2.179
19991	1942	2.158	0.286	3.587	1.297	0.043	1.190	1.412
19992	2288	2.266	0.261	3.122	1.128	0.043	1.035	1.230
19993	2824	4.093	0.391	4.486	1.621	0.032	1.522	1.728
19994	2618	4.278	0.437	6.067	2.193	0.029	2.068	2.325
20001	1811	2.348	0.262	2.895	1.046	0.048	0.950	1.153
20002	2250	1.667	0.224	2.039	0.737	0.048	0.670	0.811
20003	3031	1.944	0.296	2.058	0.744	0.036	0.692	0.799
20004	2421	2.331	0.4	3.913	1.415	0.031	1.329	1.506
20011	1662	2.341	0.267	2.277	0.823	0.051	0.743	0.912
20012	2704	1.749	0.231	2.245	0.811	0.043	0.745	0.884
20013	3417	2.051	0.261	2.021	0.731	0.037	0.679	0.786
20014	2273	3.550	0.397	4.686	1.694	0.033	1.585	1.810
20021	1879	2.532	0.328	2.352	0.850	0.044	0.779	0.928
20022	2572	1.018	0.185	1.177	0.425	0.051	0.384	0.471
20023	3130	1.621	0.247	1.813	0.655	0.039	0.606	0.709
20024	2138	2.238	0.384	4.541	1.641	0.034	1.535	1.755
20031	1994	1.479	0.288	1.801	0.651	0.045	0.595	0.712
20032	2556	0.412	0.088	0.612	0.221	0.074	0.191	0.256
20033	2786	0.491	0.129	0.654	0.236	0.058	0.210	0.266
20034	2229	2.228	0.306	3.027	1.094	0.039	1.011	1.184
20041	1937	1.048	0.165	0.997	0.360	0.062	0.318	0.408
20042	2856	0.123	0.049	0.372	0.134	0.093	0.112	0.162
20043	2333	0.868	0.123	0.762	0.276	0.065	0.242	0.314
20044	2125	3.472	0.363	5.506	1.990	0.035	1.856	2.134
20051	2018	0.961	0.263	2.055	0.743	0.045	0.679	0.812
20052	2296	0.460	0.1	1.034	0.374	0.071	0.324	0.431
20053	1909	2.359	0.247	2.024	0.732	0.050	0.662	0.809
20054	1296	4.526	0.434	5.064	1.830	0.042	1.684	1.989
20061	1209	1.662	0.294	2.613	0.945	0.055	0.847	1.054
20062	1910	1.135	0.181	1.442	0.521	0.058	0.464	0.586
20063	2263	3.574	0.331	3.342	1.208	0.039	1.119	1.305
20064	1784	4.098	0.47	5.938	2.147	0.032	2.012	2.291
20071	1605	1.735	0.281	3.062	1.107	0.048	1.006	1.217
20072	2030	0.850	0.147	1.005	0.363	0.064	0.320	0.412
20073	2791	2.134	0.271	1.958	0.708	0.039	0.655	0.765
20074	2330	2.294	0.326	2.822	1.020	0.037	0.947	1.099
20081	1635	1.597	0.3	1.363	0.493	0.051	0.445	0.546
20082	2230	0.770	0.162	0.798	0.288	0.058	0.257	0.324
20083	2498	2.715	0.296	1.763	0.637	0.041	0.587	0.691

20084	2144	2.901	0.416	3.528	1.275	0.034	1.193	1.364
20091	1520	1.411	0.243	1.098	0.397	0.060	0.352	0.447
20092	2297	0.889	0.168	0.938	0.339	0.056	0.303	0.380
20093	2816	1.962	0.281	1.679	0.607	0.039	0.561	0.656
20094	2189	2.404	0.369	2.626	0.949	0.037	0.881	1.022
20101	1653	1.287	0.281	1.332	0.481	0.052	0.434	0.534
20102	2183	0.918	0.187	0.616	0.223	0.056	0.199	0.249
20103	2008	4.054	0.608	2.272	0.821	0.032	0.771	0.875
20104	1376	3.795	0.573	2.460	0.889	0.039	0.823	0.961
20111	1258	1.811	0.36	0.791	0.286	0.056	0.256	0.320
20112	1931	2.070	0.295	1.291	0.467	0.047	0.425	0.513
20113	2398	3.450	0.452	2.692	0.973	0.033	0.911	1.039
20114	2243	3.862	0.466	3.611	1.305	0.032	1.224	1.392
20121	2099	1.181	0.293	0.875	0.316	0.047	0.288	0.348
20122	2539	1.249	0.237	1.107	0.400	0.045	0.366	0.438
20123	3094	3.167	0.476	2.925	1.057	0.027	1.001	1.117
20124	2634	1.796	0.373	1.993	0.720	0.034	0.673	0.772
20131	1971	2.169	0.365	1.748	0.632	0.043	0.580	0.689
20132	2576	0.847	0.188	0.904	0.327	0.050	0.295	0.361
20133	3064	3.209	0.44	2.688	0.972	0.029	0.917	1.030
20134	2323	3.245	0.468	2.555	0.924	0.033	0.864	0.987
20141	1762	2.349	0.394	1.622	0.586	0.044	0.536	0.640
20142	2331	1.159	0.239	1.111	0.401	0.047	0.366	0.441
20143	2715	4.268	0.506	4.015	1.451	0.028	1.373	1.534
20144	2027	2.604	0.433	2.585	0.935	0.036	0.870	1.004

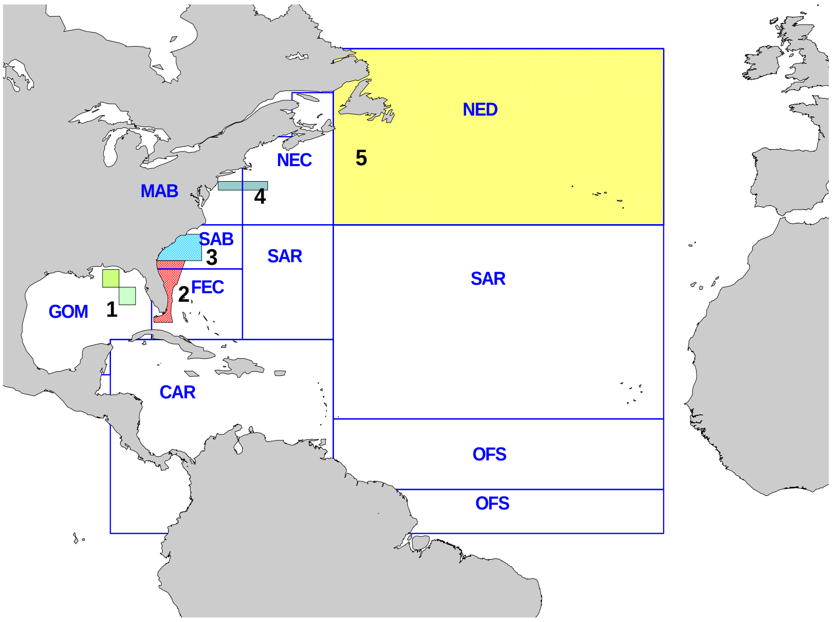

Figure 1. Geographical areas for the US Pelagic Longline fishery: CAR Caribbean, GOM Gulf of Mexico, FEC Florida east coast, SAB South Atlantic bight, MAB mid Atlantic bight, NEC North east coastal Atlantic, NED North east distant waters, SNA Sargasso Sea, and OFS Offshore waters. Shaded areas represent the current time-area closures affecting the pelagic longline fisheries. Permanent closures: (1) the DeSoto Canyon in the Gulf of Mexico and (2) The Florida east coast areas. Non-permanent closures: (3) the Charleston Bump area closed Feb-Apr, (4) the Bluefin tuna protection area closed in June, and (5) the Grand Banks closed since Oct-2000. Note that these are the old area definitions.

