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STANDARDIZED CATCH INDICES OF ATLANTIC SWORDFISH, *XIPHIAS GLADIUS,* FROM THE UNITED STATES PELAGIC LONGLINE OBSERVER PROGRAM

Matt Lauretta[1] and John Walter[1]

SUMMARY

United States pelagic longline observer data were analyzed to estimate annual indices of swordfish abundance in the western Atlantic Ocean for the periods, 1992 to 2015. Observer recorded data were filtered for sets that targeted swordfish, exclusively. A negative binomial generalized linear model was used to evaluate multiple factors which may affect catch rates, including year, month, and fishing area, as well as gear characteristics and environmental conditions. Significant factors included year, month, area, day/night, target species, light stick use, sea surface temperature, bait type, and hook type. Standardized abundance indices are presented along with estimates of mean uncertainty for both periods. In the 2013 assessment this index was split into two time periods to account for a change due to a switch to circle hooks. Subsequent analyses of the datasets indicated that hook type could be included as a model factor in the observer dataset to account for regulatory changes from predominately J hooks to circle hook and, in some regions, weak circle hooks. 165

RÉSUMÉ

Les données des observateurs palangriers pélagiques des États-Unis ont été analysées afin d'estimer les indices annuels d'abondance de l'espadon dans l'océan Atlantique Ouest pour la période comprise entre 1992 et 2015. Les données consignées par les observateurs ont été filtrées pour les opérations qui ciblaient exclusivement l'espadon. Un modèle linéaire généralisé binomial négatif a été utilisé pour évaluer de nombreux facteurs susceptibles d'affecter les taux de capture, dont l'année, le mois et la zone de pêche, ainsi que les caractéristiques des engins et les conditions environnementales. Des facteurs significatifs incluaient l'année, le mois, la zone, jour/nuit, espèce cible, utilisation de bâtons lumineux, température à la surface de la mer, type d'appât et type d'hameçon. Des indices d'abondance standardisés sont présentés ainsi que des estimations de l'incertitude moyenne pour les deux périodes. Dans l'évaluation de 2013, cet indice a été divisé en deux périodes afin de tenir compte du changement causé par le passage aux hameçons circulaires. Les analyses ultérieures des jeux de données indiquaient que le type d'hameçon pourrait être inclus comme un facteur du modèle dans le jeu de données des observateurs en vue de tenir compte des changements réglementaires, ayant principalement causé le passage des hameçons en forme de J aux hameçons circulaires et, dans certaines régions, aux hameçons circulaires « faibles ». 215

RESUMEN

Se analizaron los datos de observadores de palangre pelágico de Estados Unidos para estimar los índices anuales de abundancia de pez espada en el Atlántico occidental para el periodo, 1992 a 2015. Los datos consignados por los observadores fueron filtrados por lances dirigidos al pez espada exclusivamente. Se utilizó un modelo lineal generalizado binomial negativo para evaluar múltiples factores que podrían afectar a las tasas de captura, incluidos año, mes y zona de pesca, así como características del arte y condiciones medioambientales. Los factores significativos incluían año, mes, área, día/noche, especie objetivo, uso de bastones de luz, temperatura de la superficie del mar, tipo de cebo y tipo de anzuelo. Se presentan los índices de abundancia estandarizados junto con las estimaciones de incertidumbre media para ambos periodos. En la evaluación de 2013 este índice se dividió en dos periodos para tener en cuenta un cambio debido a la introducción de los anzuelos circulares. Los análisis subsiguientes de los conjuntos de datos *indicaron que el tipo de anzuelo podría incluirse como un factor de modelo en el conjunto de datos de observadores para tener en cuenta los cambios reglamentarios del paso del uso predominante de anzuelos en J a anzuelos circulares y, en algunas regiones, anzuelos circulares blandos. 207*

KEYWORDS

Catch/effort, commercial fishing, longline, swordfish

1. Introduction

The United States pelagic longline fishery has operated in the northwest Atlantic Ocean since the 1960s, primarily targeting swordfish, tunas, and occasionally sharks. An onboard observer program was initiated in 1992, with a target coverage of 5% of the deployed longline sets which was later expanded to 8% target coverage. Swordfish (*Xiphias gladius)* are targeted by the U.S. longline fleet and retained for commercial sale; however, several catch restrictions have been placed on swordfish, including minimum size regulations beginning in 1991, and the mandatory use of circle hooks beginning in 2004. Due to these regulatory restrictions, the use of observer recorded data is desirable to account for the discard of undersized swordfish, which may not be recorded in vessel catch logbooks. The observer database also contains information on the species targeted by the fleet, allowing for catch analyses based on vessels specifically targeting swordfish. It also includes detailed data on hook type and bait type which may allow for modeling of some regulatory changes related to these factors. Data from the pelagic observer program were analyzed to estimate standardized indices of abundance for swordfish in numbers. This report documents the analytical methods and provides standardized abundance indices for the period 1992 to 2015.

2. Material and methods

Several data exclusions were applied to the observer database, including the removal of bottom longline sets, non-swordfish targeted sets, and areas that had a closure regulation in effect during any time between 1992 and 2015. The one exception to closed area exclusion was the Northeast Distant Waters region which was closed to commercial fishing during 2001, 2002 and 2003; sets in this region were not excluded in other years. A complete list of data exclusions applied to this analysis is provided below. Gear configuration factors tested in this analysis included hook type (circle, J, weak circle or unknown), bait type (primarily squid, mackerel, or a mix of two bait types), lightsticks, day versus night setting.

2.1 Data exclusions

The following records were excluded from the U.S. pelagic longline logbook database for the analysis of swordfish standardized catch rates:

- Data from regions with closed area regulation in effect were excluded, going back in time, except the NED closed area was included as the 'closure' still allowed some exempted fishing. The Gulf of Mexico Bluefin tuna closure (April and May in part of the Gulf of Mexico) was also not modeled as a closed area since it was only in two months of the year starting in 2015. Further exploration the potential impact of this closure on SWO catch rates may be warranted.
- Records without a defined location
- Bottom longline sets
- Sets with hooks < 100, areas with fewer than 300 sets (TUN, TUS, UNK)

2.2 Data classifications

The following classifications were made to define factors:

Class variables:

- Dependent variable (number of swordfish kept and discarded)
- Year: 1992 to 2015
- Month
- Area: Florida East Coast (22 to 30 latitude, 71 to 82 longitude), Gulf of Mexico, Caribbean Sea, South Atlantic Bight (30 to 35 latitude, 71 to 82 longitude), Mid-Atlantic Bight (35 to 43 latitude, 71 to 78 longitude), Northeast Coastal Atlantic (35 to 45 latitude, 65 to 71 longitude and 35 to 50 latitude, 60 to 65 longitude), Northeast Distant Waters (35 to 55 latitude, 20 to 60 longitude), and Sargasso Sea (22 to 35 latitude, 60 to 71 longitude and 13 to 35 latitude, 20 to 60 longitude),Region: Gulf of Mexico and Caribbean, Atlantic Ocean north of 35 degrees latitude, and the Atlantic Ocean between 0 and 35 degrees latitude.
    - Bait Type: (DEAD FISH, LIVE , MIX_UNK, SQUID)
    - Hook_type: J-hook, circle-hook, weak circle hook and mix/unknown
    - Sea surface temperature in 2 degree C bins (0, 16, 18, 20, 22, 24, 34)
    - Seafloor depth (considered but not modeled)
    - Day versus night of set
    - Number of hooks between floats, modeled as a categorical factor:
        - c(0,2,seq(from=3,to=10,by=1),20, 320)
    - Effort, number of hooks set minus number of hooks lost and number of hooks bent. Ln(effort) used as a model offset
    - Target_species- a classification made by the observer based upon gear configuration and consultation with the captain of the target species for each set (BET DOL MIX SHX SWO TUN YFT)

2.3 Generalized linear models

An individual longline set was considered a sample unit with fishing effort measured as number of hooks. The catch of swordfish was modeled as the number of fish per set with log(effort) offset. The standardization analysis used a generalized linear model (GLM) of swordfish catch as a linear function of fixed factors, with an assumed negative binomial distribution and using a log link. Factors considered included year, month, area, gear configuration (hook type and bait type), and environmental conditions (sea surface temperature).

