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SAILFISH (*ISTIOPHORUS PLATYPTERUS*) CATCH RATES FROM THE U.S. PELAGIC LONGLINE FISHERY IN THE NORTHWEST ATLANTIC AND GULF OF MEXICO 1992-2014

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SUMMARY

Indices of abundance of sailfish (Istiophorus platypterus) for the U.S. pelagic longline fishery in the Northwest Atlantic and U.S. Gulf of Mexico are presented for the period 1992-2014. The index of weight (kg) per thousand hooks was estimated from the number of captured sailfish and from mean weight estimated from observations obtained by scientific observers aboard longline vessels since 1992 (Pelagic Observer Program). The standardization analysis procedure included the following variables: year, area of fishing, gear characteristics (e.g., main line size, number of hooks, light sticks, bait type, depth of gear etc.), and fishing characteristics (e.g., depth of fishing, target species, sea surface temperature etc.). The standardized indexes were estimated using Generalized Linear Mixed Models under a Delta lognormal model approach.

RÉSUMÉ

*Le présent document décrit les indices d'abondance des voiliers (*Istiophorus platypterus*) pour la pêcherie palangrière pélagique des Etats-Unis opérant dans l'Atlantique Nord-Ouest et le Golfe du Mexique des Etats-Unis pour la période 1992-2014. L'indice pondéral (kg) pour mille hameçons a été estimé à partir du nombre de voiliers capturés et des poids moyens estimés par les observations obtenues des observateurs scientifiques embarqués à bord de palangriers depuis 1992 (Programme d'observateurs pélagiques). La procédure d'analyse de la standardisation a inclus les variables suivantes : année, zone de pêche, caractéristiques des engins (p.ex. taille de la ligne principale, nombre d'hameçons, baguettes lumineuses, type d'appât, profondeur de l'engin, etc.) et caractéristiques de la pêche (p.ex. profondeur de la pêche, espèces cibles, température à la surface de la mer, etc.). Les indices standardisés ont été estimés à l'aide de modèles mixtes linéaires généralisés selon une approche du modèle delta-lognormale.*

RESUMEN

*Se presentan, para el periodo 1992-2014, índices de abundancia de pez vela (*Istiophorus platypterus*) para la pesquería de palangre pelágico estadounidense en el Atlántico noroccidental y en el golfo de México estadounidense. Se estimó el índice de peso (kg) por mil anzuelos a partir del número de peces vela capturados y a partir del peso medio estimado con las observaciones obtenidas por observadores científicos a bordo de palangreros desde 1992 (Programa de observadores pelágicos). El procedimiento de análisis de estandarización incluía las siguientes variables: año, zona de pesca, características del arte (por ejemplo, tamaño de la línea madre, número de anzuelos, bastones de luz, tipo de cebo, profundidad del arte, etc.) y las características pesqueras (por ejemplo, profundidad de la pesca, especie objetivo, temperatura de la superficie del mar, etc.). Los índices estandarizados se estimaron utilizando modelos lineales mixtos generalizados con un enfoque del modelo delta lognormal.*

KEYWORDS

Catch/effort, Longlining, Sailfish

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1. Introduction

This paper presents two indices of catch rates for Atlantic sailfish (*Istiophorus platypterus*) obtained using observer program collected data from the United States pelagic longline (PLL) fleet. The U.S. PLL fleet operates across a wide area of the western North Atlantic Ocean, Gulf of Mexico and the Caribbean Sea, where swordfish (*Xiphias gladius*) and tunas are the primary target species. Istiophorid billfishes are neither targeted nor landed by the fleet, but are still subject to incidental catch. A previous version of this index used both logbook and observer data but the authors feel that an observer-only based index is likely more reflective of catch rates of a bycatch species (Ortiz *et al.* 2009).

2. Materials and Methods

Data sets

Since 1992, the U.S. PLL fleet has been sampled by the Pelagic Observer Program (POP), which places trained observers aboard commercial longliners to record detailed information on gear characteristics, fishing operations and biological and morphometric information pertaining to catch, and bycatch, which would not otherwise be collected. The target coverage percentage is 8% of the fishing sets deployed in each location/quarter stratum, however under special research programs and for limited periods of time the coverage of the fleet has been expanded in certain regions up to 100% (Beerkircher *et al.* 2009). The POP data provides detailed fishing information, which allows evaluation of relationships between sailfish catch rates and other factors such as environmental (*e.g.* sea surface temperature, wind direction and intensity, and general weather conditions), gear configurations and characteristics (main line type and length; gangion type and length; hook type, size, and density per unit of main line; floats number and density; rattlers; light sticks; surface light-buoys; *etc.*), and fishing operations (bait type, condition, and number; depth of set; soaking time; etc.).

The longline fishing grounds for the U.S. PLL fleet extend from the Grand Banks in the North Atlantic to latitudes of 5-10°S, off the South America coast, including the Caribbean Sea and the Gulf of Mexico (**Figure 1**). Ten geographical locations of PLL fishing were used for the analysis: the Caribbean (CAR), Gulf of Mexico (GOM), Florida East Coast (FEC), South Atlantic Bight (SAB), Mid-Atlantic Bight (MAB), New England Coastal (NEC), Sargasso Sea (SAR), North Central Atlantic (NCA), Tuna North (TUN; between 5°N and 13°N latitude) and Tuna South (TUS; between 0° and 5°N latitude).

The fishery has operated under several time-area restrictions since 2000, due to management regulations related to swordfish and other species (**Figure 2**). These restrictions include: the Desoto Canyon closure in the Gulf of Mexico (effective in 2000), the Florida East Coast closure (effective in 2001), and the Grand Banks closure (closed from July 17th 2001 – January 9th 2002). Two time-area closures also occurred: the Charleston Bump off the North Carolina coast (closed from February 1st – April 30th starting in 2001), the Bluefin Tuna Protection Area off the New England Coast (closed from June 1st – June 30th starting in 1999). The most recent time/area closure impact the Gulf of Mexico and prohibits longlining during April and May starting in 2015. For the present study, any sets located in closed areas prior to or after the closure were removed from the data set. For time-area closures, we removed data for that area and during the closed months from all years.

Calendar quarters were used to account for seasonal fishery distribution through the year (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec). Other factors included in the analyses of catch rates included: target species (targ), temperature (temp, taken as the average over the temperature at either set start, end or haul start or end), a categorical factor for the number of light-sticks per hook (light), and the number of hooks between floats (HBFL), the maximum depth of the hooks the maximum depth of the sea floor over the area fished (BOTTOM_DEPTH_MAX_CAT), hook type (circle or J) and live or dead bait . The number of hooks between floats acts as a proxy for the depth at which the gear is actually fishing, as depth of the hook typically increases with the number of hooks between floats. The number of hooks between floats, number of light sticks per hook, bottom depth maximum, hook depth and temperature were treated as categorical variables, and values were binned as specified in **Figure 3**.The time of day (evening (PM) or morning (AM)) of set (BSPM) was also evaluated as a model factor.

The U.S. PLL fleet primarily targets swordfish (SWO) and yellowfin tuna *Thunnus albacares* (YFT), and to a lesser extent bigeye tuna *T. obesus* (BET). A smaller number of trip-sets target other pelagic species such as sharks, dolphin *Coryphaena hippurus*, and small tunas (TUN).

Data exclusions

Very low numbers (or none) of sailfish were reported from the North and central offshore locations (NED, NEC, NCA and TUS) thus these locations and any sets where location was unknown were excluded. Experimental sets were also excluded. Furthermore, any set for which the complete set of model factors were not available were excluded from modeling.

Modeling

Catch rates were calculated as the total number of sailfish caught per 1000 hooks. The number of hooks was calculated as the number of hooks set minus the number of hooks lost. Fish length measurements are made directly by POP observers. For released or discarded animals (the majority of sailfish) not brought on board, lengths were estimated by observers. Measurements for billfish species were generally made as the curved distance from the tip of the lower jaw to the fork of the tail. To obtain CPUE in weight (kg/1000 hook) we used the average size of sailfish in each location/quarter stratum estimated from the POP data (available from 1992-2014. For missing lengths, we used the average length of all other observed individuals from the same year and area. Length to weight conversions for sailfish were based on equations in Prager *et al.* (1995) for combined sex sailfish.

For the POP data, indices of relative abundance (number of fish/1000 hooks and kg/1000 hooks) were estimated by a GLM approach assuming a delta-lognormal model distribution. The delta model fits separately the: 1) proportion of positive sets, assuming a binomial error distribution, and 2) the mean catch rate of sets where at least one sailfish was caught, assuming a lognormal error distribution. The estimated proportion is a linear function of fixed effects and interactions. The logit function was used as a link between the linear factor component and the binomial error. For sets that caught at least one sailfish, estimated CPUE was assumed to follow a lognormal error distribution of a linear function of fixed factors and random effect interactions. A step-wise regression process was used to determine the set of systematic factors and interactions that significantly explained the observed variability. Model selection of fixed factors was based on the relative percent of deviance per degree of freedom explained by adding the factor in evaluation (using a cutoff of >1%). Two way interactions were also evaluated and included according to the same criterion. Two-way interactions with year were modeled as random effects, except in situations where the models did not converge.

The final set of explanatory variables in the binomial model for the proportion of positive sets included: year, area, season, temperature, and light-sticks (fixed effects), and year*season, year*light-sticks, season*light-sticks, and area*season (random effects) (**Table 1**). For the log of positive catches in abundance, the variables selected were: year, area, season, and hooks between floats (fixed effects), and area*season, area*target, and area*light sticks (random effects; **Table 2**).

Model selection was performed by iterative forward selection based upon reduction in deviance per degree of freedom. This was conducted in R. Final model fitting, after factor selection was performed in SAS.