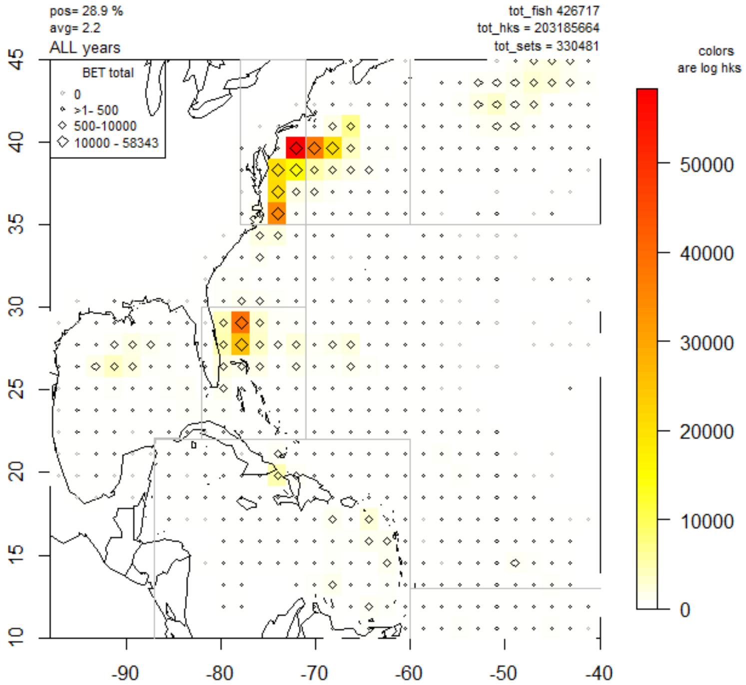

Figure 2. Spatial distribution of catch and effort in the US Pelagic longline fishery for selected years 1987-2013. Scale is log (hooks set) per grid cell. Cell size is approximately 40 x 40 nautical miles.

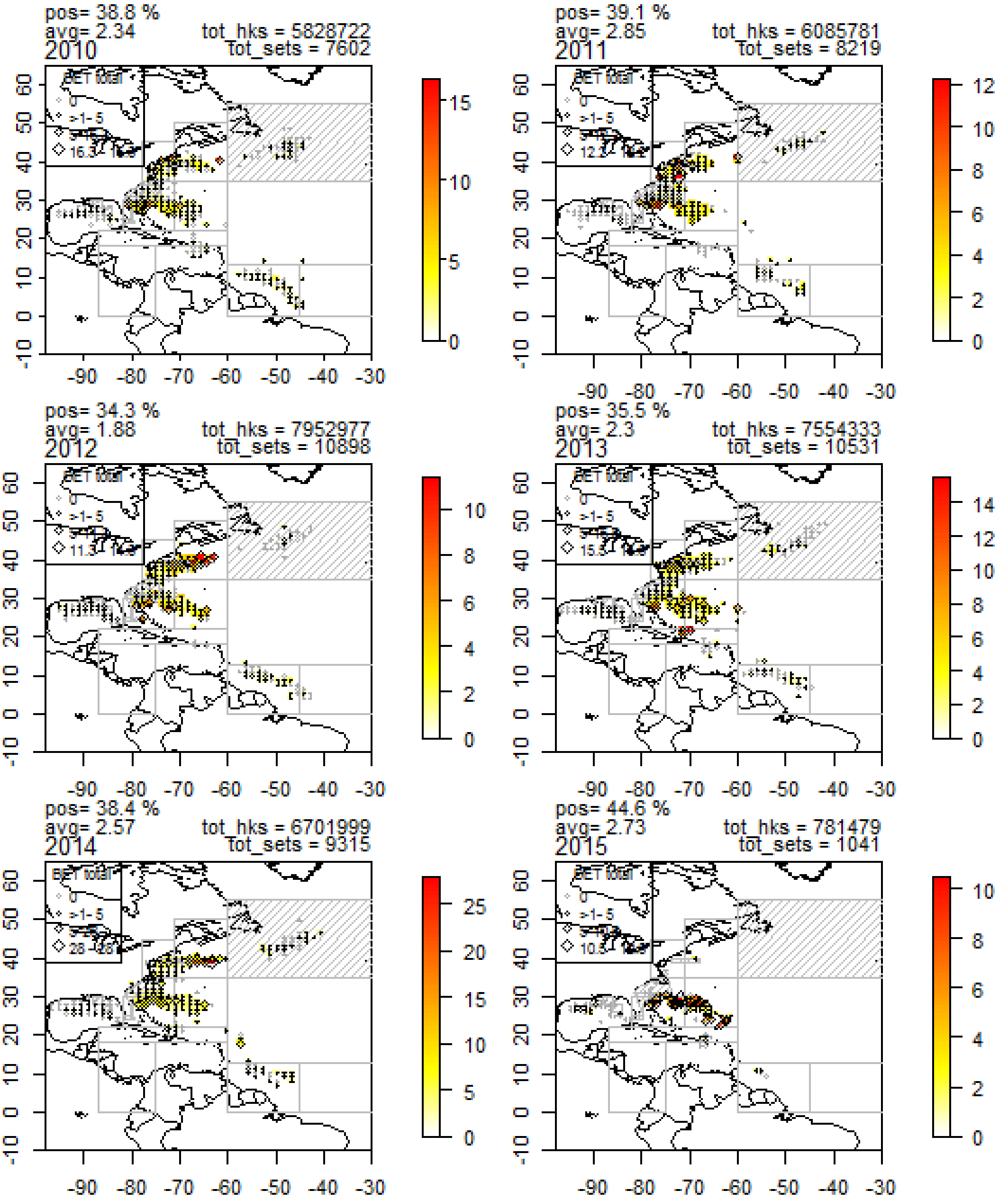

Figure 3. Spatial distribution of catch and effort in the US Pelagic longline fishery for selected years 1987-2013. Scale is log (hooks set) per grid cell. Cell size is approximately 40 x 40 nautical miles.