A stepwise approach was used to quantify the relative importance of the main factors explaining the variance in catch. That is, first the Null model was ran, in which no factors were entered in the model (intercept only model). These results reflect the distribution of the nominal data. Each potential factor was then tested iteratively. The results were ranked from greatest to least reduction in percent deviance when compared to the Null model. The factor which resulted in the greatest reduction in deviance was then incorporated into the model, provided two conditions were met: 1) the effect of the factor was determined to be significant based on AIC model selection criteria, and 2) the deviance per was reduced by at least 1% from the less complex model. This process was repeated, adding factors one at a time at each step, until no factor met the criteria for incorporation into the final model or the model demonstrated a lack of convergence. Note that models with two-way factor interactions demonstrated poor model convergence. Model fitting was performed in R using the glm.nb() function. Least-square means were obtained either with the R package LSmeans (Lenth 2012), or when large matrix memory issues precluded a solution in R, were obtained by estimating the same model in SAS. SAS and R estimates gave exactly similar answers for when a reduced model was compared between the two. Standardized indices are presented in numbers along with estimates of uncertainty.

Models:

Initial (full) model (for dataset without Experimental data)
SWO~TARGET_SPECIES+fNight +area +lghtc +fYear+fMonth+BAIT+fSST+hooktype +fHBFL + EXPERIMENTAL_TREATMENT + offset(ln_effort)

Final (reduced) model
SWO~TARGET_SPECIES+fNight +area +lghtc +fYear+fMonth+BAIT+fSST+ EXPERIMENTAL_ TREATMENT + hooktype +offset(ln_effort)

Note that the models without experimental data did not use EXPERIMENTAL_TREATMENT and the models without other target species data did not use TARGET_SPECIES.

3. Results and Discussion

3.1 Geographic coverage

The spatial distributions of observer longline sets used in the analysis are shown in **Figure 1.** Data are in number of sets per 5 degree longitude by 5 degree latitude spatial cell. In general, the geographic coverage of the data included the eastern Gulf of Mexico, Caribbean Sea, U.S. east coast, Grand Banks, and Sargasso Sea. Notable trends in the geographical distribution of sets include the closure of the Northeast Atlantic distant waters (Grand Banks area) during 2001 through 2003, and decreased effort in offshore waters over the last decade compared to the 1990s, indicating fleet contraction Sample sizes ranged in the tens to hundreds of samples per individual stratum (**Figure 2**). Nominal mean catch rates, number of swordfish, proportion positive and sample size by model factors indicate the relative influence of factors and distribution of samples (**Figure 3**). Time series of nominal CPUE by area with and without experiment sets and without closed areas indicates little effect of including or excluding the experimental sets but a substantial historical impact if the closed area data was included back in time, particularly for the FEC and the GOM (**Figure 4**). The FEC closure was put in place to protect juvenile SWO, hence the steep decline in the nominal data is due to a shift out of the Straits of Florida to the remaining open part of the FEC.

3.2 Time Series Continuity

The observer time series ran from 1992 to 2015.

3.3 Standardized Indices

Year, month, area, bait type, target_species, night vs day set, use of light sticks and sst were identified as significant factors in the negative binomial regression of swordfish catches. Hook type was also used in the final model, despite it accounting for a small percentage of the deviance because it was an important regulatory impact due to the mandated change to circle hooks after 2004 and the regulations to use weak hooks in the Gulf of Mexico in 2011. Target species demonstrated the largest reduction in model residual deviance, followed by night versus day (**Table 1**). Overall the modeled categories strongly differentiated swordfish targeted sets from other species. Results from the model development procedure and the final selected models are listed in **Table 1**. Descriptive statistics and annual standardized indices are presented in **Table 2**. Nominal and model estimated mean catch and yield rates and 95% confidence intervals are shown in **Figures 4**. In general, with the index showed peaks in relative abundance during the late 1990s and 2000s.

Overall, given the very slight differences between the parameter estimates for hook and bait type categories for the index with and without the experimental data (**Figure 6**) and the substantially greater number of parameters it does not seem necessary to include to experimental data to estimate a hook and bait type effect that could capture the regulatory shifts and allow continuity of this index. Hence it is recommended to remove the experimental sets for the final index (**Figure 7**).

Similarly, a previous iteration of this index used just targeted sets, however the index without targeting data has a much higher average CV(0.23) versus the index with only SWO targeted sets (**Figure 8**). Hence it is recommended to use all targeted sets and the model categories to account for changes in fishing due to differential targeting.

3.4 Model diagnostics

The negative binomial probability distribution demonstrated relatively good fit to the observed catch rates tails (**Figure 5**). Overall parameter estimates were well determined (**Figure 6**).

3.5 Final recommended model

The final model recommended by the authors uses all target categories, but removes experimental sets (**Figure 9**). The modeled index shows fairly substantial divergence from the nominal commensurate with a general increase in the proportion of sets targeting species other than SWO (**Figure 2**) by the U.S. fleet.

3.6 Size structure of swordfish

Swordfish sizes ranged from approximately 40 to 290 cm lower-jaw fork length, with the highest catches of fish between 100 and 150 cm (**Figure 10**). Both kept and discarded fish are measured and shown in Figure 9. Mean size differs by area **(Figure 11**) with the largest fish observed in the more northern regions, generally. Note that the fish observed in the closed areas have not been removed from these length frequencies, which might be desirable if this length comp (and the discards) are used in an integrated model. The dashed blue lines represent the current size limits.

Table 1. Atlantic swordfish indices negative binomial glm selection criteria summary using deviance reduction by iterative inclusion of fixed factors.

Factors	*Df*	*Deviance*	*AIC*	*PercRed*
<none>		21703.26	117832.8	0.00
fYear	23	20328.76	116504.3	6.33
fMonth	11	20868.79	117020.4	3.84
area	8	18152.53	114298.1	16.36
fSST	5	20446.91	116586.5	5.79
hooktype	3	20512.95	116648.5	5.48
BAIT	3	20410.86	116546.4	5.95
fHBFL	10	20618.26	116767.8	5.00
TARGET_SPECIES	6	13698	109839.6	36.89
lghtc	3	14086.62	110222.2	35.09
fNight	1	15922.44	112054	26.64
EXPERIMENTAL_TREATMENT	19	19998.38	116166	7.86
TARGET_SPECIES+		21011.88	107656.7	0.00
fYear	23	19965.75	106656.6	4.98
fMonth	11	20465.1	107132	2.60
area	8	19808.51	106469.4	5.73
fSST	5	20424.39	107079.3	2.80
hooktype	3	20284.34	106935.2	3.46
BAIT	3	20782.15	107433	1.09
fHBFL	10	20707.94	107372.8	1.45
lghtc	3	19655.64	106306.5	6.45
fNight	1	19474.05	106120.9	7.32
EXPERIMENTAL_TREATMENT	19	20524.91	107207.8	2.32
TARGET_SPECIES+fNight		20623.56	106078.5	0.00
fYear	23	19758.95	105259.9	4.19
fMonth	11	20156.58	105633.5	2.26
area	8	19527.36	104998.3	5.32
fSST	5	20192.06	105657	2.09
hooktype	3	20201.53	105662.4	2.05
BAIT	3	20352.73	105813.6	1.31
fHBFL	10	20359.22	105834.1	1.28
lghtc	3	19962.54	105423.4	3.21
EXPERIMENTAL_TREATMENT	19	20186.62	105679.5	2.12
TARGET_SPECIES+fNight+area		20720.89	104952.1	0.00
fYear	23	20007.58	104284.8	3.44
fMonth	11	20232.38	104485.6	2.36
fSST	5	20365.64	104606.9	1.71
hooktype	3	20419.29	104656.5	1.46
BAIT	3	20548.49	104785.7	0.83
fHBFL	10	20532.63	104783.9	0.91
lghtc	3	19834.8	104072	4.28
EXPERIMENTAL_TREATMENT	19	20322.44	104591.7	1.92
TARGET_SPECIES+fNight+area+lightc		20564.14	104050.3	0.00
fYear	23	19851.35	103383.5	3.47
fMonth	11	20136.15	103644.3	2.08
fSST	5	20276.7	103772.9	1.40
hooktype	3	20280.79	103772.9	1.38
BAIT	3	20417.53	103909.7	0.71