The initial, full models with interactions and final fitted models were as follows (**Table 1).**

full.mod.BN: success ~ BAIT_LD + season + HBFL_CAT+FISHING_AREA+TARGET_SPECIES+
TEMP_CAT + HOOK_DEPTH_CAT+ lghtc+BOTTOM_DEPTH_MAX_CAT + HOOK_TYPE + BSPM+
YEAR + TEMP_CAT*FISHING_AREA+TEMP_CAT*BOTTOM_DEPTH_MAX_CAT +
TEMP_CAT:YEAR*TEMP_CAT:season+ FISHING_AREA*BOTTOM_DEPTH_MAX_CAT+
FISHING_AREA*season + BOTTOM_DEPTH_MAX_CAT*YEAR +
BOTTOM_DEPTH_MAX_CAT*season + YEAR*season

Final Binomial model: success ~ TEMP_CAT + FISHING_AREA + BOTTOM_DEPTH_MAX_CAT + YEAR + BAIT_LD + season + *YEAR:season* + *TEMP_CAT:YEAR* + *BOTTOM_DEPTH_MAX_CAT:YEAR*

For the lognormal component the initial, full model was (**Table 2**):

full.mod.LN = lcpue ~ BAIT_LD + season + HBFL_CAT+FISHING_AREA+TARGET_SPECIES+ TEMP_CAT + HOOK_DEPTH_CAT+ lghtc+ BOTTOM_DEPTH_MAX_CAT + HOOK_TYPE + YEAR + all two-way interactions with year

and, the final selected model was:

Final LN model= lcpue ~ BAIT_LD + season + HBFL_CAT + FISHING_AREA + TARGET_SPECIES + TEMP_CAT + HOOK_DEPTH_CAT + lghtc + BOTTOM_DEPTH_MAX_CAT + HOOK_TYPE + YEAR + *YEAR*BOTTOM_DEPTH_MAX_CAT* + *YEAR*FISHING_AREA* + *YEAR*TEMP_CAT* + *YEAR*HBFL_CAT* + *YEAR*season*+ *YEAR*lghtc* + *YEAR*TARGET_SPECIES*

All year*factor interactions were modeled as random effects. For the CPUE in weight and number the same model factors were used, as the conversion of CPUE in number to CPUE in weight would be unlikely to have changed the model factors.

Annual CPUE 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 unbalanced characteristics of the data. LSmeans of lognormal positive trips were bias corrected using Lo *et al.* (1992) algorithms and the variance of the index calculated as the product of two uncorrelated random variables (Goodman 1960). Analyses were done using the R (for model selection and data manipulation and GLIMMIX procedures from the SAS™ statistical computer software (SAS Institute Inc.: Cary, NC, USA).

3. Results and Discussion

Overall, the final binomial model explained 21% of the residual deviance and the final model for the lognormal component explained 36% of the residual deviance indicating that there is substantial unexplained variability in the data. This is not uncommon for a bycatch species with high variability in catch rates and low proportion of positive observations. Deviance tables indicate the percent reduction in deviance per degree of freedom as each model factor is sequentially added to the null model, then the model factor with the highest percent reduction is then selected and the sequential process repeated until no further factor explains greater than 1% of the deviance per degree of freedom (**Tables 1, 2**)

Plots of the nominal mean CPUE as a function of each potential model factor (**Figure 3**) show the influence of individual model factors on CPUE. Model fit diagnostics indicated some lack of fit to the assumed log-normality (**Figure 4**) likely due to the presence of discrete numbers of sailfish per set (e.g. 1, 2, 3…). However these departures from strict lognormality are not any worse than for most other species. Plots of residuals over time indicate adequate model performance (**Figure 5**), with most residuals being distributed fairly normally around a mean of zero for each year. Fixed parameter estimates for the final models indicate the strength and direction of the influence of model factors (**Tables 3** and **4**). Key model factors influencing catch rates were depth fished with shallower sets more likely to both encounter sailfish and when positive, to have higher catch rates. Sea surface temperature also was an influential factor with the highest temperatures (>81ºC) having the highest catch rates. Bait type (live versus dead) was also influential on the overall catch rate due to increasing the proportion of positive sets as it was not significant in the lognormal model component. Note that since **Figure 3** shows only nominal CPUE some of the model factors may appear influential due to collinearity with other model factors and hence may not have appeared in the final, selected models.

Overall the percentage of positive sets ranged from 8-29% and the average catch rate ranged from 0.17 to 1.2 sailfish per 1000 hooks (**Table 4**). Standardized CPUE series in number (fish / 1000 hooks, **Table 5, Figure 6**) and weight (kg / 1000 hooks, **Table 5, Figure 7**) indicate no clear single trend over the time series. There is some divergence from the nominal values indicating that the model standardization has some impact. However the modeled CPUE largely tracks the nominal.

For comparative purposes, the previous (Ortiz *et al.* 2009) index of CPUE in weight is also shown (**Figure 7**) as well as the CPUE series in numbers and weight scaled to their overall mean and plotted together (**Figure 8**). The model-estimated annual CVs range from 0.36-0.46 reflective of relatively high variance.

Plots of the median length of captured sailfish over time show little discernable trend (**Figure 10**) other than that the number of sailfish actually measured, as opposed to estimated, is quite low (~15-25%). This median estimated sailfish size has remained exactly 150 cm since 2000 indicating that estimated measures are unlikely to track any changes in size. Furthermore, the low percentage and number of actually measured sailfish indicate that these trends are unlikely to be useful for consideration of inferences based upon mean lengths.

It is noteworthy to comment on the potential impact of regulations prohibiting the use of live bait in the Gulf of Mexico starting in 2002. By design this regulation was expected to reduce catch rates of billfishes (Scott *et al.* 2000). There appears to be a substantial decline in the index during this time period which may be coincident with this regulation. While bait type was tested as a model factor it was not retained in the lognormal component, potentially due to this impact being largely a Gulf of Mexico phenomenon; and, potentially because this regulatory switch affected vessel catch rates by altering their fishing practices in ways that have not been captured by the statistical standardizations. It may be that the current index still does not account for the potential impacts of live/dead bait, which was evident in **Figure 3**. It is also important to consider the weak hook regulation enacted in 2011 which required use of a hook designed to bend with large fish. This regulation required the use of these weak hooks in the Gulf of Mexico to protect Bluefin tuna. Experiments were conducted to compare the catch rates of Bluefin and other species with the standard hooks and found no significant differences in catch rates of sailfish. Hence no correction for this weak hook regulatory change was made to these indices.

Maps of the spatial distribution of catch and effort (**Figure 11**) indicate that most sailfish are captured either in the Gulf of Mexico the area just west of the Florida straits and the South Atlantic Bight which reflects the largely warm water distribution of the species. Note that in **Figure 11** catches from within the closed areas have been removed both before and after the closure so that the data in these plots reflects the same data used for the index.

Plots of the nominal CPUE and the proportion positive by area indicate some differential patterns between areas. For the positive CPUE this was reflected as year*area interactions in the model. The key pattern appears to be a substantial reduction in the nominal CPUE on the Gulf of Mexico after the year 2000, which may partially reflect the prohibition against live baits enacted in 2002. It is also important to note that the large increases in nominal and standardized CPUE for years 1999 and 2000 (**Figures 6 and 7**) are attributed entirely to catches in the Gulf of Mexico. These spikes are quite high and appear to be outliers (given the extreme rise before and the extreme drop after these two years), particularly as they were observed only in the Gulf of Mexico and not in any other area.

In conclusion the indices presented here are quite similar to the previous indices derived by Ortiz *et al.* (2009), though some model factors (notably Op code) were not used in this analysis, as these factors have not been updated in recent years. The indices in number and weight are quite similar, as the mean weights are usually a simple multiplier and there is little trend in mean weight over time. Lastly, comparison with a logbook index developed in 2009 (Ortiz *et al.* 2009) shows some differences over the time series (**Figure 9**), notably less of a longer-term decline and a later starting date (1992) versus 1986. However, due to the bycatch nature of sailfish we recommend use of the observer based data over logbook reports to derive indices of abundance.

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Table 1. Deviance analysis table of sailfish proportion positive from the U.S. PLOP data. Percent of reduction refers to the reduction in deviance per degree of freedom obtained by iteratively adding each individual factor to the base (no model factors) model; p value refers to the Chi-square probability test between two consecutive models. Factors identified in yellow were selected for the model.