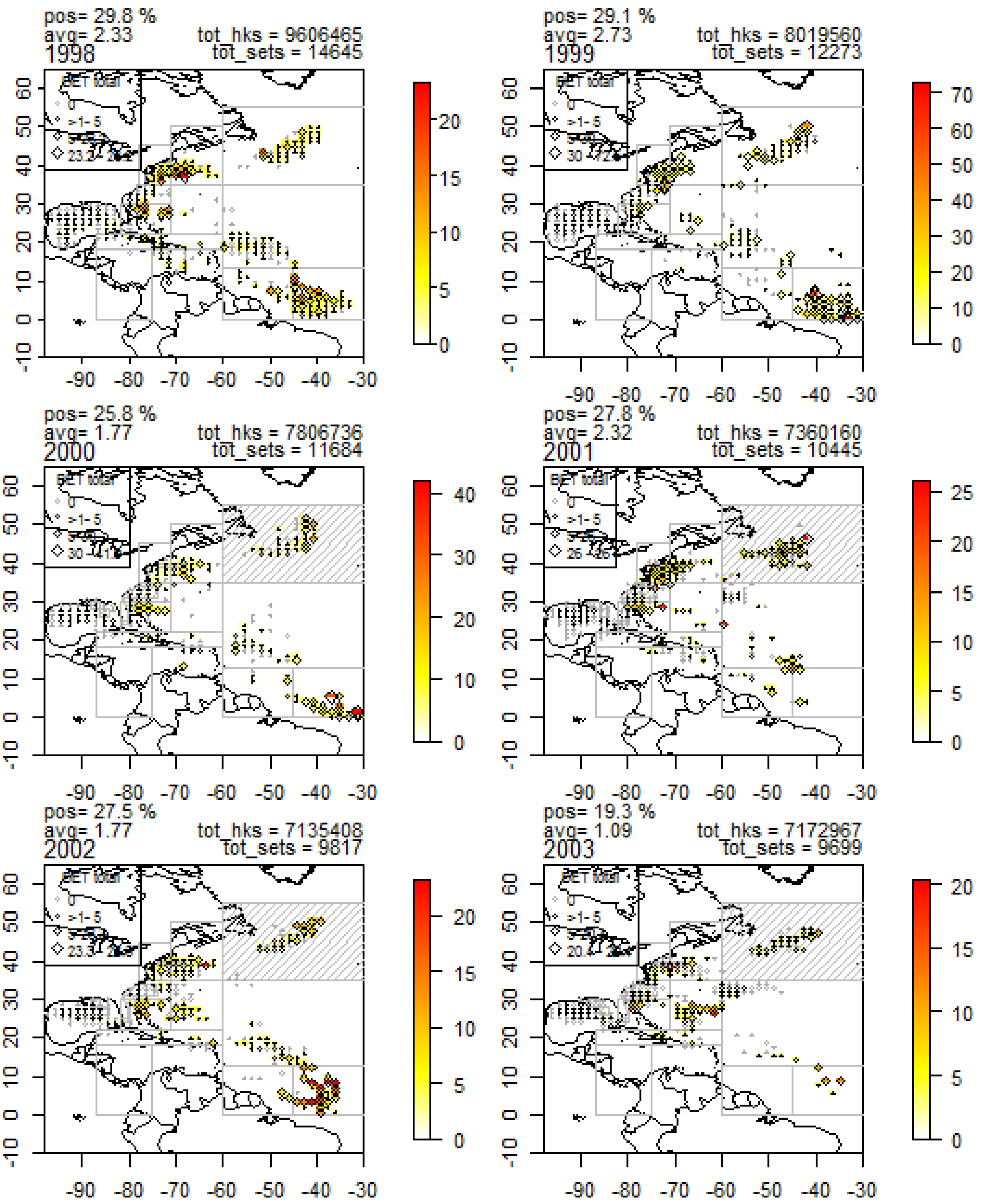

Figure 3. cont.

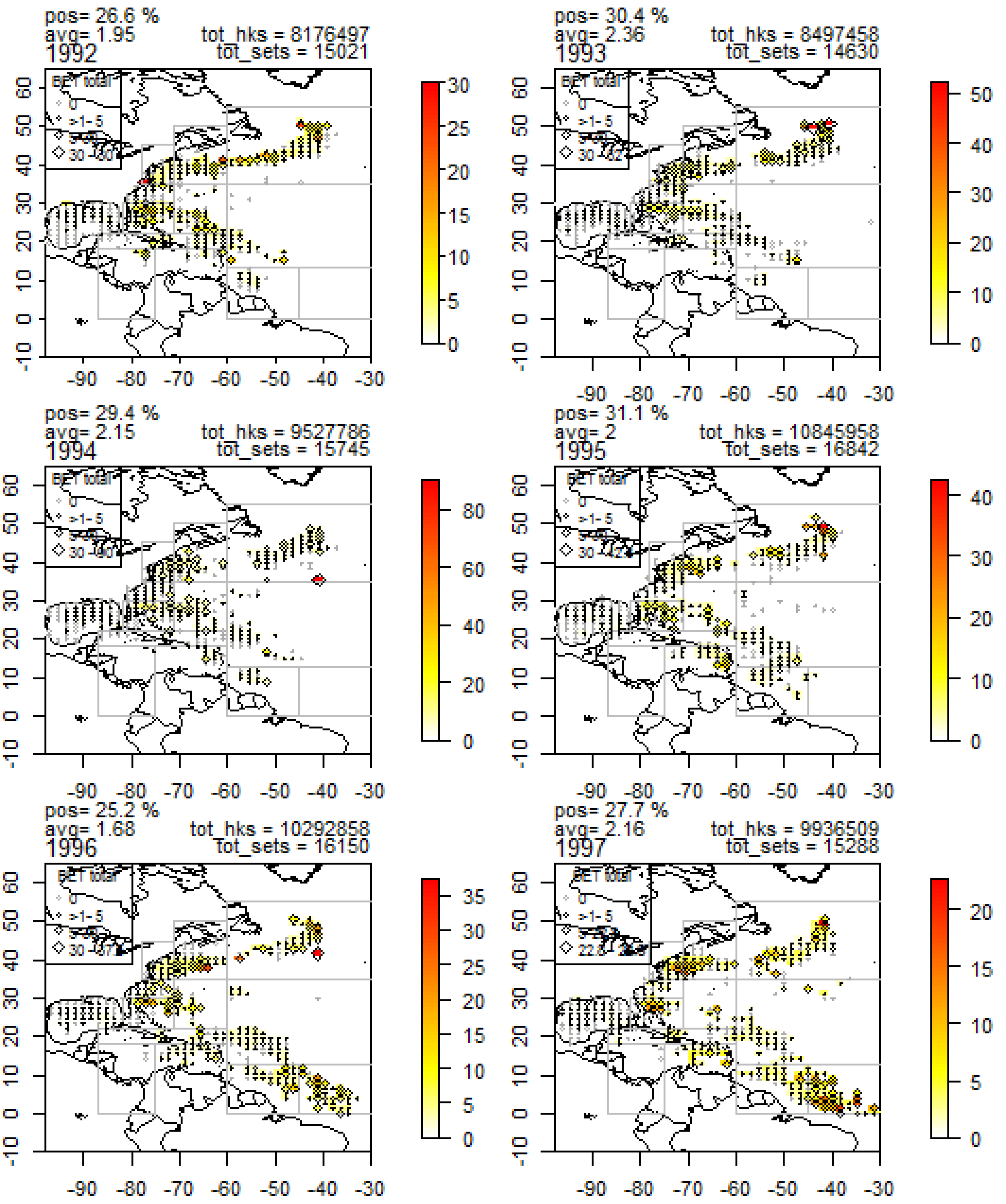

Figure 3. cont.