fHBFL	10	20408.04	103914.2	0.76
EXPERIMENTAL_TREATMENT	19	20076.55	103600.7	2.37
TARGET_SPECIES+fNight+area+lightc+fyear		20534.83	103372.1	0.00
fMonth	11	20114.12	102973.4	2.05
fSST	5	20198.25	103045.5	1.64
hooktype	3	20429.96	103273.2	0.51
BAIT	3	20242.97	103086.2	1.42
fHBFL	10	20416.41	103273.7	0.58
EXPERIMENTAL_TREATMENT	19	20142.43	103017.7	1.91
TARGET_SPECIES+fNight+area+lightc+fyear+month		20479.19	102971.5	0.00
fSST	5	20265.47	102767.8	1.04
hooktype	3	20354.66	102852.9	0.61
BAIT	3	20183.27	102681.6	1.44
fHBFL	10	20381.57	102893.9	0.48
EXPERIMENTAL_TREATMENT	19	20108.97	102639.3	1.81
<none>7		20480.45	102633.2	0.00
fSST	5	20271.21	102433.9	1.02
hooktype	3	20453.8	102612.5	0.13
BAIT	3	20181.11	102339.8	1.46
fHBFL7	10	20390.73	102563.5	0.44
TARGET_SPECIES+fNight+area+lightc+fyear+month+ EXPERIMENTAL_TREATMENT+BAIT		20434.07	102338.6	0.00
fSST	5	20233.32	102147.8	0.98
hooktype	3	20407.56	102318	0.13
fHBFL	10	20353.16	102277.6	0.40
TARGET_SPECIES+fNight+area+lightc+fyear+month+ EXPERIMENTAL_TREATMENT+BAIT+fSST		20416.57	102145.7	0.00
hooktype	3	20382.11	102117.3	0.17
fHBFL	10	20332.84	102082	0.41
TARGET_SPECIES+fNight+area+lightc+fyear+month+ EXPERIMENTAL_TREATMENT+BAIT+fSST+hooktype+		20498.08	102456.2	0.00
area:fMonth	65	19234.28	101322.3	6.17*
BAIT:hooktype	8	20473.54	102447.6	0.12
area:fYear	156	19382.26	101652.3	5.44*

*Poor model convergence, likely due to overparameterization.

Table 2. Summary statistics and standardized catch indices (catch in numbers per unit effort) of swordfish from the United States pelagic observer program database.

year	*Nsets*	*Experimental sets*	*SWO Target sets*	*Total Swo*	*Effort (hooks)*	*Prop Pos*	*Nominal CPUE*	*Scaled INDEX*	*CV*
1992	262	0	115	2595	158837	0.905	18.024	0.993	0.092
1993	703	0	255	5114	477277	0.824	12.496	0.941	0.081
1994	521	0	179	4215	357035	0.827	13.39	0.968	0.084
1995	625	0	251	5384	433991	0.824	13.877	0.962	0.082
1996	262	0	137	1744	166465	0.794	14.27	0.804	0.094
1997	364	0	115	2649	260696	0.832	11.246	0.95	0.088
1998	235	0	98	2204	150749	0.911	20.281	1.379	0.094
1999	336	0	120	3491	234702	0.851	16.893	1.286	0.088
2000	410	0	161	4050	282424	0.834	15.031	0.99	0.087
2001	759	373	468	9173	435549	0.931	26.589	0.882	0.089
2002	852	505	630	13051	688484	0.979	19.016	1.081	0.088
2003	1086	538	718	15748	992666	0.96	16.106	0.944	0.084
2004	703	62	347	6197	523696	0.872	12.637	0.81	0.079
2005	790	240	299	7442	573321	0.886	14.937	1.159	0.083
2006	554	0	181	4617	409072	0.91	12.292	1.075	0.083
2007	929	0	196	7218	700606	0.888	10.976	1.347	0.081
2008	1262	78	215	8643	931142	0.796	9.918	1.249	0.08
2009	1518	151	267	9656	1137299	0.812	8.883	1.035	0.079
2010	1005	136	285	4971	738988	0.7	7.43	0.736	0.08
2011	879	15	431	6489	572717	0.85	12.441	1.011	0.081
2012	1042	115	268	5895	694412	0.808	9.327	1.025	0.08
2013	1511	54	497	8619	1014908	0.795	8.883	0.92	0.079
2014	1222	16	414	5827	856490	0.75	7.116	0.719	0.08
2015	1092	0	301	5124	678389	0.691	8.036	0.733	0.08

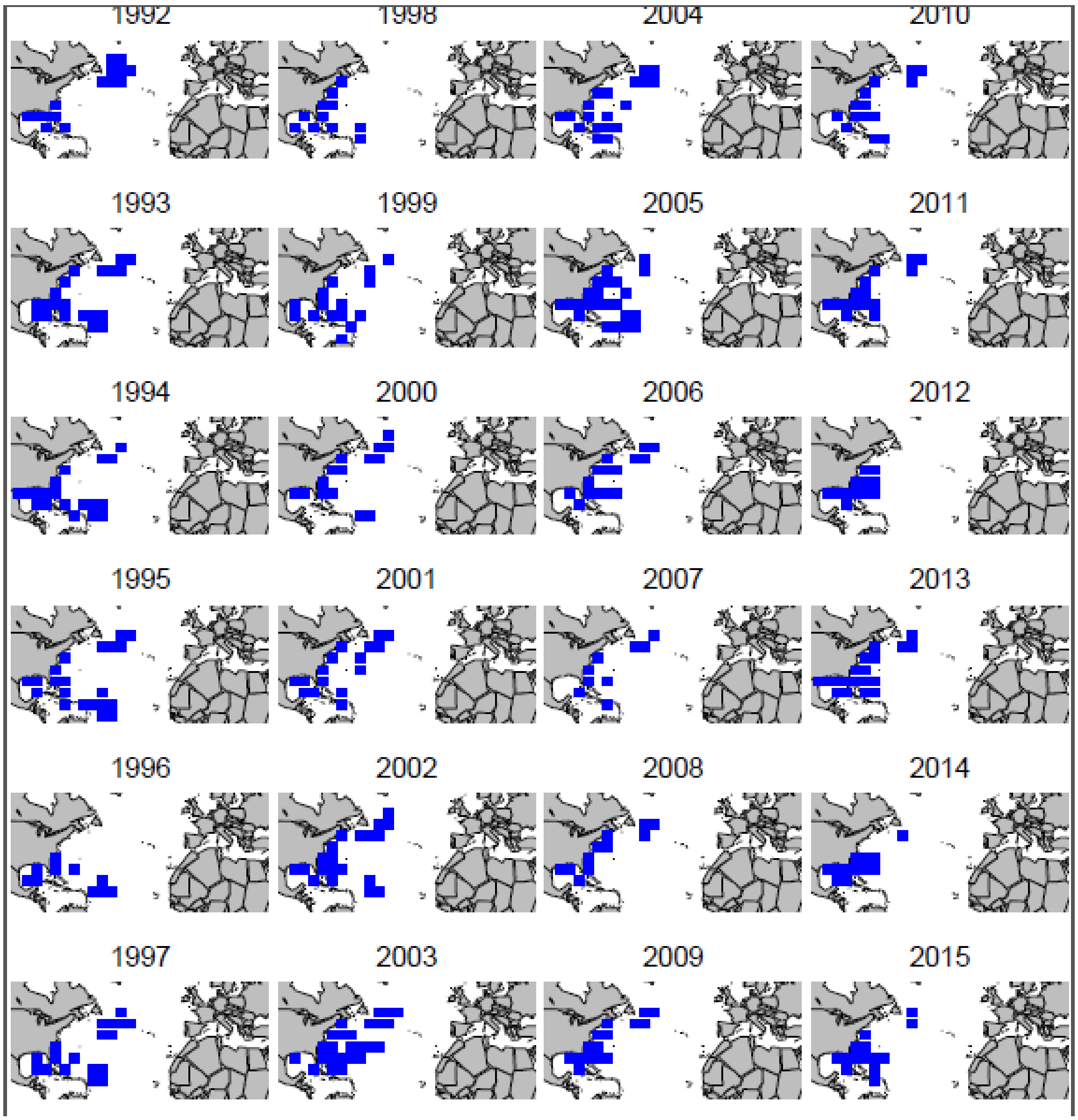

Figure 1. Spatial distribution of pelagic longline observer samples.