Factor	Deviance	DF	DevpDF	LLik	Per Red	Chi SQ	Prob Chi SQ
+ TEMP	12419	17574	0.71	-6209.6	8.55	1577	0
+ FISHING_AREA	12926	18110	0.71	-6463.0	7.64	1070	0
+ season	13376	18113	0.74	-6688.1	4.44	619.5	0
+ BAIT_LD	13597	18102	0.75	-6798.7	2.8	398.3	0
+ TARGET_SPECIES	13722	18112	0.76	-6860.8	1.96	274.2	0
+ lghtc	13745	18109	0.76	-6872.7	1.78	250.4	0
+ YEAR	13749	18094	0.76	-6874.3	1.67	247.2	0
+ HOOK_TYPE	13796	18113	0.76	-6898.1	1.44	199.6	0
+ BOTTOM_DEPTH	13608	17836	0.76	-6803.8	1.27	388.2	0
+ HOOK_DEPTH	13816	18107	0.76	-6908.0	1.26	179.7	0
+ Intercept	13996	18116	0.77	-6997.9	0.03	0.0	Inf
+ HBFL	13972	18081	0.77	-6986.2	0	23.3	0.02
TEMP + FISHING_AREA	11886	17568	0.68	-5942.8	4.35	533.6	0
TEMP + BAIT_LD	12125	17560	0.69	-6062.6	2.38	294.0	0
TEMP + YEAR	12180	17552	0.69	-6090.2	1.89	238.8	0
TEMP + BOTTOM_DEPTH	12017	17294	0.69	-6008.5	1.76	402.1	0
TEMP + HOOK_DEPTH	12271	17565	0.70	-6135.7	1.23	147.8	0
TEMP + season	12308	17571	0.70	-6153.8	0.97	111.4	0
TEMP + TARGET_SPECIES	12307	17570	0.70	-6153.7	0.97	111.8	0
TEMP + lghtc	12312	17567	0.70	-6155.9	0.91	107.3	0
TEMP + HOOK_TYPE	12324	17571	0.70	-6161.8	0.84	95.6	0
TEMP + base	12419	17574	0.71	-6209.6	0.09	0.0	Inf
TEMP + HBFL	12407	17541	0.71	-6203.5	0	12.2	3E-04
TEMP + FISHING_AREA + BOTTOM_DEPTH	11428	17288	0.66	-5713.9	2.34	457.8	0
TEMP + FISHING_AREA + YEAR	11652	17546	0.66	-5826.1	1.89	233.3	0
TEMP + FISHING_AREA + BAIT_LD	11676	17554	0.67	-5837.9	1.74	209.8	0
TEMP + FISHING_AREA + season	11711	17565	0.67	-5855.4	1.5	174.7	0
TEMP + FISHING_AREA + HOOK_TYPE	11821	17565	0.67	-5910.4	0.58	64.7	0
TEMP + FISHING_AREA + TARGET_SPECIES	11833	17564	0.67	-5916.4	0.47	52.8	0
TEMP + FISHING_AREA + HOOK_DEPTH	11830	17559	0.67	-5915.2	0.46	55.2	0
TEMP + FISHING_AREA + lghtc	11836	17561	0.67	-5917.8	0.43	49.9	0
TEMP + FISHING_AREA + base	11886	17568	0.68	-5942.8	0.05	0.0	Inf
TEMP + FISHING_AREA + HBFL	11869	17535	0.68	-5934.6	0	16.4	0.004
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR	11208	17266	0.65	-5603.9	1.86	219.9	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + BAIT_LD	11218	17275	0.65	-5609.0	1.82	209.7	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + season	11288	17285	0.65	-5643.8	1.27	140.1	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + TARGET_SPECIES	11367	17284	0.66	-5683.3	0.57	61.2	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + HOOK_TYPE	11373	17285	0.66	-5686.5	0.52	54.8	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + HOOK_DEPTH	11379	17279	0.66	-5689.6	0.43	48.5	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + lghtc	11384	17281	0.66	-5692.2	0.4	43.4	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + base	11428	17288	0.66	-5713.9	0.06	0.0	Inf
TEMP + FISHING_AREA + BOTTOM_DEPTH + HBFL	11413	17255	0.66	-5706.3	0	15.2	0.002
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD	11030	17253	0.64	-5514.9	1.56	178.2	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + season	11055	17263	0.64	-5527.4	1.39	153.1	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + HOOK_TYPE	11121	17263	0.64	-5560.6	0.8	86.7	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + TARGET_SPECIES	11158	17262	0.65	-5578.9	0.47	50.0	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + lghtc	11156	17259	0.65	-5578.2	0.47	51.5	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + HOOK_DEPTH	11161	17257	0.65	-5580.5	0.41	46.9	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + base	11208	17266	0.65	-5603.9	0.05	0.0	Inf
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + HBFL	11192	17233	0.65	-5595.8	0	16.2	0.004
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season	10898	17250	0.63	-5448.9	1.21	131.8	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + HOOK_TYPE	10981	17250	0.64	-5490.3	0.46	49.1	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + lghtc	10995	17246	0.64	-5497.6	0.3	34.6	1E-5
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + TARGET_SPECIES	11001	17249	0.64	-5500.4	0.27	28.9	0

TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + HOOK_DEPTH	11005	17244	0.64	-5502.6	0.2	24.6	0.001
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + base	11030	17253	0.64	-5514.9	0.03	0.0	Inf
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + HBFL	11012	17220	0.64	-5505.9	0	17.8	0.007
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season HOOK_TYPE	10857	17247	0.63	-5428.4	0.4	41.0	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season lghtc	10860	17243	0.63	-5430.0	0.35	37.9	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season TARGET_SPECIES	10870	17246	0.63	-5434.8	0.28	28.3	0
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season HOOK_DEPTH	10869	17241	0.63	-5434.6	0.25	28.7	3E-04
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season base	10898	17250	0.63	-5448.9	0.04	0.0	Inf
TEMP + FISHING_AREA + BOTTOM_DEPTH + YEAR + BAIT_LD + season HBFL	10881	17217	0.63	-5440.7	0	16.5	0.004

Table 2. Deviance analysis table of sailfish catch rates in weight from the U.S. PLOP data. Percent of reduction refers to the reduction in deviance per degree of freedom obtained by iteratively adding each individual factor to the base (no model factors) model; p value refers to the Chi-square probability test between two consecutive models. Factors identified in yellow were selected for the model.

Factor	Deviance	DF	Dev pDF	LLik	Per Red	ChiSQ	Prob ChiSQ
+ YEAR	1003.73	2331	0.431	-2337	13.03	161.3	0.00
+ TEMP	1015.77	2281	0.445	-2316	10.06	149.3	0.00
+ TARGET_SPECIES	1081.97	2349	0.461	-2425	6.97	83.06	0.00
+ HOOK_TYPE	1086.83	2350	0.462	-2431	6.59	78.19	0.00
+ HBFL	1091.91	2350	0.465	-2436	6.16	73.11	0.00
+ season	1092.73	2350	0.465	-2437	6.09	72.29	0.00
+ lghtc	1095.29	2350	0.466	-2440	5.87	69.73	0.00
+ BOTTOM_DEPTH	1082.44	2301	0.470	-2400	4.99	82.58	0.00
+ BAIT_LD	1143.92	2351	0.487	-2490	1.73	21.11	0.00
+ AREA	1150.24	2347	0.490	-2497	1.02	14.78	0.01
+ HOOK_DEPTH	1159.65	2350	0.493	-2507	0.33	5.37	0.06
+ base	1165.02	2353	0.495	-2512	0	0	Inf
YEAR + TEMP	903.52	2259	0.400	-2182	7.11	100.2	0.00
YEAR + lghtc	953.62	2328	0.410	-2277	4.87	50.11	0.00
YEAR + season	954.17	2328	0.410	-2277	4.82	49.56	0.00
YEAR + BOTTOM_DEPTH	935.72	2279	0.411	-2232	4.65	68.01	0.01
YEAR + TARGET	955.92	2327	0.411	-2279	4.6	47.81	0.00
YEAR + HBFL	968.72	2328	0.416	-2295	3.36	35.01	0.00
YEAR + AREA	988.94	2325	0.425	-2319	1.22	14.79	0.01
YEAR + HOOK_DEPTH	996.32	2328	0.428	-2328	0.61	7.41	0.03
YEAR + HOOK_TYPE	998.79	2328	0.429	-2331	0.36	4.94	0.08
YEAR + BAIT_LD	1002.14	2329	0.430	-2335	0.07	1.59	0.23
YEAR + base	1003.73	2331	0.431	-2337	0	0	Inf
YEAR + TEMP+ BOTTOM_DEPTH	839.94	2207	0.381	-2078	4.93	63.58	0.02
YEAR + TEMP+ TARGET	858.40	2255	0.381	-2124	4.91	45.12	0.00
YEAR + TEMP+ lghtc	863.82	2256	0.383	-2131	4.35	39.7	0.00
YEAR + TEMP+ HBFL_CAT	873.92	2256	0.387	-2144	3.23	29.6	0.00
YEAR + TEMP+ AREA	887.44	2253	0.394	-2162	1.6	16.08	0.01
YEAR + TEMP+ season	890.30	2256	0.395	-2165	1.42	13.22	0.00
YEAR + TEMP+ HOOK_DEPTH	895.58	2256	0.397	-2172	0.83	7.94	0.02
YEAR + TEMP+ HOOK_TYPE	901.47	2256	0.400	-2180	0.18	2.05	0.20
YEAR + TEMP+ base	903.52	2259	0.400	-2182	0.08	0	Inf
YEAR + TEMP+ BAIT_LD	903.48	2257	0.400	-2182	0	0.03	0.49
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET	806.52	2203	0.366	-2033	3.81	33.42	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ HBFL	815.92	2204	0.370	-2046	2.74	24.02	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ lghtc	818.14	2204	0.371	-2049	2.47	21.79	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ AREA	817.97	2201	0.372	-2048	2.36	21.96	0.00

YEAR + TEMP+ BOTTOM_DEPTH+ season	831.86	2204	0.377	-2067	0.84	8.08	0.02
YEAR + TEMP+ BOTTOM_DEPTH+ BAIT_LD	836.23	2205	0.379	-2073	0.36	3.7	0.08
YEAR + TEMP+ BOTTOM_DEPTH+ HOOK_TYPE	836.76	2204	0.380	-2074	0.25	3.17	0.15
YEAR + TEMP+ BOTTOM_DEPTH+ base	839.94	2207	0.381	-2078	0.01	0	Inf
YEAR + TEMP+ BOTTOM_DEPTH+ HOOK_DEPTH	838.88	2204	0.381	-2077	0	1.05	0.24
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA	785.93	2197	0.358	-2004	2.29	20.58	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ HBFL	787.03	2200	0.358	-2005	2.28	19.49	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ lghtc	796.14	2200	0.362	-2018	1.15	10.37	0.01
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ season	796.45	2200	0.362	-2019	1.11	10.06	0.01
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ BAIT_LD	802.79	2201	0.365	-2027	0.37	3.73	0.08
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ HOOK_DEPTH	803.13	2200	0.365	-2028	0.28	3.39	0.13
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ HOOK_TYPE	803.32	2200	0.365	-2028	0.26	3.2	0.14
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ base	806.52	2203	0.366	-2033	0	0	Inf
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL	767.37	2194	0.350	-1977	2.23	18.56	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ lghtc	774.44	2194	0.353	-1987	1.33	11.49	0.00
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ season	778.66	2194	0.355	-1993	0.79	7.27	0.03
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HOOK_DEPTH	781.66	2194	0.356	-1998	0.41	4.27	0.10
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HOOK_TYPE	781.96	2194	0.356	-1998	0.37	3.97	0.11
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ BAIT_LD	783.11	2195	0.357	-1999	0.27	2.82	0.12
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ base	785.93	2197	0.358	-2004	0	0	Inf
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ lghtc	759.08	2191	0.346	-1965	0.95	8.29	0.02
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ season	760.21	2191	0.347	-1967	0.8	7.16	0.03
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ HOOK_DEPTH	760.97	2191	0.347	-1968	0.7	6.4	0.04
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ HOOK_TYPE	763.27	2191	0.348	-1971	0.4	4.11	0.10
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ BAIT_LD	764.80	2192	0.349	-1973	0.24	2.58	0.14
YEAR + TEMP+ BOTTOM_DEPTH+ TARGET+ AREA+ HBFL+ base	767.37	2194	0.350	-1977	0	0	Inf

Table 3. Table of fixed effects for binomial submodel.