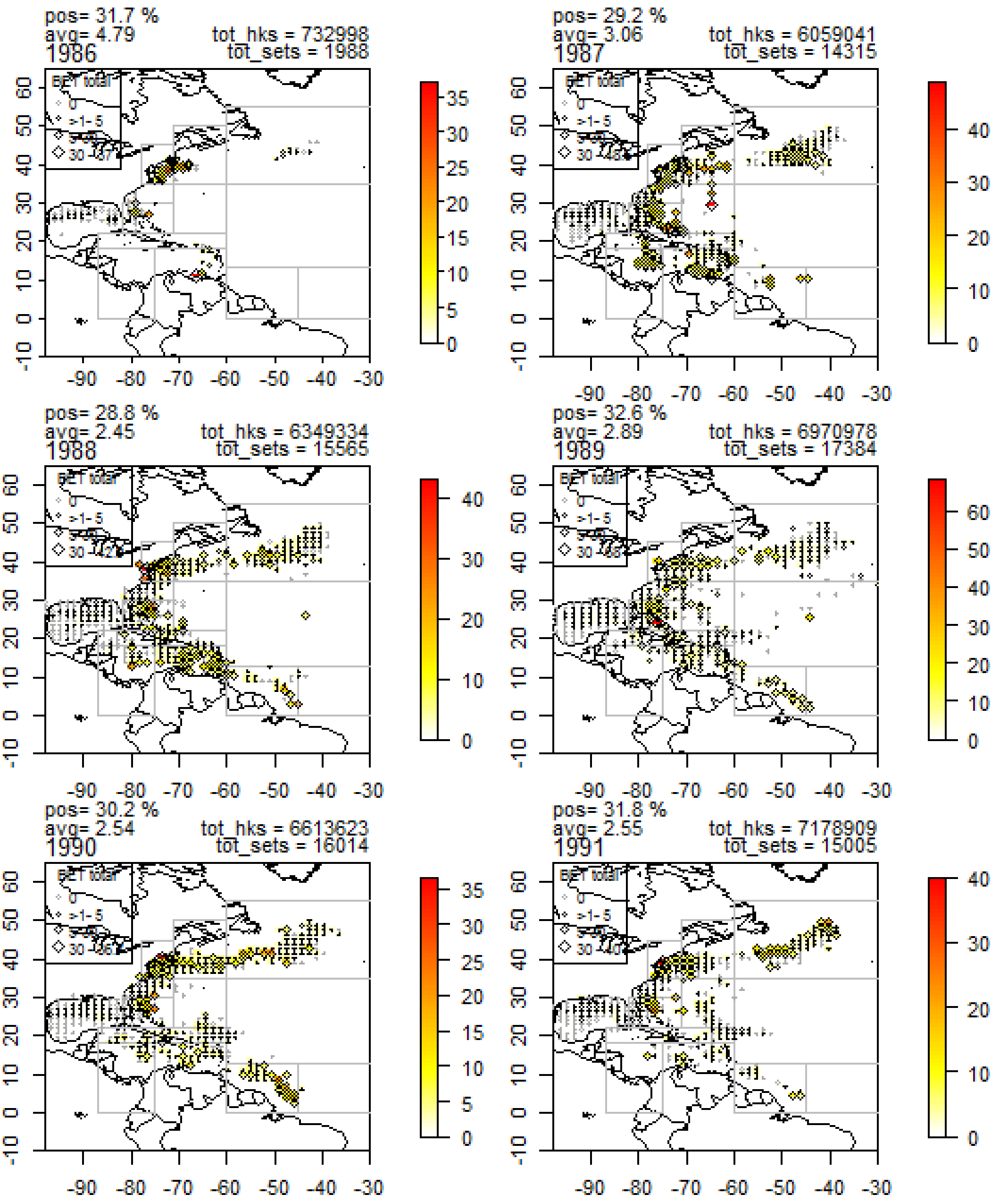

Figure 3. cont.

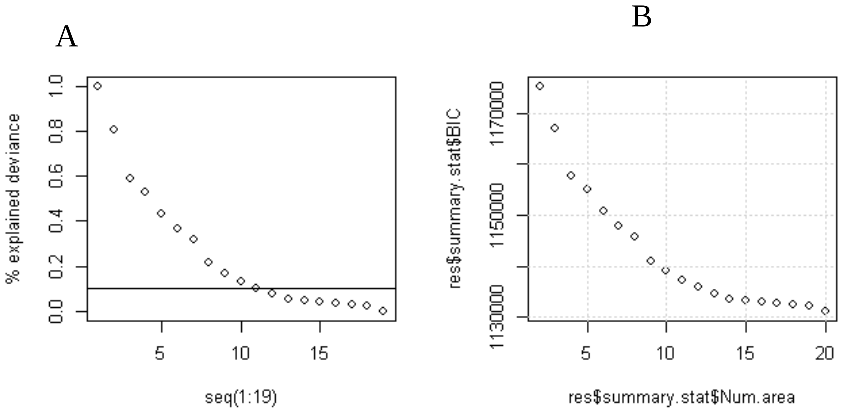

Figure 3. A. Percent of deviance explained and B. Bayesian information criterion as a function of the number of area splits. The horizontal line is the 0.10 value used as the cutoff value.

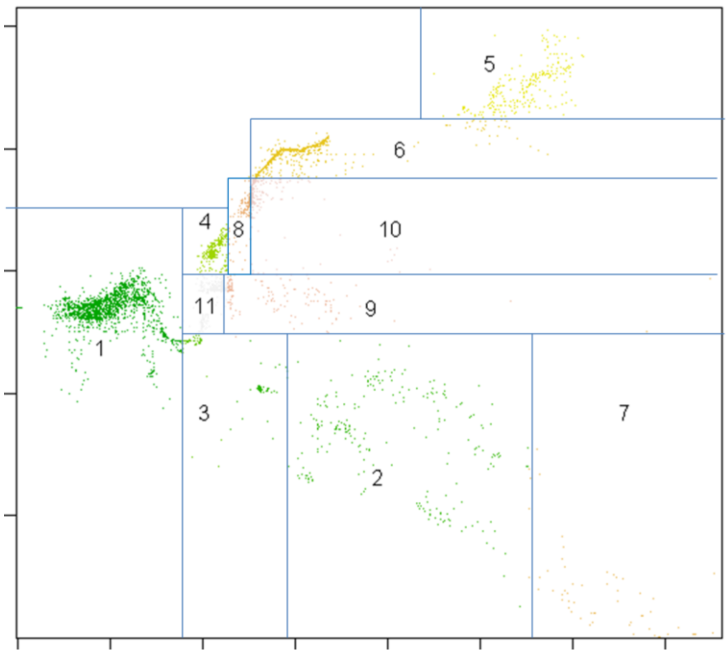

Figure 4. Adaptive areas as defined by the algorithm of Ichinokawa and Brodziak (2010).