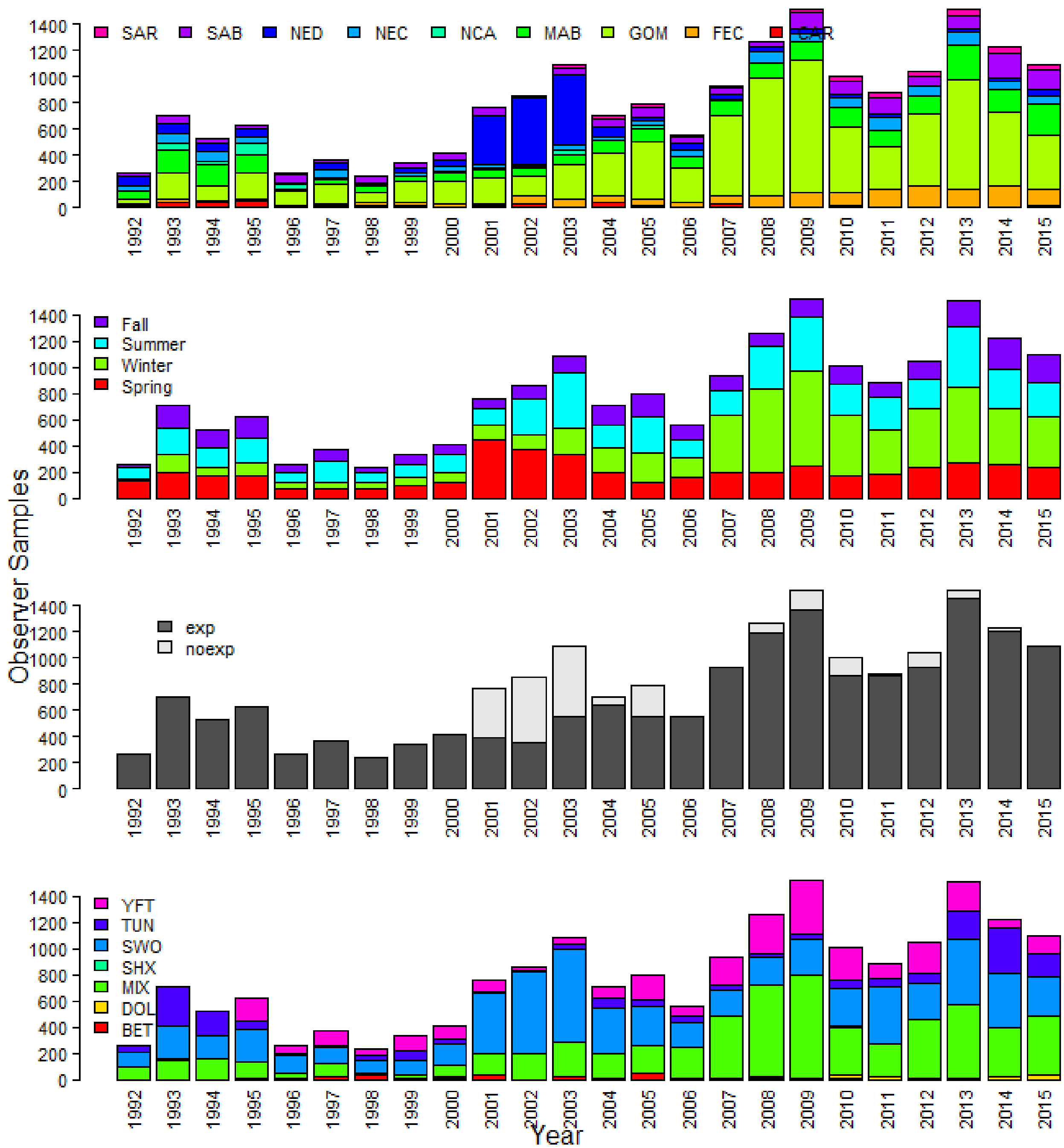

Figure 2. Yearly sample sizes of swordfish targeted longline sets per region and season strata.

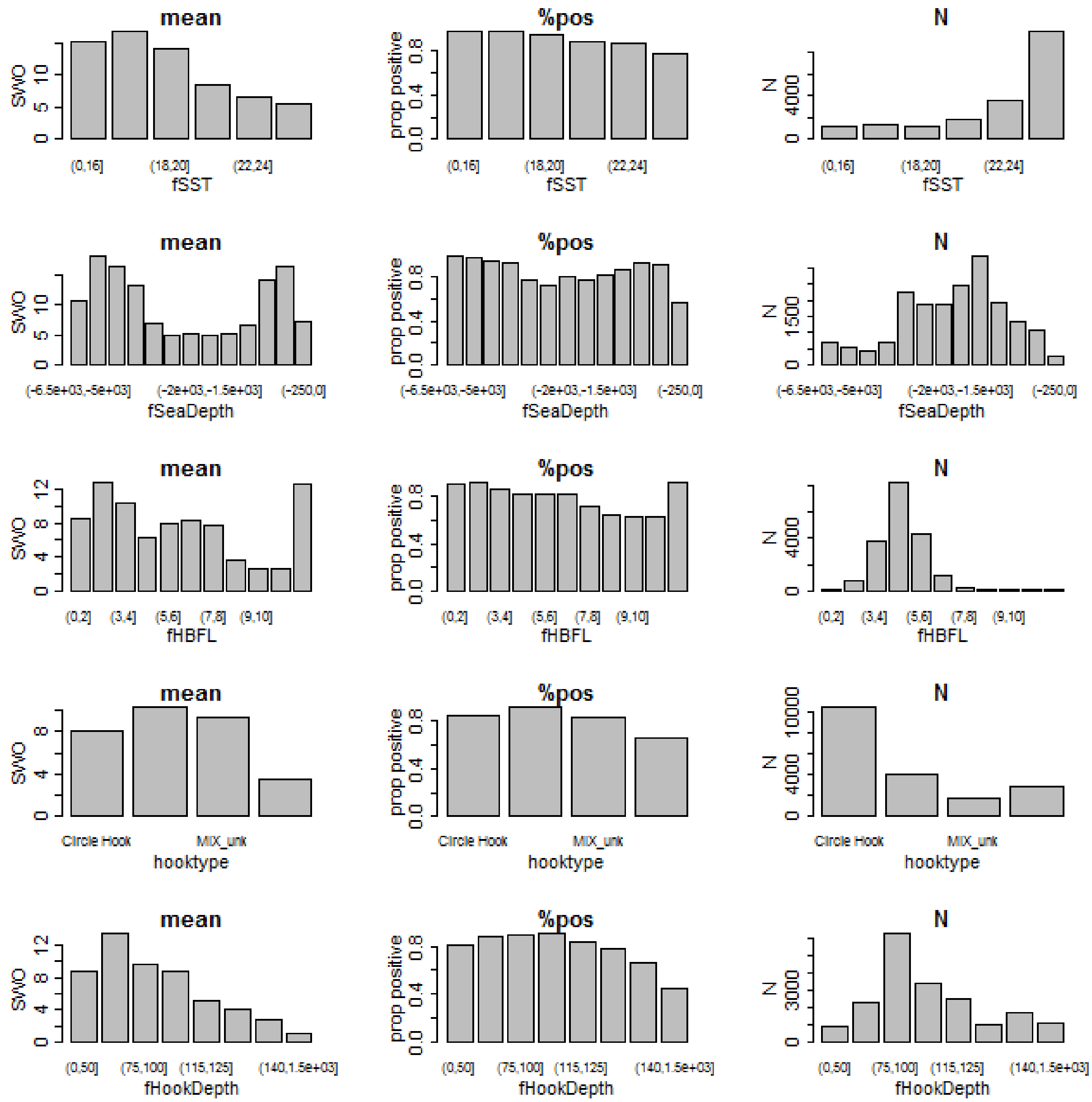

Figure 3. Mean swordfish per set(kept and released, in number), proportion positive and number of sets by factor categories.