Effect	YEAR	area	season	TEMP_CAT	BAIT_LD	depth	Estimate	StdErr
Intercept	_						0.66	0.58
temp	_			(0,72.2]			-1.71	0.25
temp	_			(72.2,77.2]			-1.26	0.21
temp	_			(77.2,81.2]			-0.65	0.20
temp	_			(81.2,92.4]			0.00	
area	_	CAR					-0.78	0.25
area	_	FEC					-1.08	0.19
area	_	GOM					-1.43	0.18
area	_	MAB					-3.59	0.25
area	_	SAB					-1.42	0.19
area	_	SAR					-2.29	0.32
area	_	TUN					0.00	
depth	_					(1.6e+03,5	-0.69	0.16
depth	_					(13,530]	0.23	0.16
depth	_					(1e+03,1.6	-0.70	0.16
depth	_					(530,1e+03	0.00	
YEAR	1992						1.55	0.80
YEAR	1993						1.11	0.73
YEAR	1994						0.19	0.77
YEAR	1995						0.16	0.75
YEAR	1996						-0.01	0.77
YEAR	1997						0.60	0.75
YEAR	1998						-0.24	0.79
YEAR	1999						1.06	0.74
YEAR	2000						1.07	0.74
YEAR	2001						0.39	0.75
YEAR	2002						0.05	0.76
YEAR	2003						-0.72	0.77
YEAR	2004						0.41	0.74
YEAR	2005						0.74	0.74
YEAR	2006						-0.06	0.76
YEAR	2007						0.29	0.73
YEAR	2008						0.40	0.73
YEAR	2009						0.67	0.72
YEAR	2010						0.30	0.73
YEAR	2011						0.53	0.73
YEAR	2012						0.35	0.74
YEAR	2013						-0.15	0.74
YEAR	2014						0.00	
BAIT_LD	_				0		-1.39	0.13
BAIT_LD	_				1		0.00	
season	_		Apr-Jun				0.79	0.21
season	_		Jan-Mar				0.18	0.23
season	_		Jul-Sep				0.99	0.22
season	_		Oct-Dec				0.00	

Table 3. Table of fixed effects for lognormal submodel for CPUE in number.

Effect	YEAR	area	season	HBFL	temp	lghtc	depth	target	Estimate	StdErr
Intercept	_					_			0.641	0.275
YEAR	1992					_			0.232	0.385
YEAR	1993					_			0.436	0.346
YEAR	1994					_			0.250	0.364
YEAR	1995					_			0.224	0.358
YEAR	1996					_			0.151	0.349
YEAR	1997					_			0.127	0.342
YEAR	1998					_			0.397	0.354
YEAR	1999					_			0.110	0.335
YEAR	2000					_			0.389	0.336
YEAR	2001					_			0.158	0.342
YEAR	2002					_			-0.031	0.343
YEAR	2003					_			0.004	0.362
YEAR	2004					_			-0.030	0.331
YEAR	2005					_			0.025	0.327
YEAR	2006					_			-0.074	0.337
YEAR	2007					_			0.031	0.319
YEAR	2008					_			0.139	0.321
YEAR	2009					_			-0.196	0.318
YEAR	2010					_			0.117	0.330
YEAR	2011					_			0.101	0.318
YEAR	2012					_			0.360	0.317
YEAR	2013					_			0.139	0.320
YEAR	2014					_			0.000	
temp	_				(0,72.2]	_			0.044	0.111
temp	_				(72.2,77.2]	_			-0.248	0.078
temp	_				(77.2,81.2]	_			-0.218	0.070
temp	_				(81.2,92.4]	_			0.000	
target	_					_		DOL	-0.317	0.120
target	_					_		MIX	0.022	0.071
target	_					_		SWO	0.282	0.088
target	_					_		TUN	0.157	0.082
target	_					_		YFT	0.000	
depth	_					_	(1.6e+03,5		-0.223	0.048
depth	_					_	(13,530]		0.196	0.040
depth	_					_	(1e+03,1.6		-0.218	0.039
depth	_					_	(530,1e+03		0.000	
HBFL	_			(0,4.01]		_			0.177	0.078
HBFL	_			(4.01,4.15]		_			-0.036	0.077
HBFL	_			(4.15,5.2]		_			0.173	0.074
HBFL	_			(5.2,315]		_			0.000	
area	_	CAR				_			-0.283	0.180
area	_	FEC				_			-0.153	0.143
area	_	GOM				_			-0.039	0.133
area	_	MAB				_			0.004	0.179
area	_	SAB				_			-0.313	0.141
area	_	SAR				_			-0.643	0.241
area	_	TUN				_			0.000	
season	_		Apr-Jun			_			0.086	0.071
season	_		Jan-Mar			_			0.033	0.085
season	_		Jul-Sep			_			0.166	0.073
season	_		Oct-Dec			_			0.000	
lghtc	_					0			0.047	0.099
lghtc	_					1			-0.141	0.089
lghtc	_					2			-0.182	0.080
lghtc	_					3			0.000	

Table 4. Sailfish nominal and standardized catch rates (fish / 1000 hooks), coefficient of variation, index, and 95% confidence interval (CI) limits for the standardized index from the U.S. PLOP data (1992-2014).

Year	*Number obs.*	*Prop. positive*	*Nominal CPUE*	*Standardized CPUE*	*Index*	*Lower 95% CI*	*Upper 95% CI*	*CV*	*Std. error*
1992	261	0.188	0.874	0.715	1.965	0.867	4.457	0.427	0.305
1993	712	0.152	0.765	0.598	1.645	0.785	3.448	0.383	0.229
1994	526	0.095	0.455	0.332	0.913	0.398	2.097	0.434	0.144
1995	526	0.099	0.367	0.248	0.681	0.300	1.544	0.427	0.106
1996	364	0.154	1.056	0.257	0.707	0.314	1.592	0.423	0.109
1997	352	0.151	0.342	0.329	0.906	0.411	1.997	0.411	0.136
1998	277	0.083	0.473	0.242	0.666	0.278	1.599	0.460	0.111
1999	367	0.240	1.272	0.674	1.854	0.909	3.782	0.368	0.248
2000	420	0.293	1.198	0.978	2.689	1.347	5.367	0.356	0.348
2001	436	0.151	0.375	0.364	1.002	0.462	2.173	0.402	0.147
2002	401	0.087	0.173	0.240	0.661	0.295	1.481	0.420	0.101
2003	643	0.073	0.221	0.166	0.456	0.198	1.051	0.436	0.072
2004	758	0.119	0.245	0.288	0.791	0.373	1.678	0.390	0.112
2005	666	0.147	0.334	0.368	1.011	0.491	2.082	0.373	0.137
2006	693	0.097	0.179	0.190	0.521	0.238	1.142	0.408	0.077
2007	1073	0.092	0.236	0.221	0.608	0.288	1.284	0.387	0.086
2008	1279	0.163	0.453	0.402	1.105	0.539	2.265	0.371	0.149
2009	1588	0.153	0.297	0.290	0.796	0.394	1.609	0.363	0.105
2010	999	0.098	0.315	0.319	0.877	0.410	1.873	0.394	0.125
2011	1108	0.136	0.432	0.279	0.768	0.368	1.607	0.382	0.107
2012	1255	0.145	0.514	0.395	1.087	0.529	2.233	0.372	0.147
2013	1804	0.096	0.210	0.230	0.631	0.299	1.334	0.388	0.089
2014	1635	0.119	0.255	0.239	0.658	0.316	1.369	0.379	0.091

Table 5. Sailfish nominal and standardized catch rates (kg / 1000 hooks), coefficient of variation, index, and 95% confidence interval (CI) limits for the standardized index from the U.S. PLOP data (1992-2014).