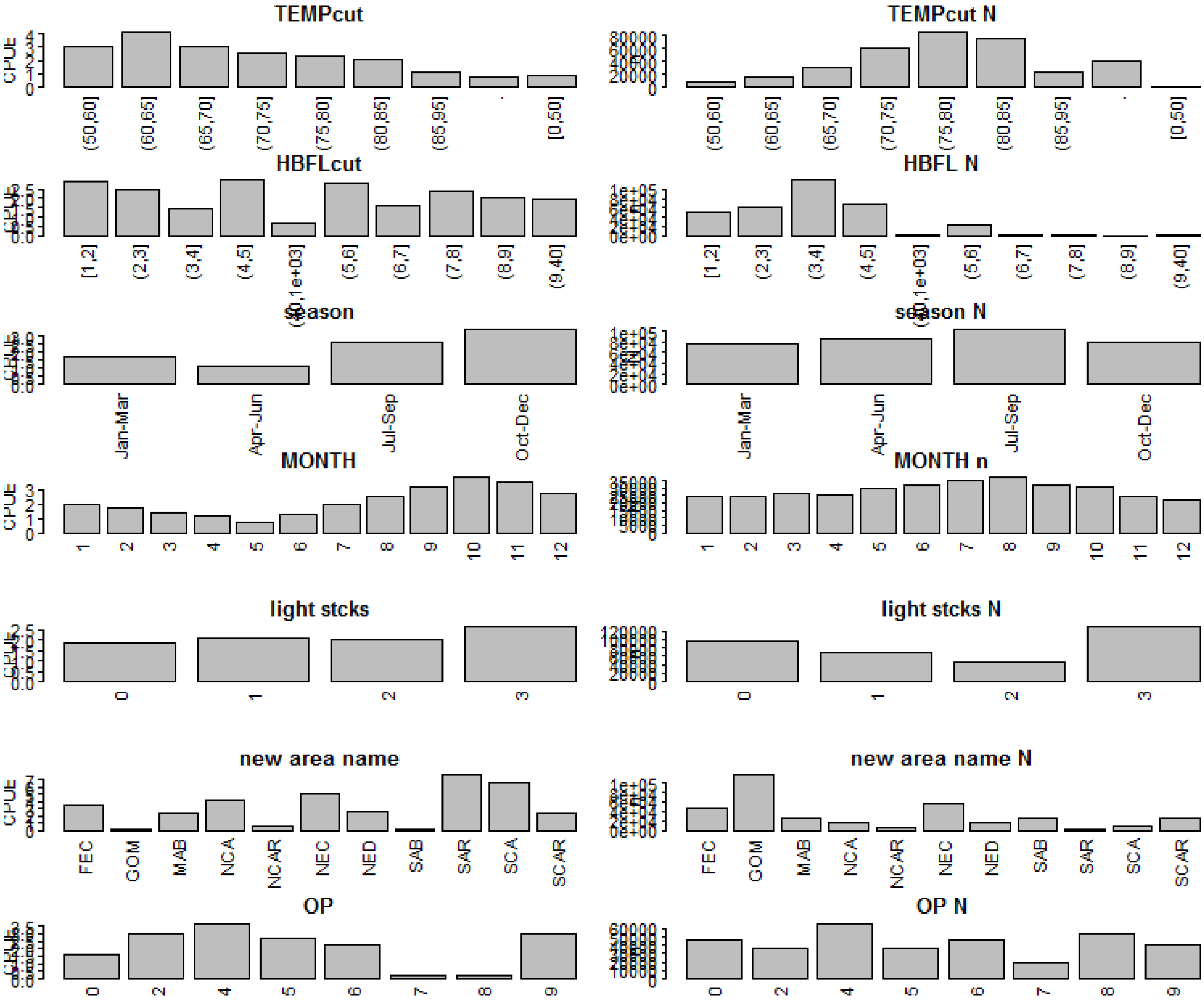

Figure 5. Number of BET/1000 hooks by factor levels from pelagic longline logbook data.