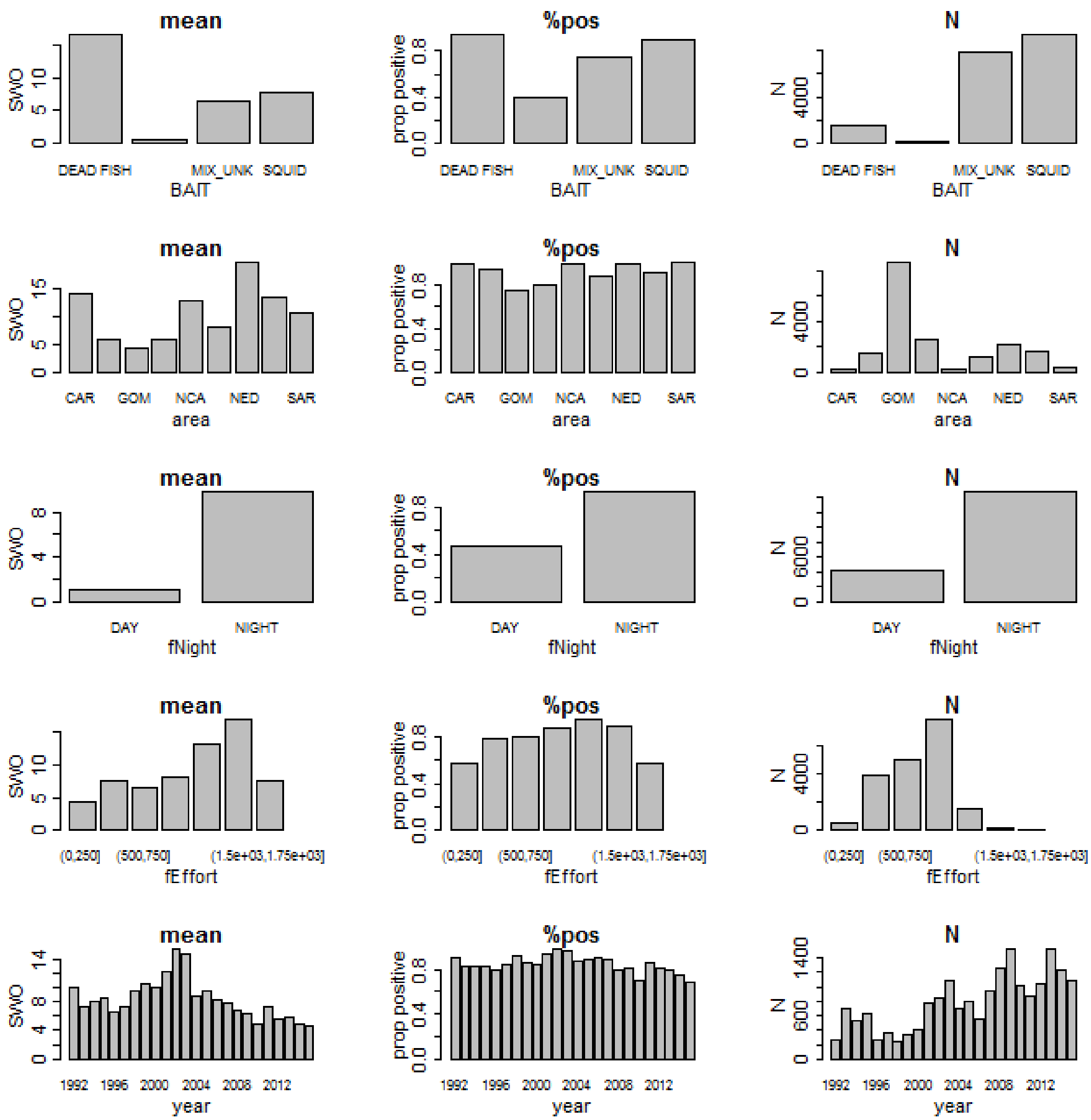

Figure 3. Cont. Mean swordfish per set(kept and released, in number), proportion positive and number of sets by factor categories.

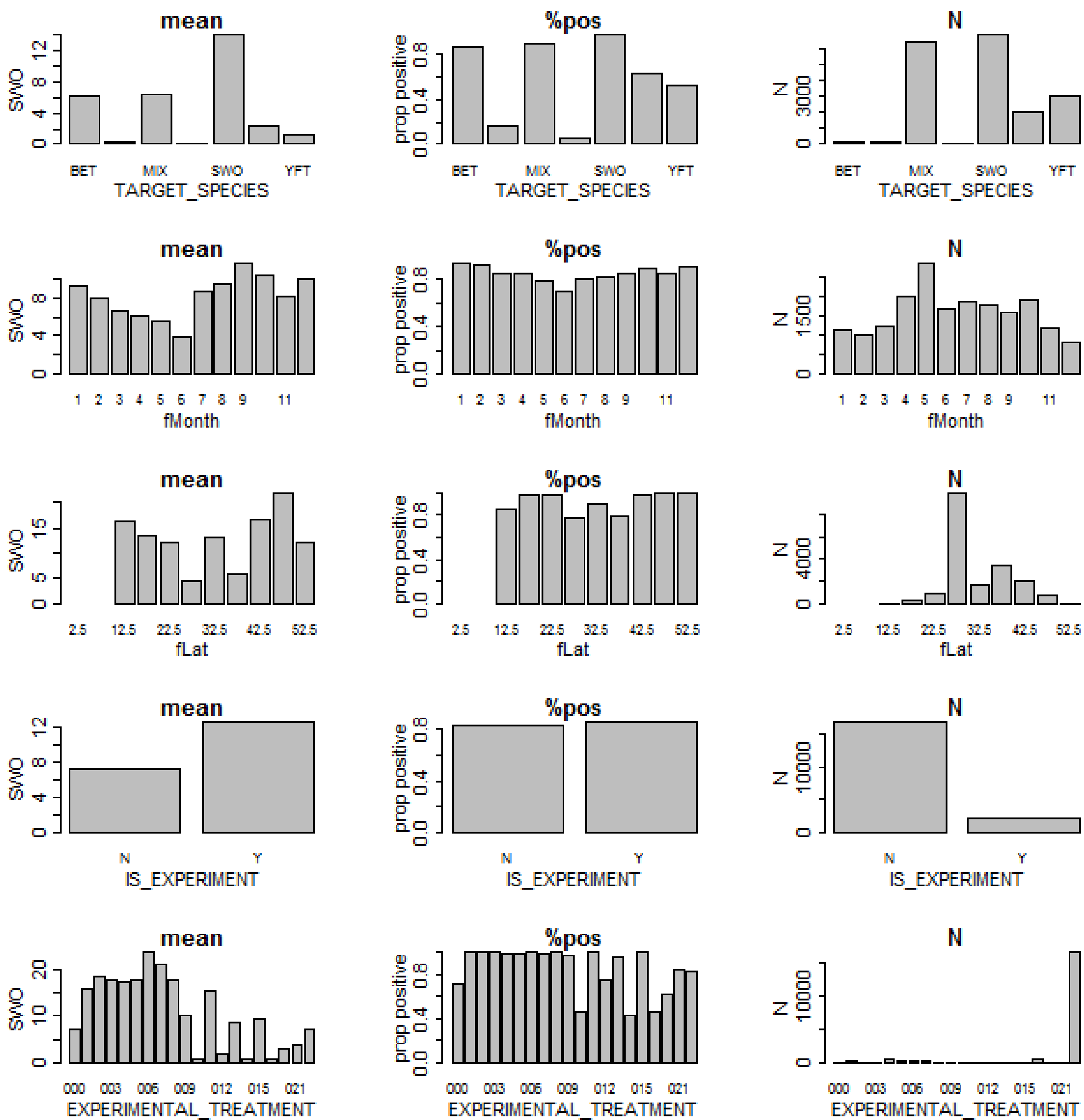

Figure 3. Cont. Mean swordfish per set(kept and released, in number), proportion positive and number of sets by factor categories.