Year	*Number obs.*	*Prop. positive*	*Nominal CPUE*	*Standardized CPUE*	*Index*	*Lower 95% CI*	*Upper 95% CI*	*CV*	*Std. error*
1992	261	0.188	13.540	12.153	1.977	0.869	4.499	0.429	5.214
1993	712	0.152	12.080	9.329	1.518	0.704	3.272	0.399	3.719
1994	526	0.095	9.091	6.024	0.980	0.419	2.293	0.445	2.680
1995	526	0.099	5.747	4.035	0.657	0.284	1.519	0.439	1.770
1996	346	0.162	16.559	3.975	0.647	0.282	1.483	0.433	1.722
1997	351	0.151	6.457	6.860	1.116	0.497	2.506	0.421	2.891
1998	277	0.083	8.011	4.378	0.712	0.293	1.730	0.466	2.042
1999	364	0.242	22.801	12.758	2.076	1.003	4.295	0.376	4.796
2000	420	0.293	17.913	16.252	2.644	1.300	5.381	0.367	5.959
2001	436	0.151	5.703	6.116	0.995	0.451	2.193	0.411	2.514
2002	400	0.088	2.457	3.712	0.604	0.266	1.373	0.428	1.590
2003	608	0.077	3.629	2.871	0.467	0.199	1.097	0.447	1.283
2004	694	0.130	3.872	4.702	0.765	0.355	1.647	0.398	1.870
2005	632	0.152	4.124	4.896	0.797	0.379	1.675	0.385	1.885
2006	661	0.101	2.668	2.931	0.477	0.215	1.059	0.415	1.217
2007	1052	0.094	3.823	3.907	0.636	0.298	1.357	0.393	1.536
2008	1278	0.163	8.051	7.530	1.225	0.591	2.542	0.377	2.842
2009	1546	0.157	4.882	4.932	0.802	0.393	1.641	0.369	1.821
2010	929	0.105	4.828	4.583	0.746	0.345	1.610	0.400	1.832
2011	1026	0.141	7.323	4.699	0.764	0.358	1.632	0.393	1.847
2012	1177	0.153	9.131	7.269	1.183	0.567	2.467	0.380	2.764
2013	1740	0.098	3.251	3.634	0.591	0.275	1.271	0.397	1.443
2014	1548	0.125	4.055	3.809	0.620	0.293	1.312	0.389	1.480

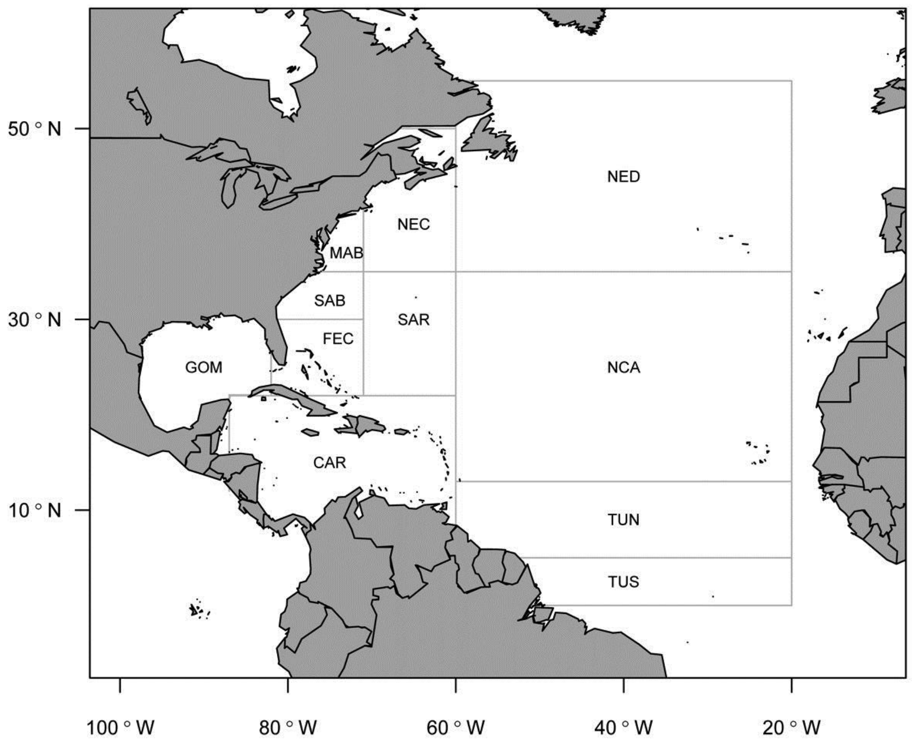

Figure 1. Geographical location classification of U.S. pelagic longline fleet operations used for analyses. *CAR* Caribbean, *GOM* Gulf of Mexico, *FEC* Florida East Coast, *SAB* South Atlantic Bight, *MAB* Mid-Atlantic Bight, *NEC* Northeast Coastal, *SAR* Sargasso, *NCA* North Central Atlantic, *TUN* Tuna North, and *TUS* Tuna South. The *NED* (Northeast Distant) sets are excluded from this analysis due to the Grand Banks closure.

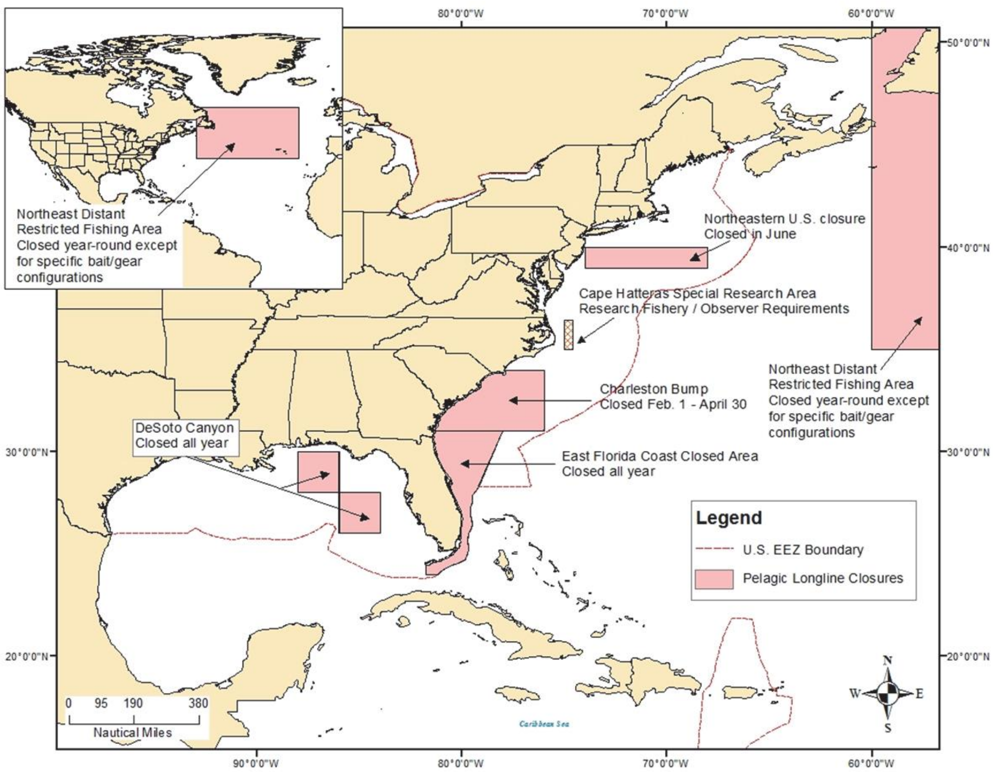

Figure 2. Time/area closures that restrict use of pelagic longline gear in the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. An additional closed area for the months of April and May in the Gulf of Mexico has been implemented beginning in 2015 (http://www.fisheries.noaa.gov/sfa/hms/compliance/regulations/index.html).

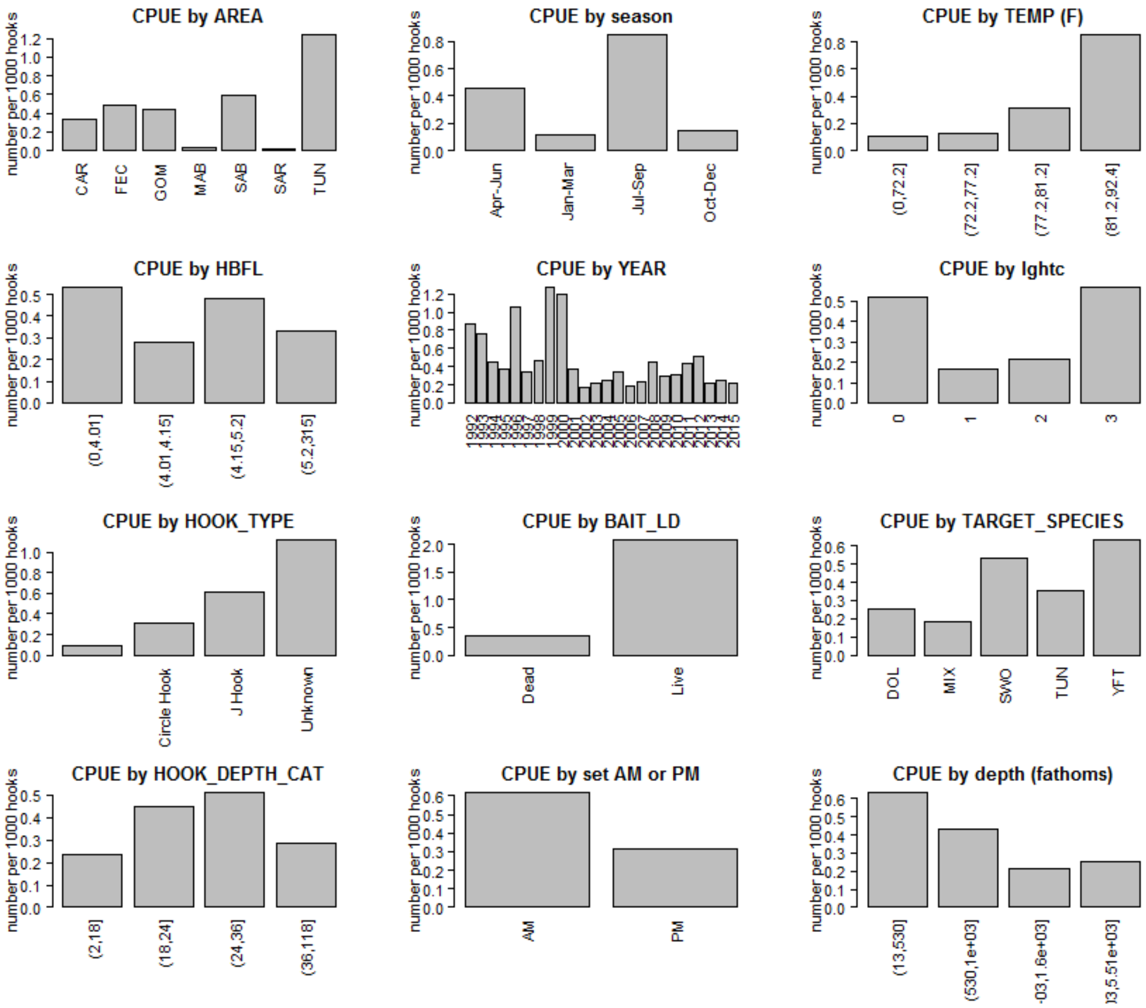

Figure 3. Plots of mean nominal abundance catch rates by model factors.