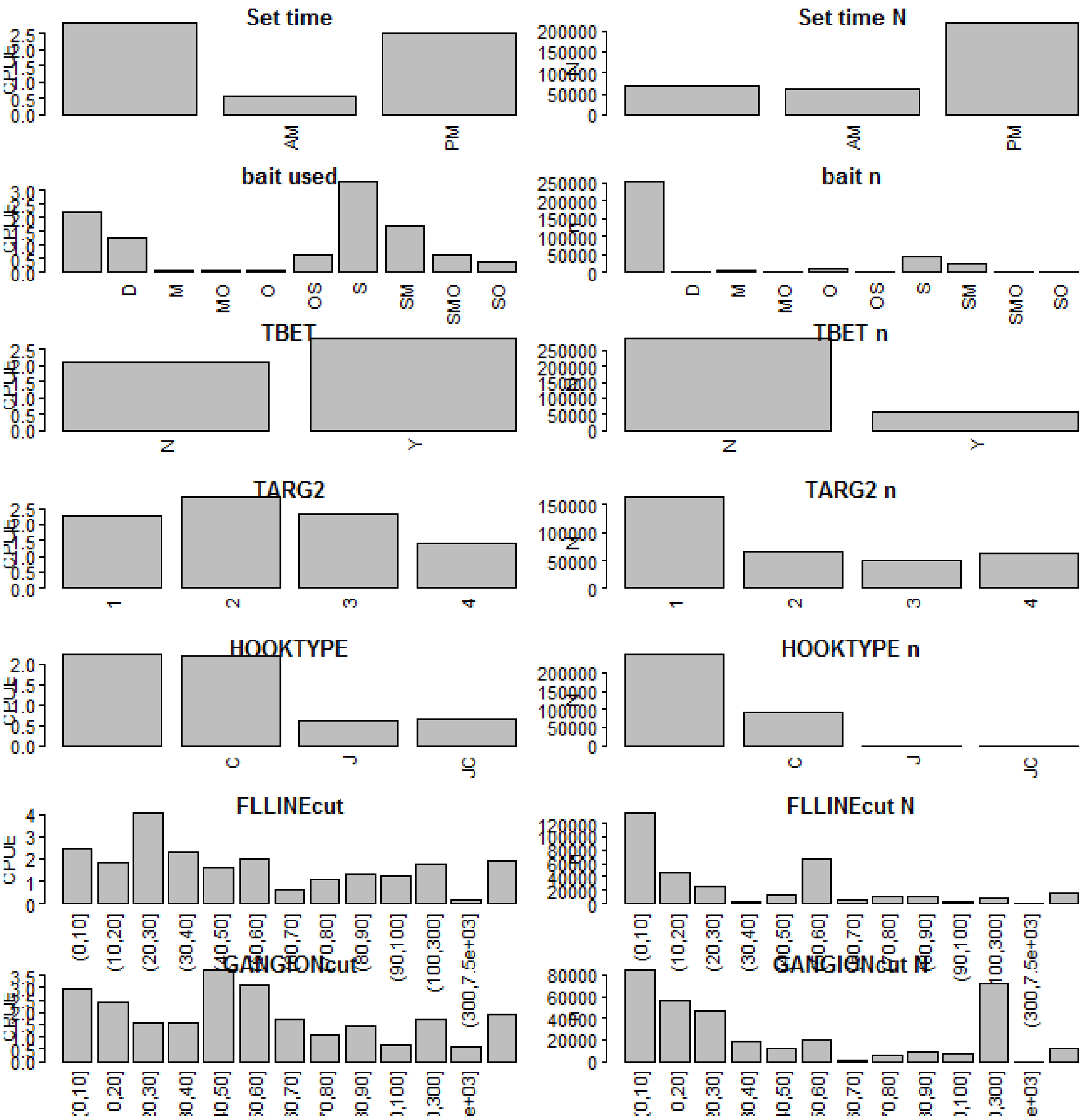

Figure 6. Number of BET/1000 hooks by factor levels from pelagic longline logbook data.

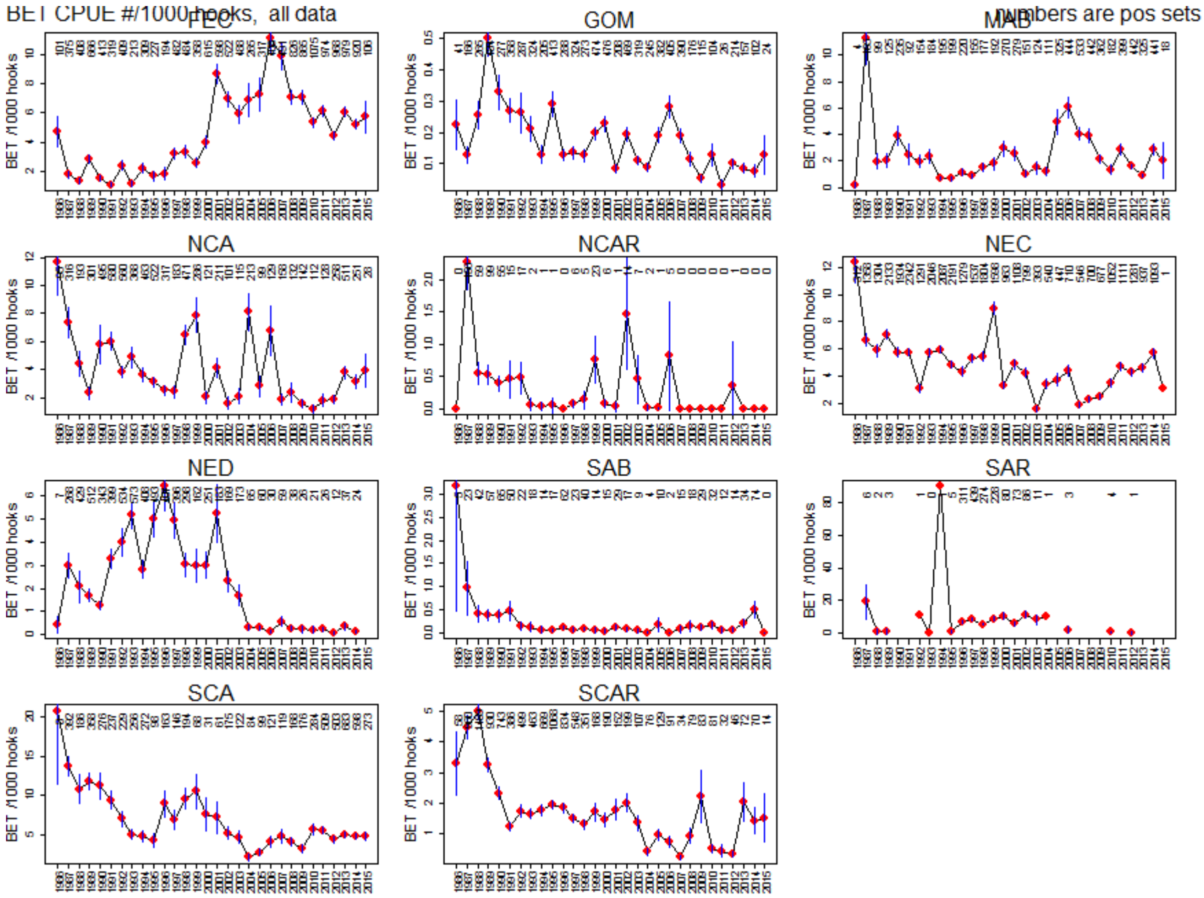

Figure 7. Nominal bigeye tuna catch per 1000 hooks for each area from logbook data with revised areas. Upper and lower limits are 95% confidence intervals. Numbers are the total number of daily logbook sets reporting positive bigeye catches.