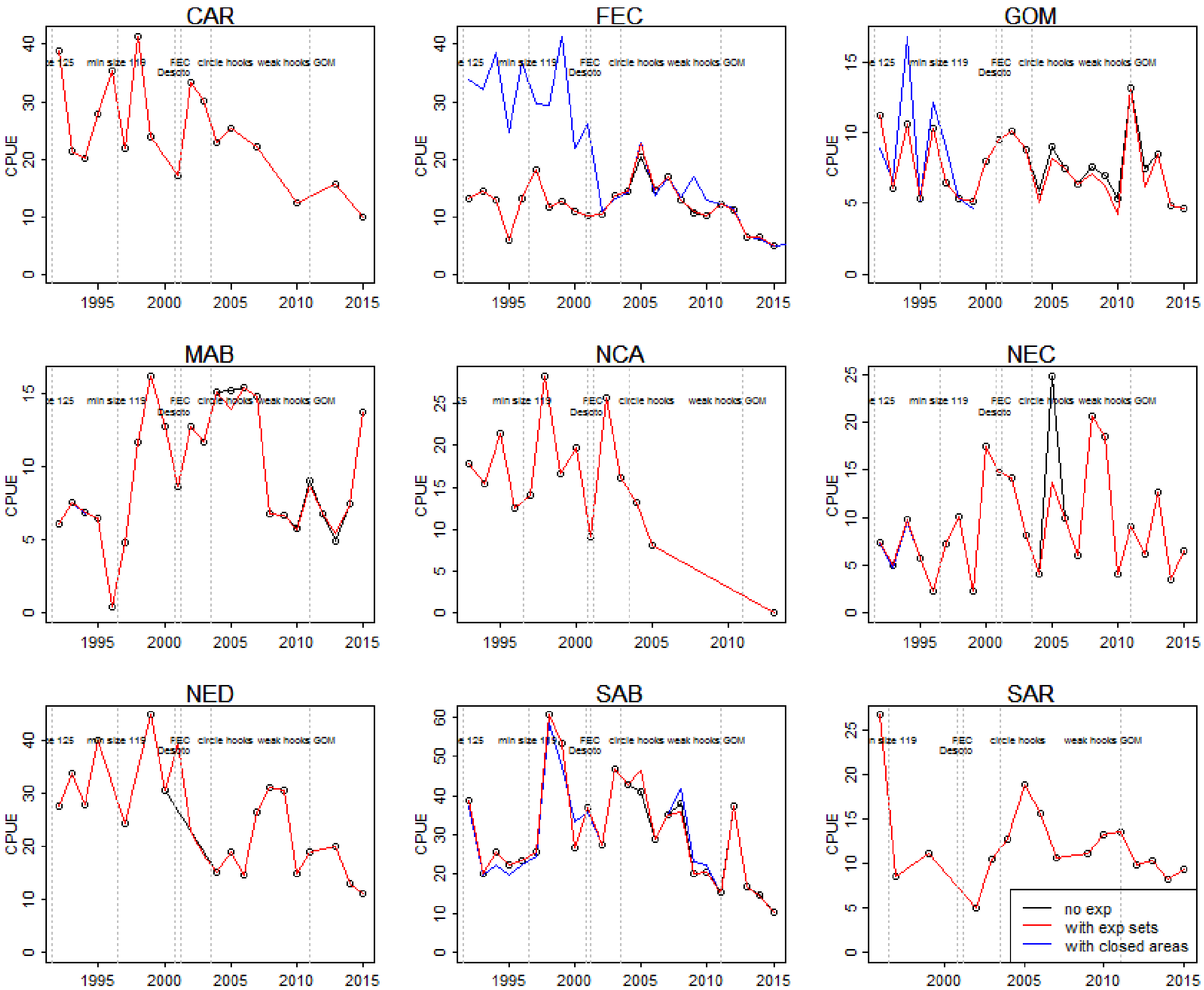

Figure 4. Nominal CPUE by area without (black) and with (red) experimental sets. Blue lines are the data set without removing the areas that were subsequently closed.

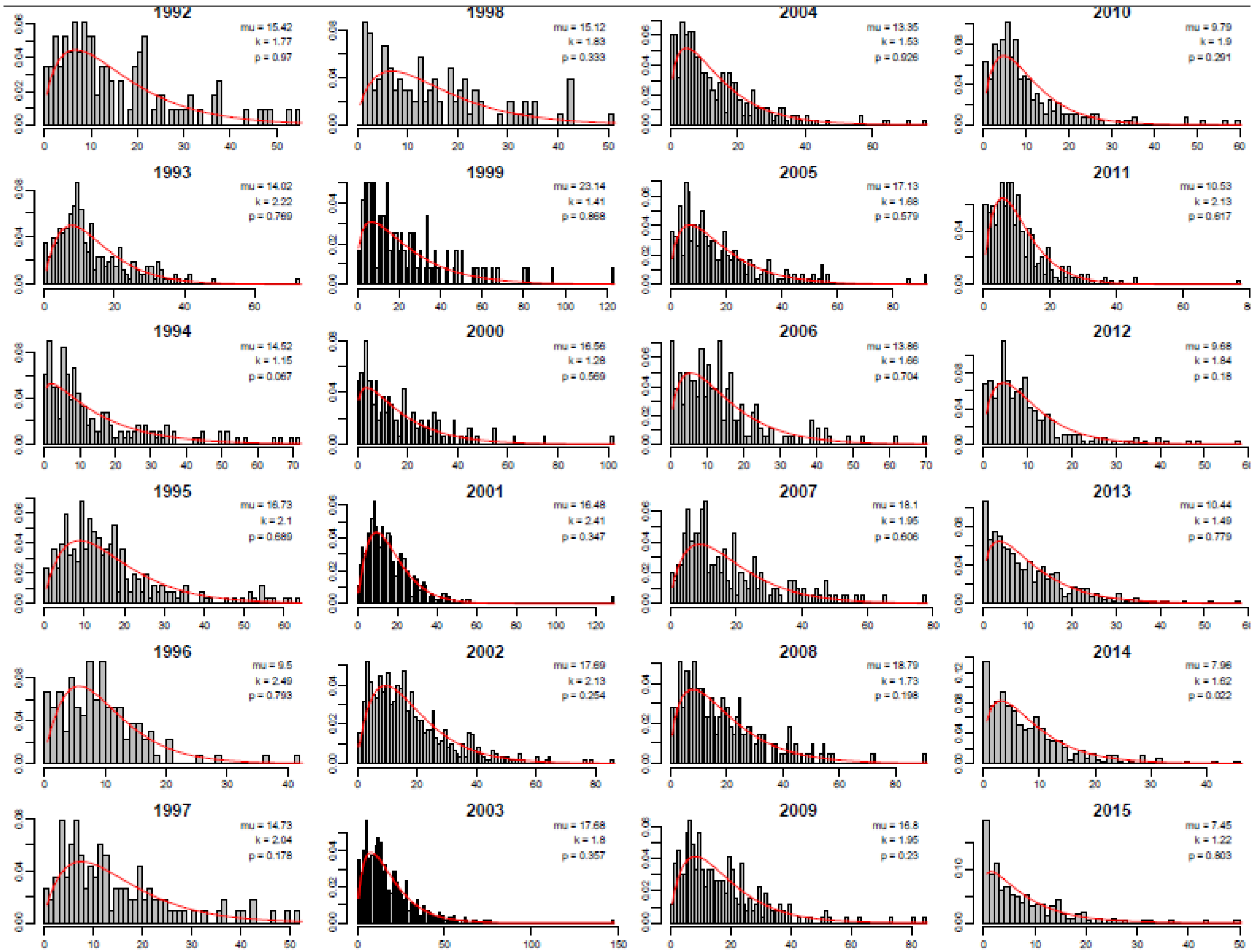

Figure 5. Observed distribution of swordfish catches (numbers) and negative binomial model fits.

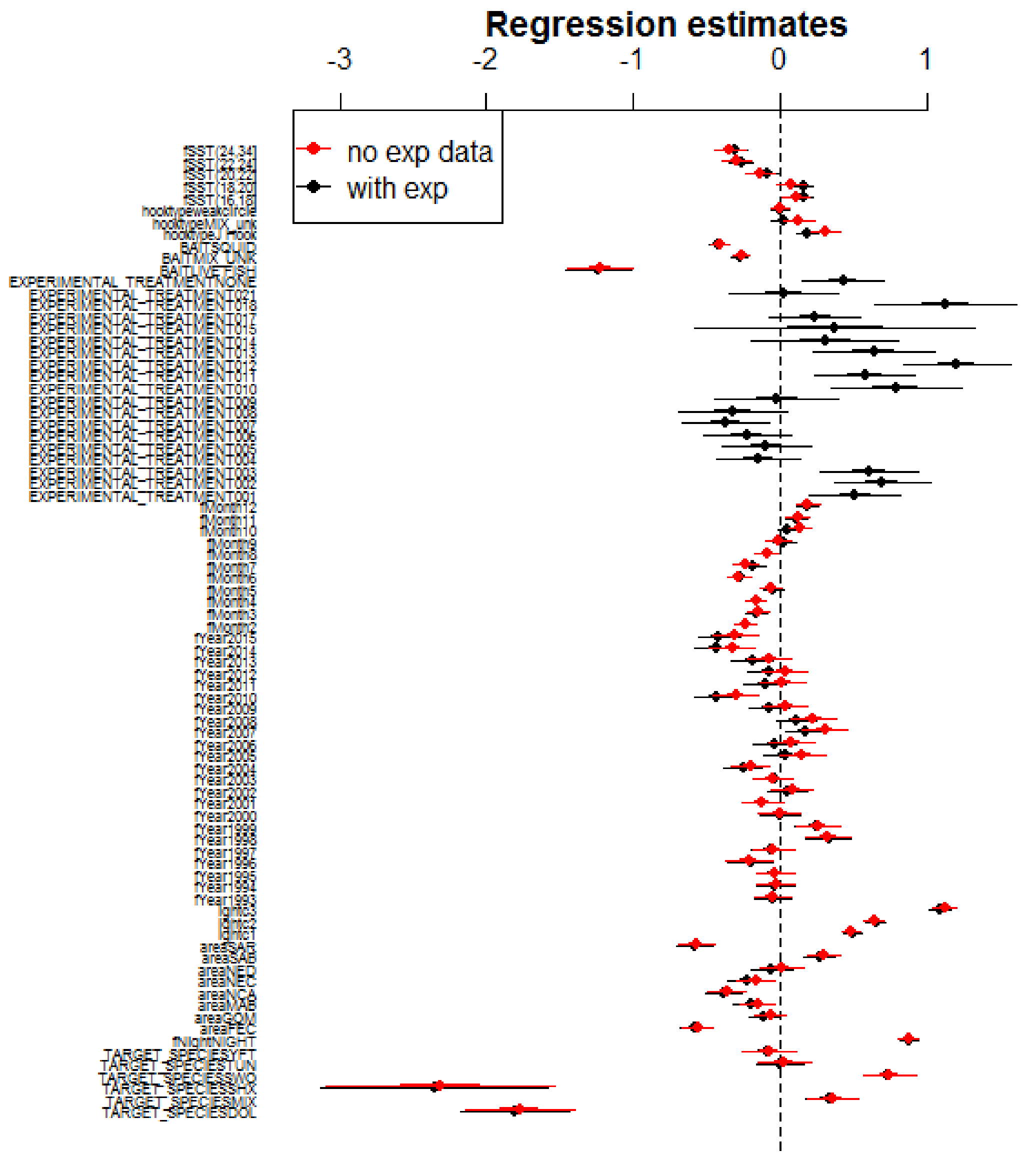

Figure 6. Regression parameter estimates from negative binomial models using all data (black) and excluding experimental data (red).