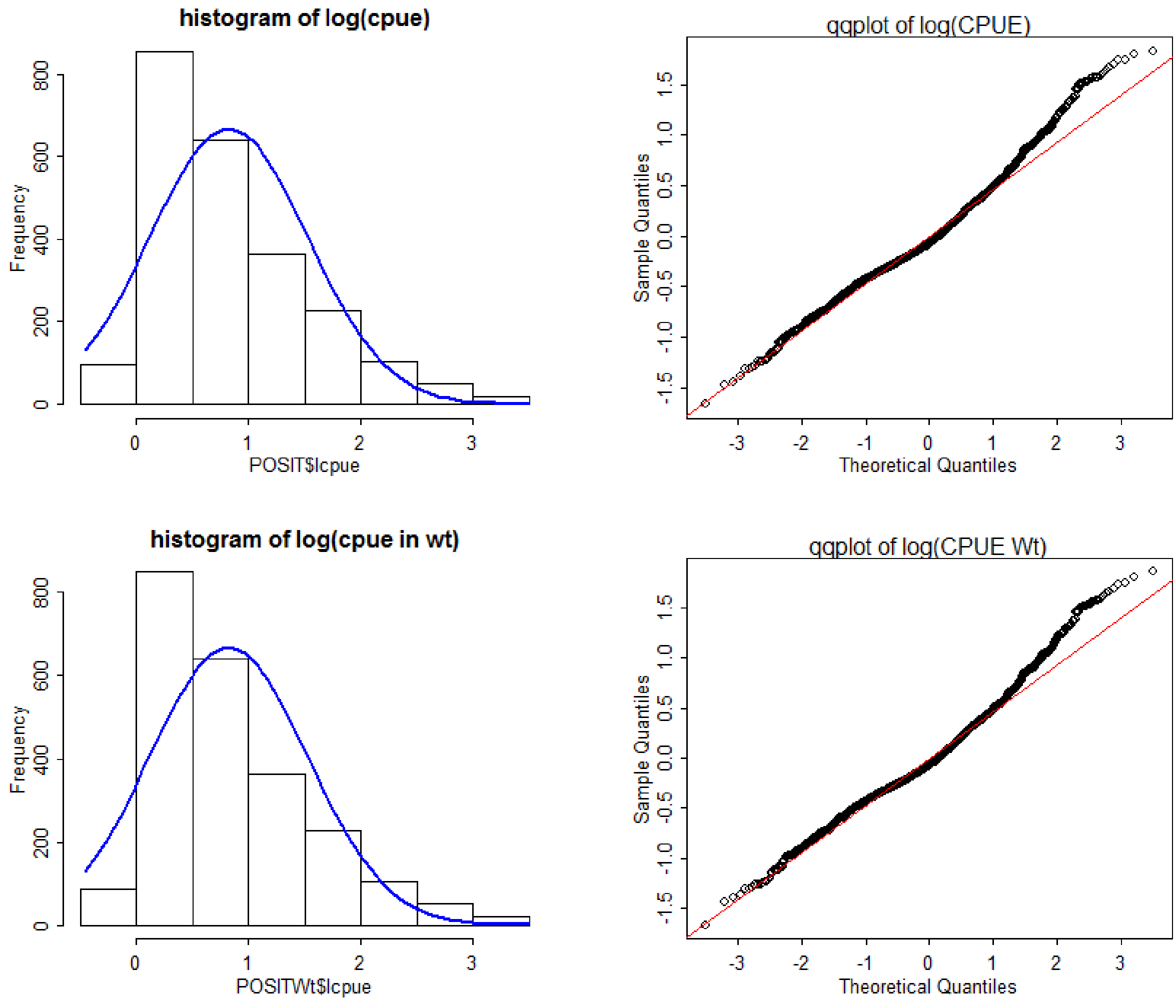

Figure 4. Frequency distribution for log transformed CPUE positive catches generated from U.S. Pelagic Observer Program data (1992-2014) in numbers (fish/1000 hooks) and weight (kg/1000 hooks) and corresponding fitted qqplots.

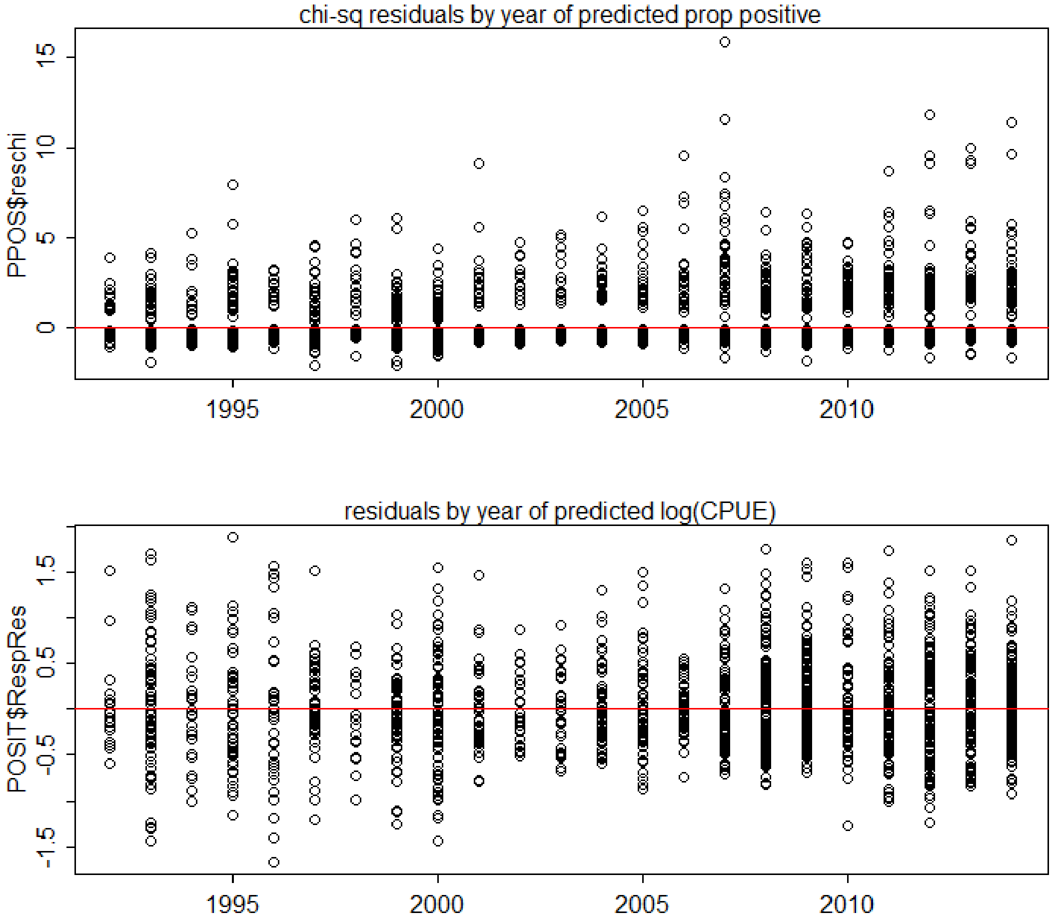

Figure 5. Chi-square residuals by year for the GLM model fit of binomial component (top) and standardized residuals for the positive observations for abundance (bottom) from the U.S. Pelagic Observer Program data (1992-2014).

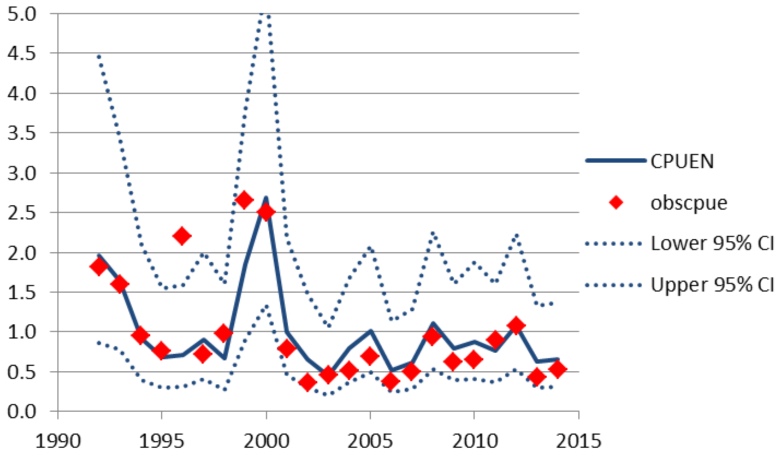

Figure 6. Estimated nominal and standardized CPUE for combined sailfish (fish / 1000 hooks) from the U.S. Pelagic Observer Program data (1992-2014). Dashed lines correspond to upper and lower 95% confidence intervals for the standardized CPUE.