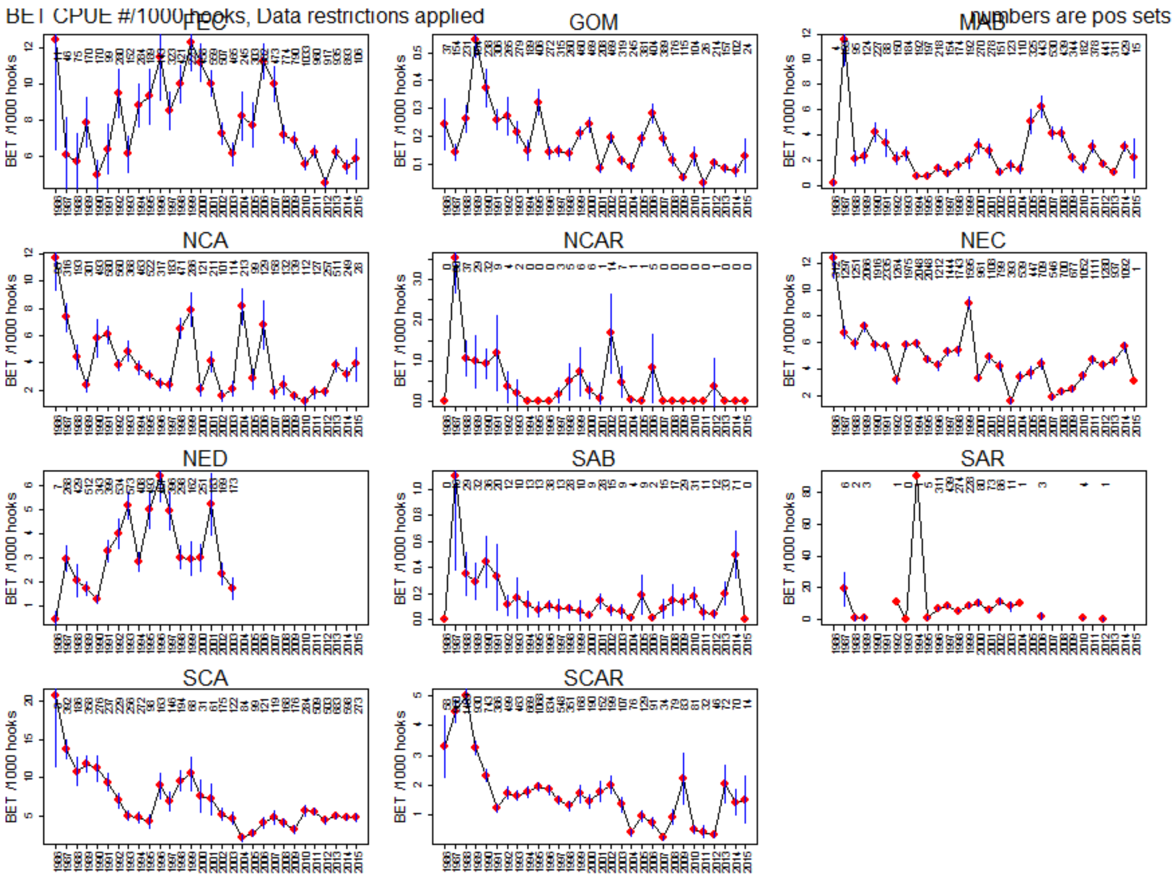

Figure 8. Nominal bigeye tuna catch per 1000 hooks for each area from logbook data with revised areas and removal of closed areas or observations that were clearly influenced by management measures. Upper and lower limits are 95% confidence intervals. Numbers are the total number of daily logbook sets reporting positive bigeye catches.

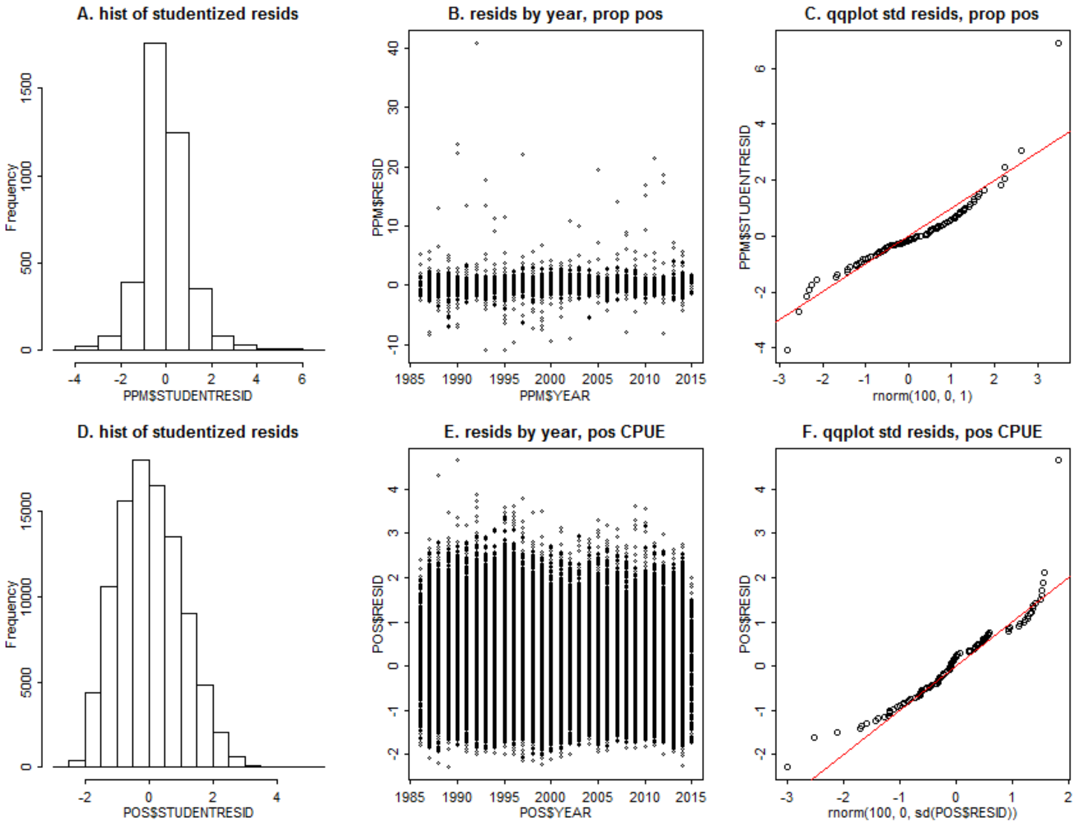

Figure 9. Diagnostic plots for the model 3. Top row, for binomial submodel, (A) overall studentized residuals, (B) raw residuals by year and (C) qq plot of residuals. Bottom row, for lognormal submodel (D) histogram of studentized residuals, (E) raw residuals by year and (F) qq plot of residuals.

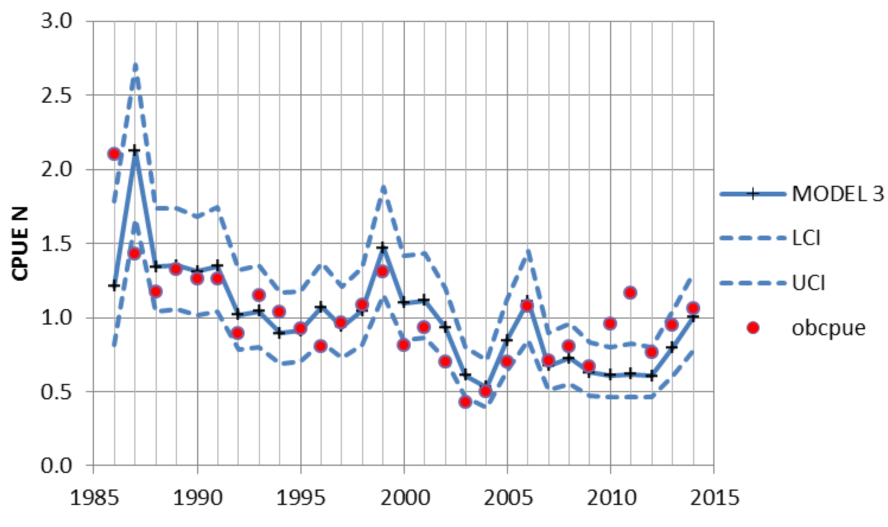

Figure 10. Standardized logbook bigeye tuna CPUE in number per 1000 hooks.