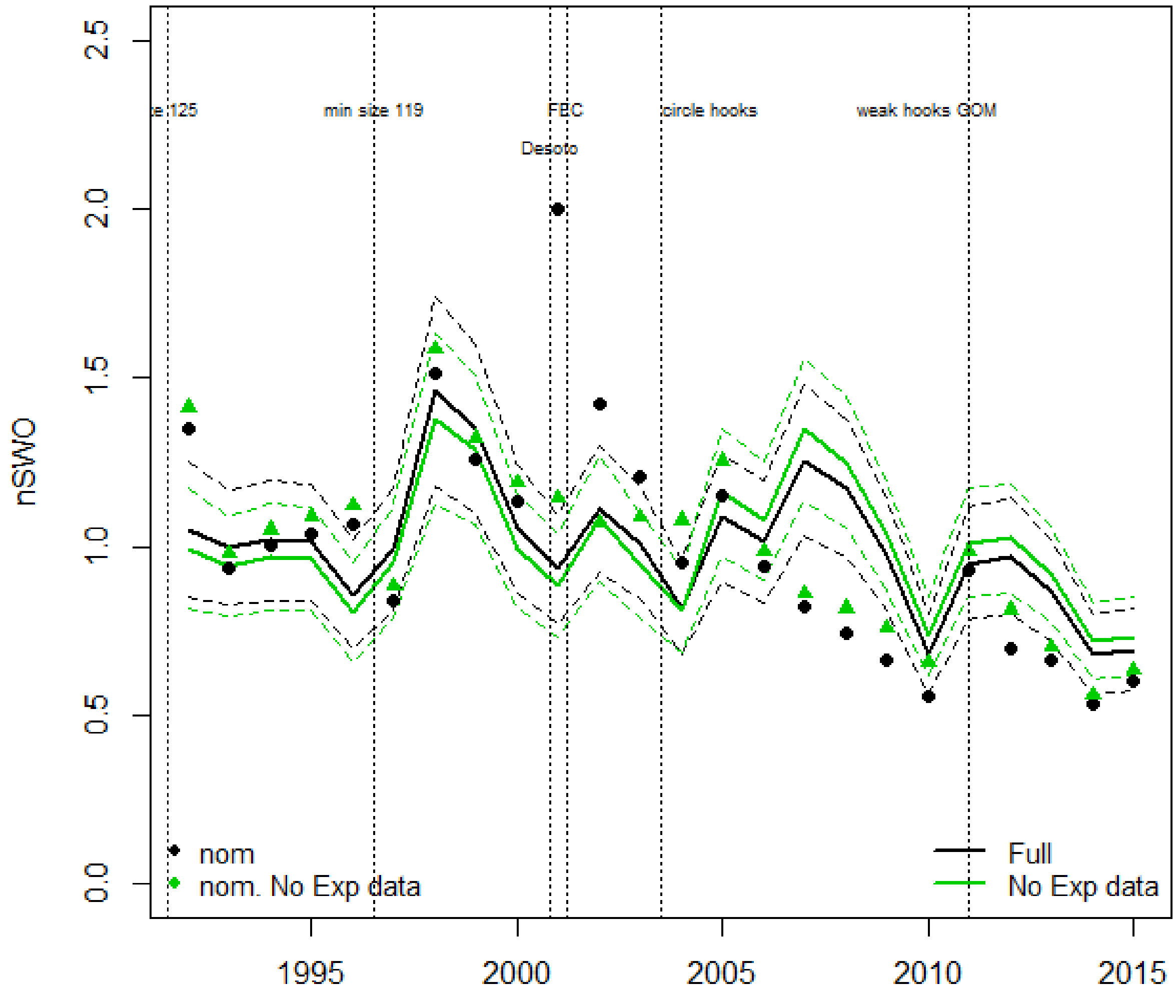

Figure 7. Index with all data or excluding experimental data. The index is similar (R2=0.9); the average CV of the all non-experimental sets (0.08) is slightly lower than that of all sets (0.09).

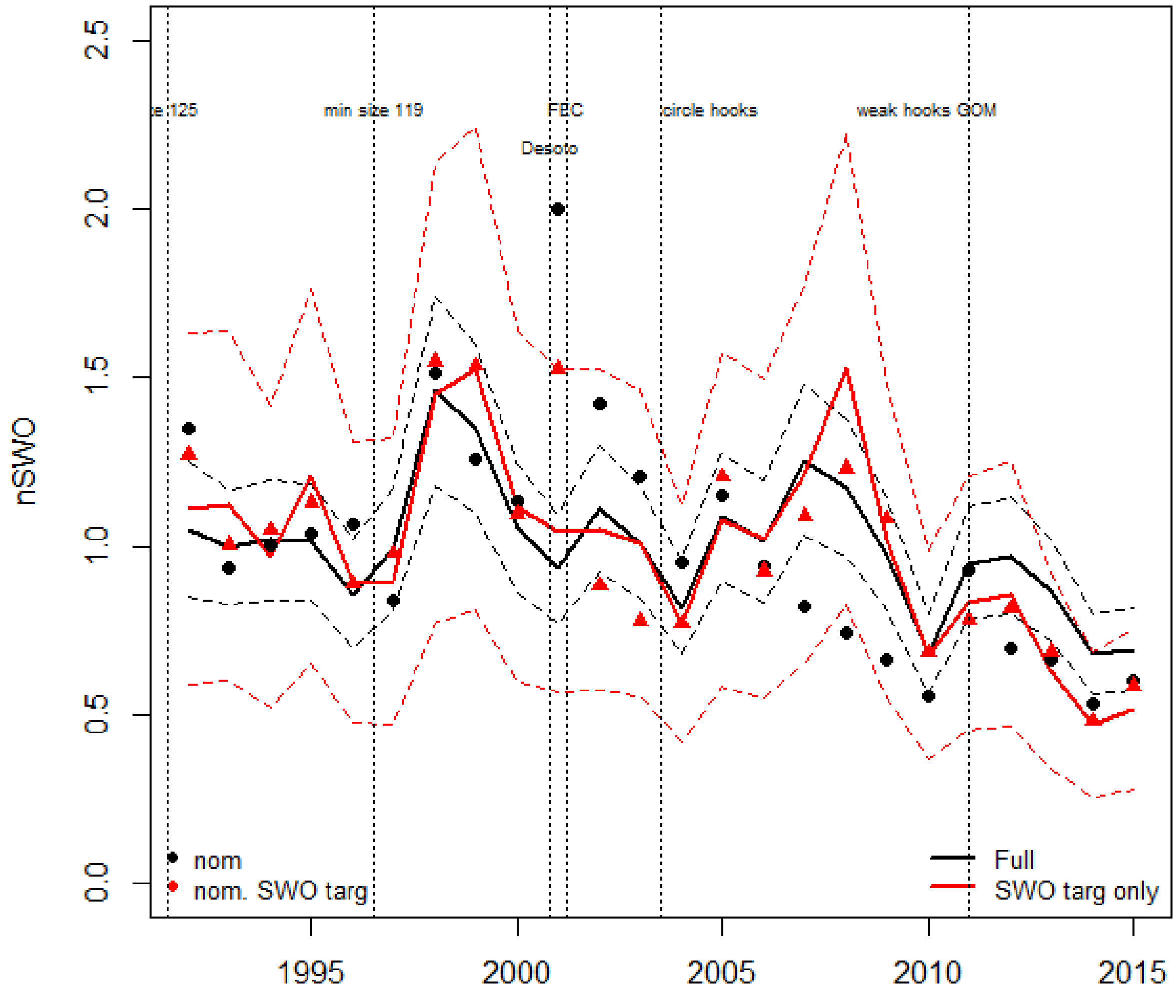

Figure 8. Index with all targeting categories or with only sword targeted sets. The index is similar (0.82), however the average CV of the all targeting sets (0.09) is lower than that of just the SWO targeted (0.24).