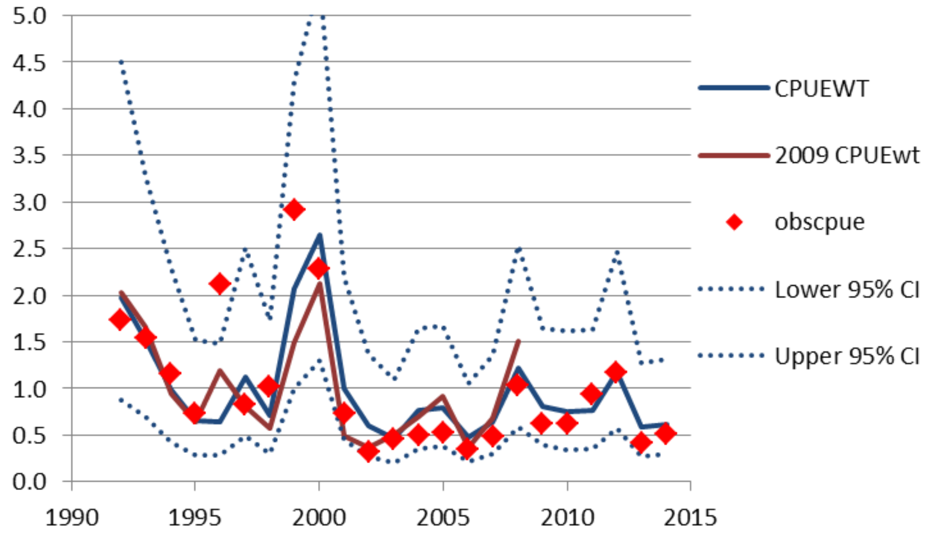

Figure 7. Estimated nominal and standardized CPUE for sailfish (kg / 1000 hooks) from the U.S. Pelagic Observer Program data (1992-2014). Dashed lines correspond to upper and lower 95% confidence intervals for the standardized CPUE.

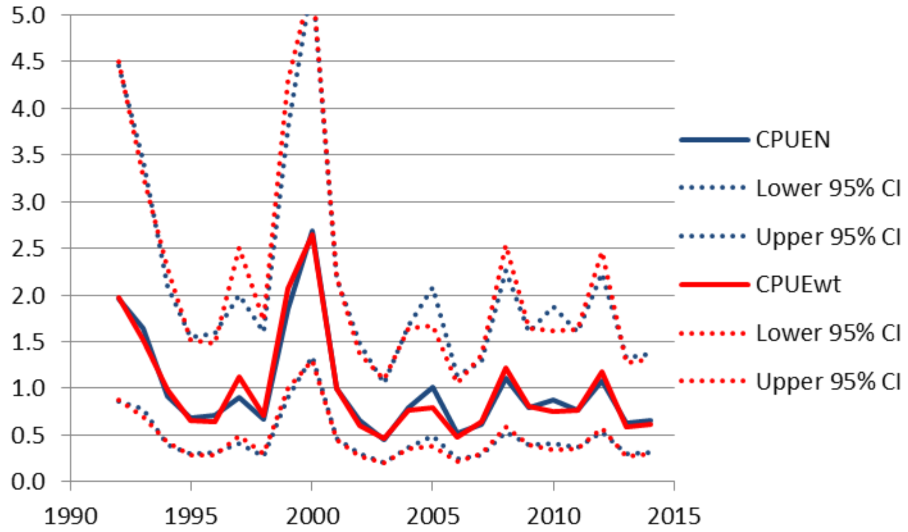

Figure 8. Sailfish standardized CPUE series in weight (kg / 1000 hooks) and number of fish (fish / 1000 hooks) estimated from the U.S. Pelagic Observer Program data (1992-2014). Dashed lines correspond to upper and lower 95% confidence intervals of their respective standardized CPUE. For comparative purposes, series are scaled to their overall mean.

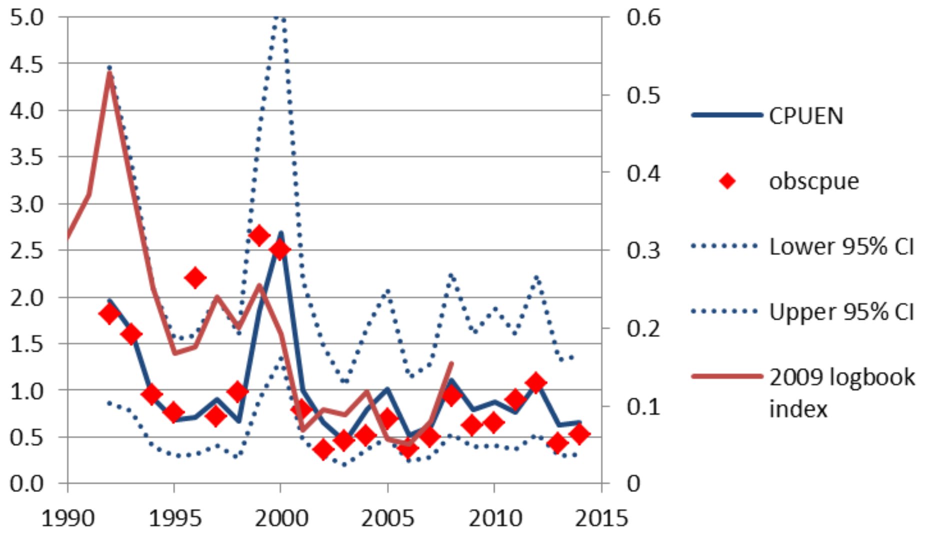

Figure 9. Comparison of current observer index of CPUE in number with the previous logbook index. Note that the logbook index is on a separate axis.

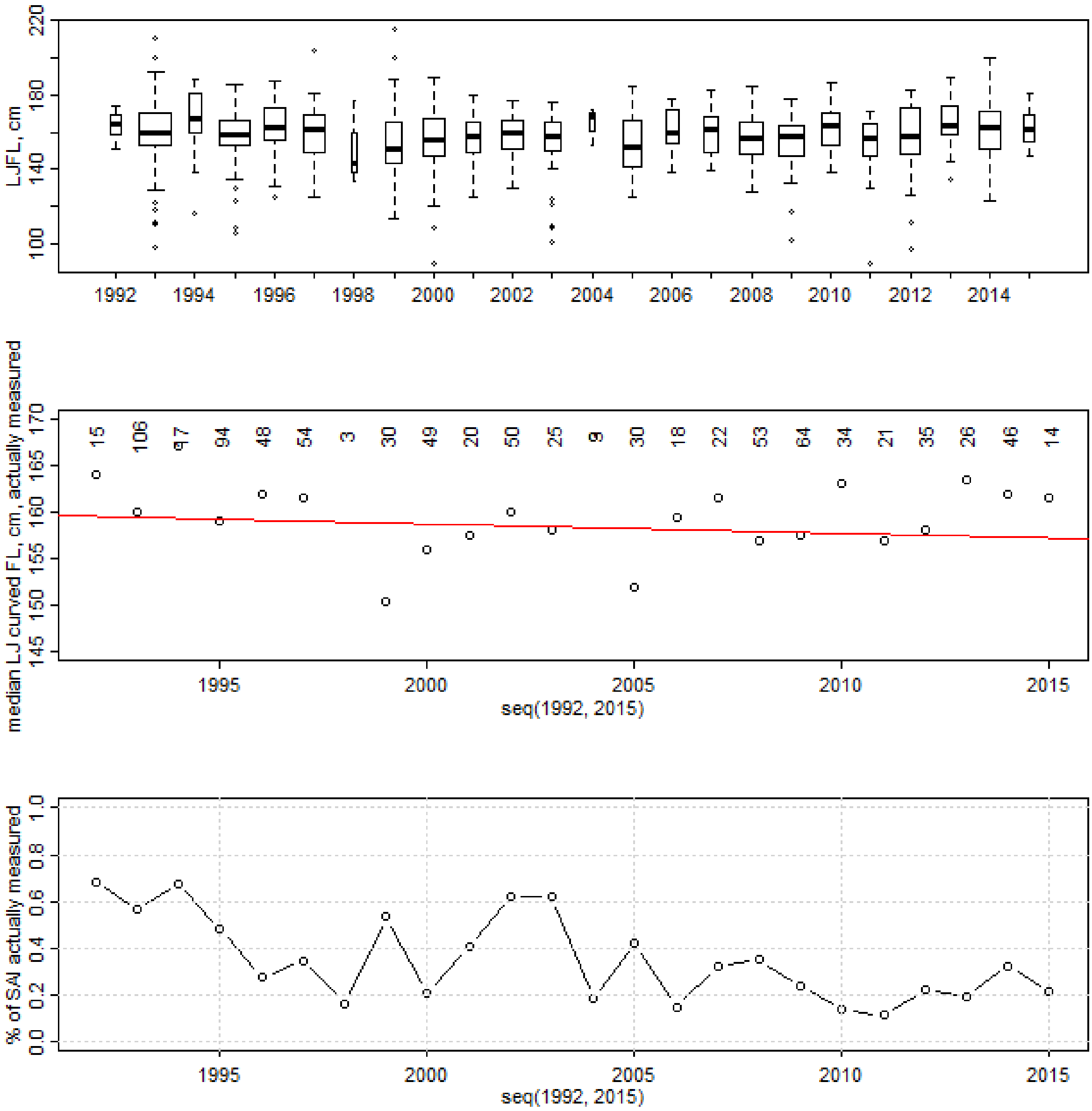

Figure 10. Box and whisker plots (median, 1st, 3rd quartile, minimum and maximum) of sailfish lengths by year in the U.S. PLOP data (1992-2011). Box widths are proportional to sample size. Middle plot is the median lower jaw fork length (cm) and a regression over time. Lower plot is the fraction of sailfish actually measured. Most (~70%) are only estimated lengths and the median estimated length has not varied from 150 cm LJFL since 2000.