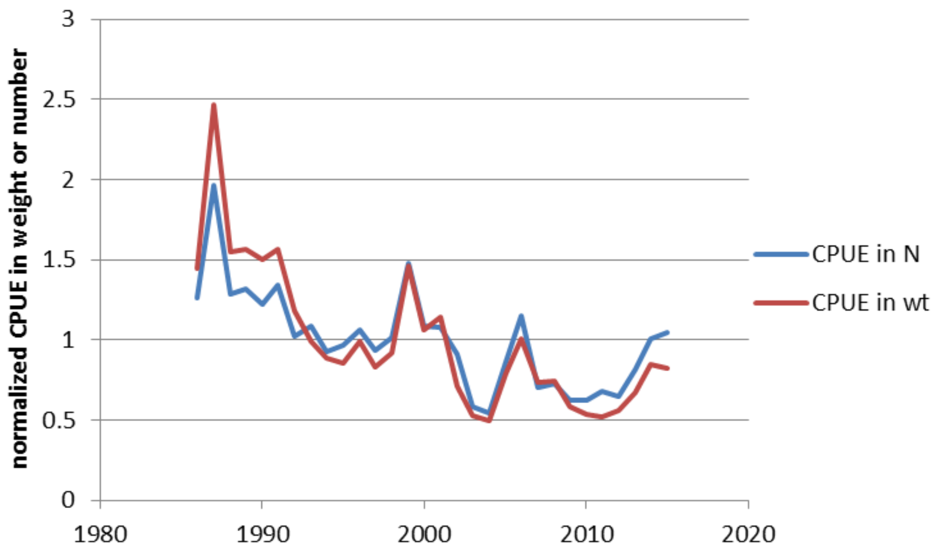

Figure 11. Standardized CPUE in weight and number R^2=0.94.

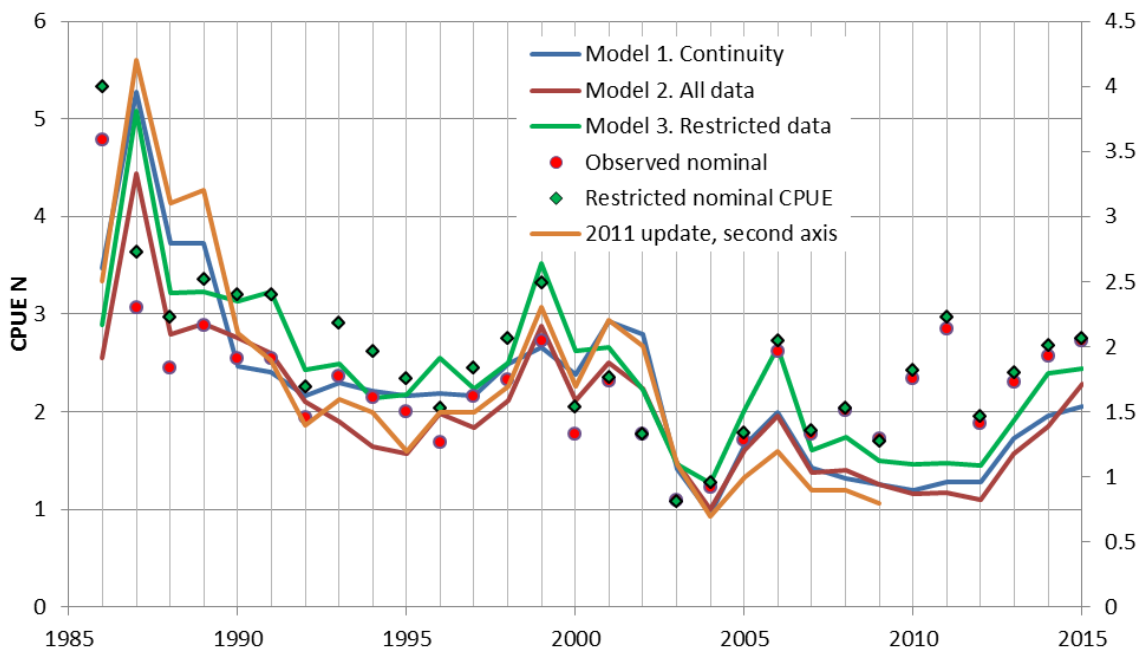

Figure 12. CPUE in number for models 1-3 and nominal CPUE. Orange line is the 2011 index from Ortiz and Calay (2011).

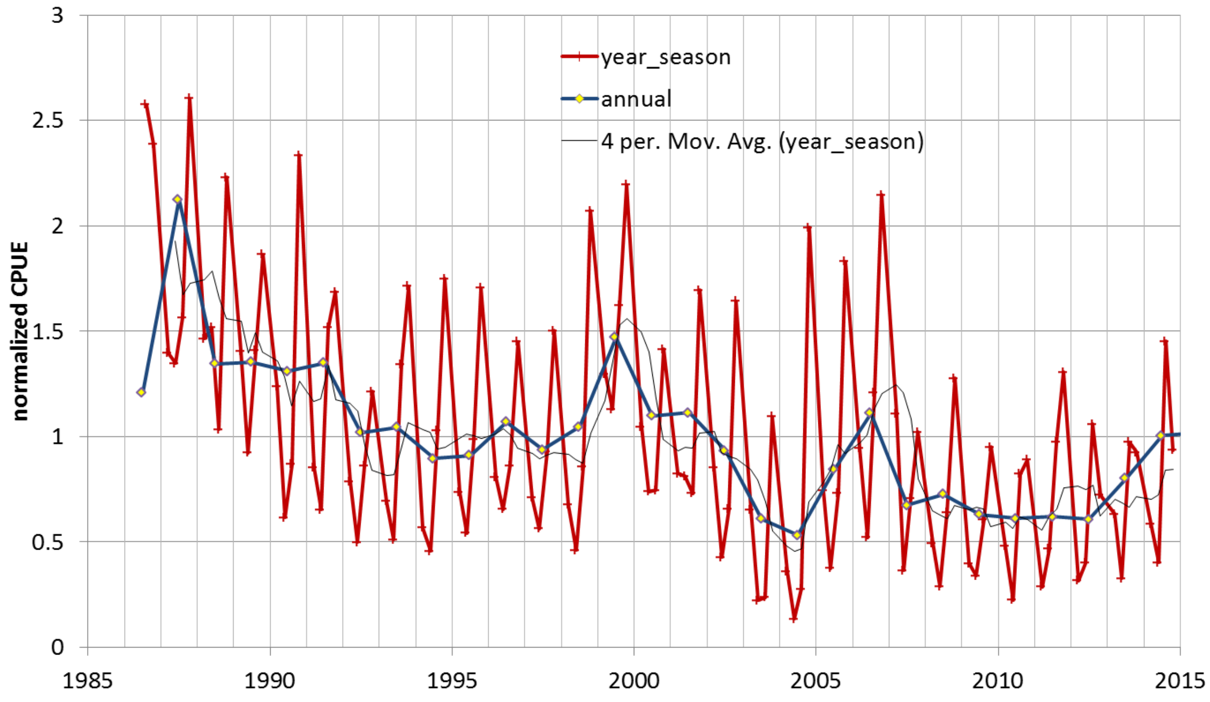

Figure 13. CPUE in number for model 3 annual (blue) and by season (red) the thin black line is a four point moving average of the seasonal means.