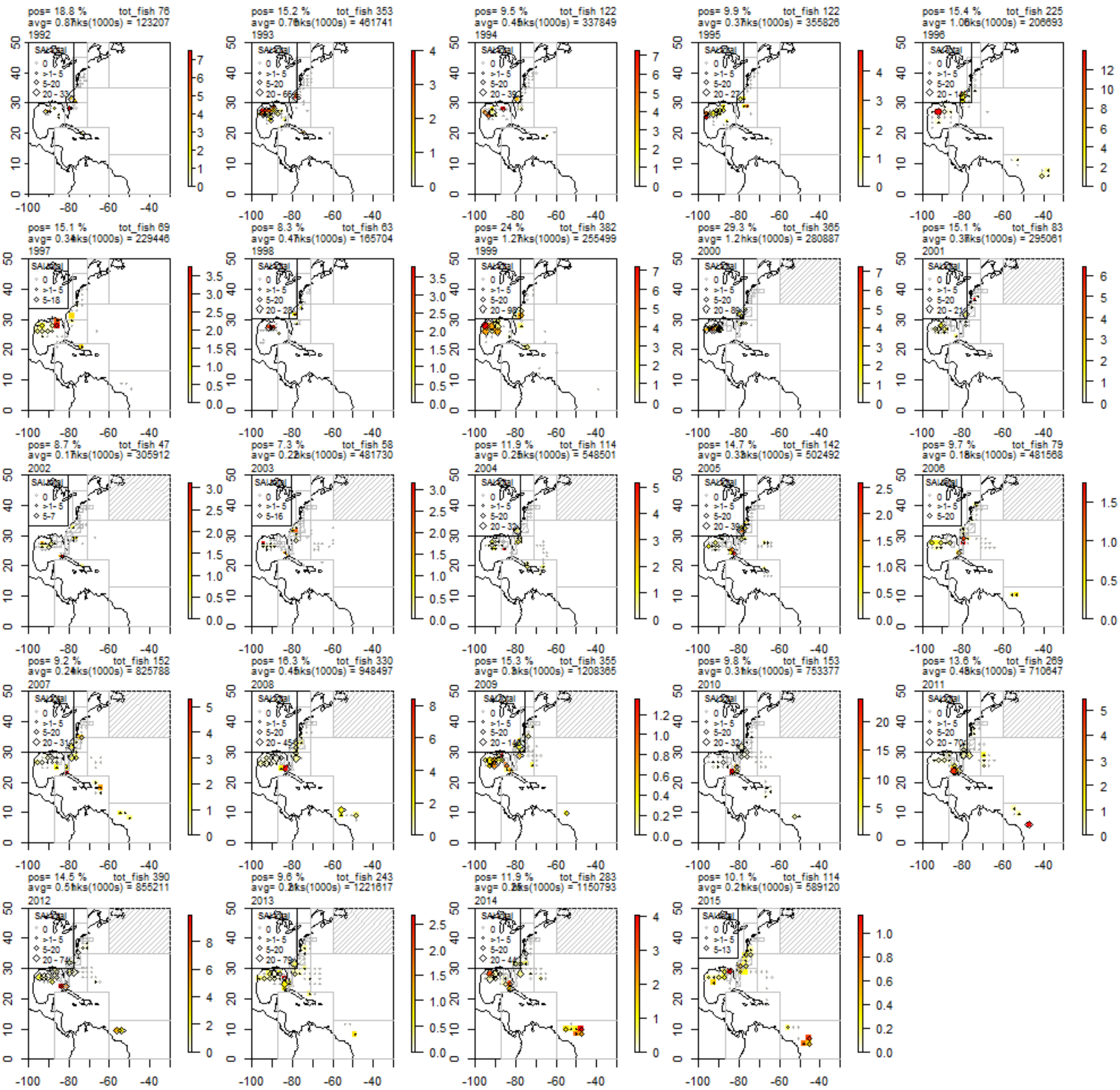

Figure 11. Spatial distribution of catch and effort in the U.S. Pelagic Longline Observer Program for 1992-2011. Cell size is approximately 110 x 110 nautical miles.

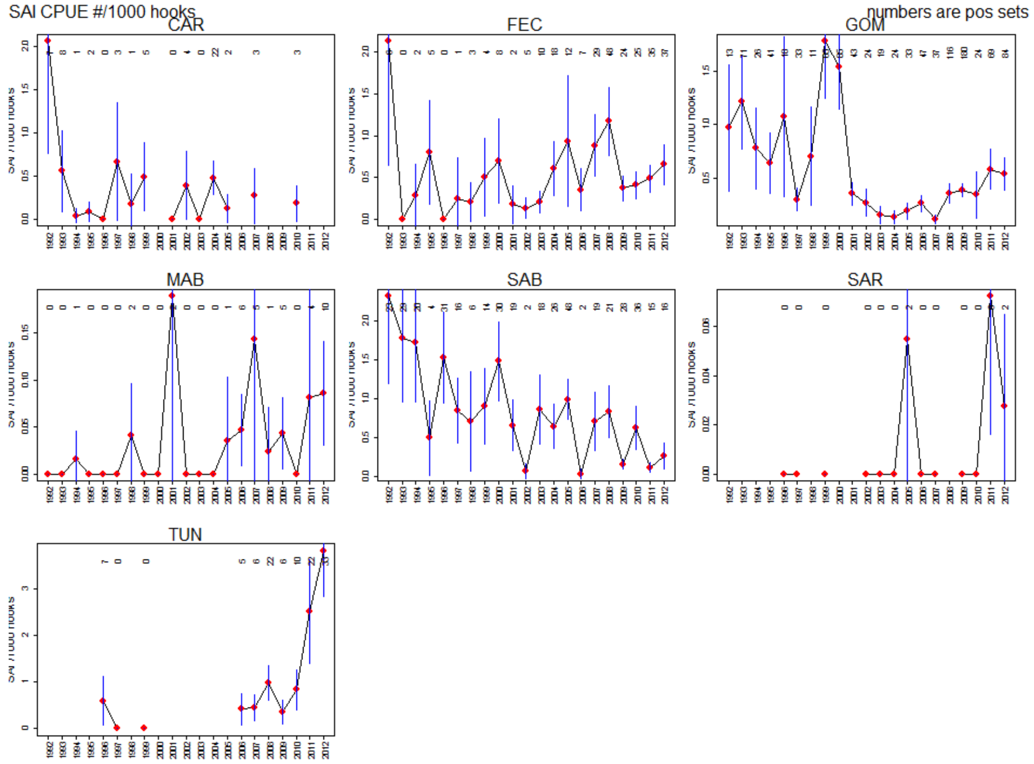

Figure 12. Nominal Sailfish CPUE in number by area. Numbers represent the number of positive sets.

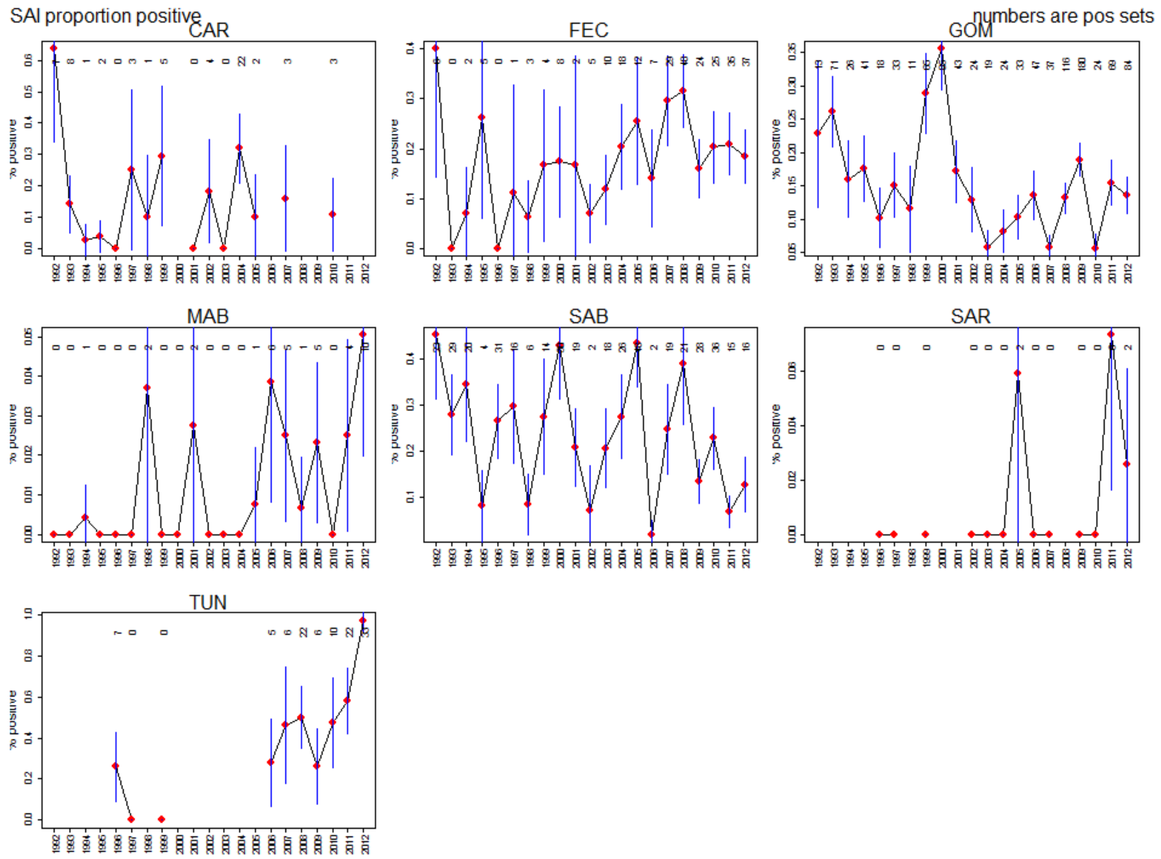

Figure 13. Percentage of positive CPUE in number by area. Numbers represent the number of positive sets.