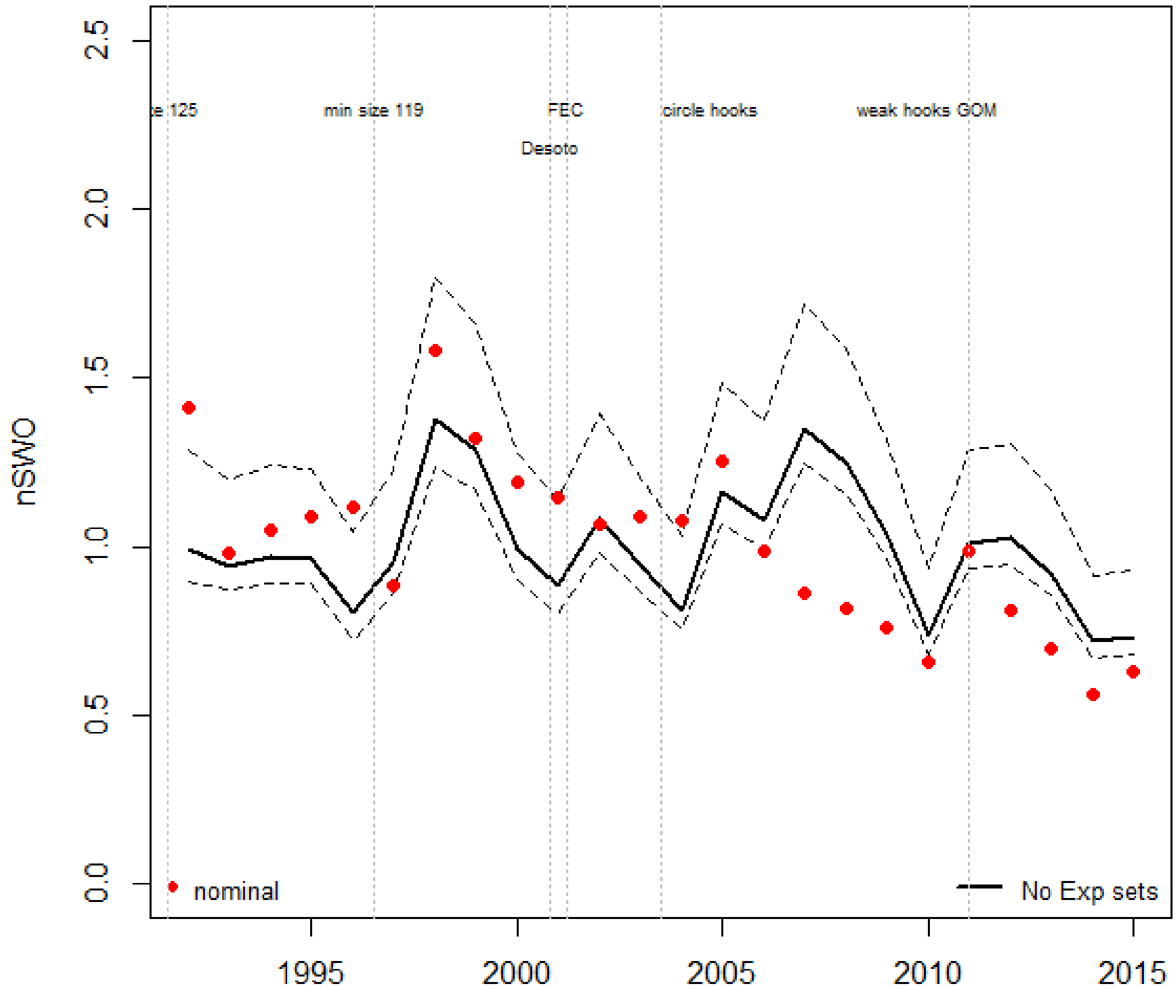

Figure 9. Final recommended model with experimental sets removed, and all target categories included.

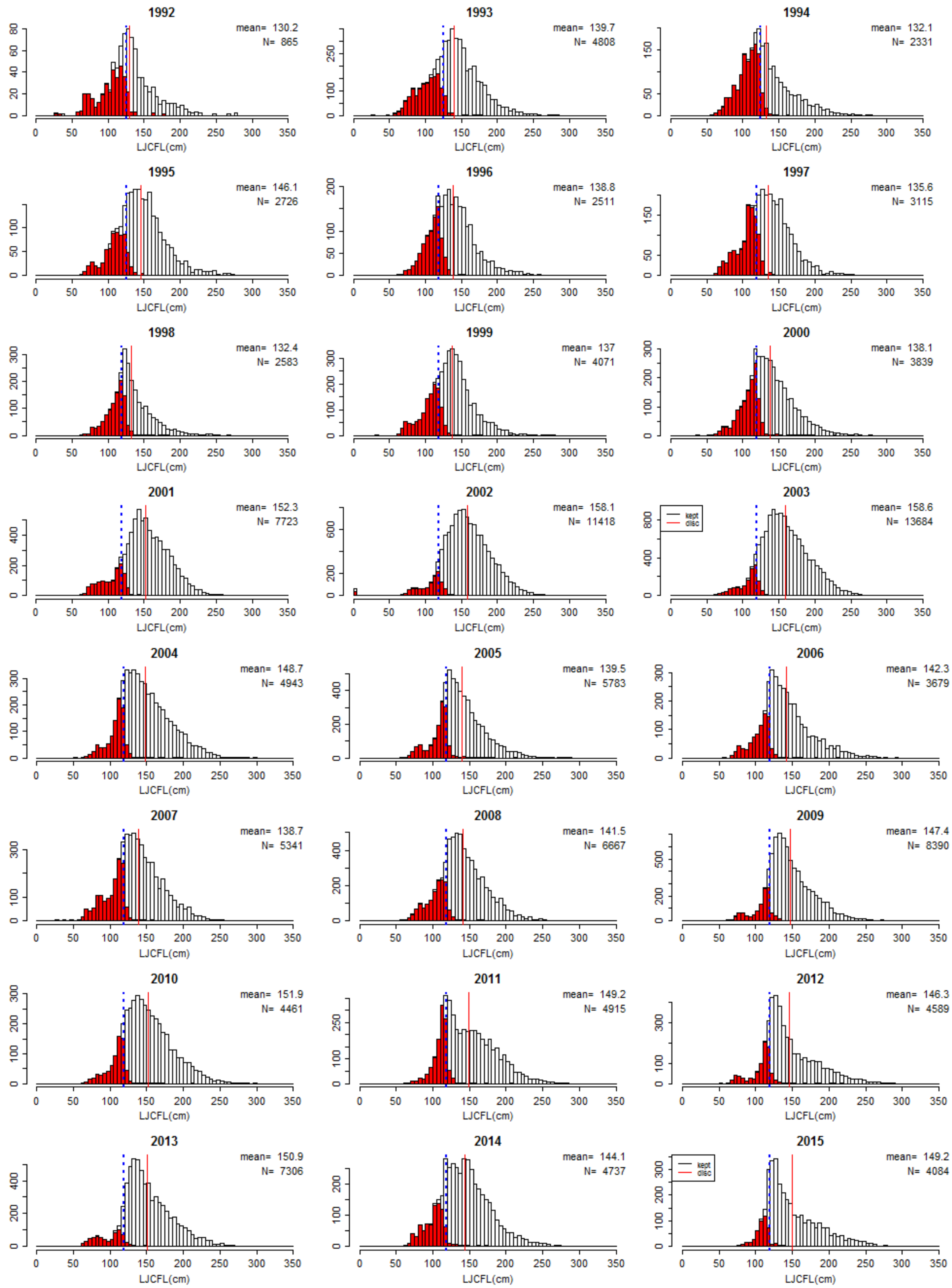

Figure 10. Size (cm lower jaw fork length frequency distributions of swordfish measured by onboard observers of swordfish targeted trips during 1992 to 2015. Red bars are discarded fish, dashed blue lines are size limits in place at the time and red lines are the mean size in each year.

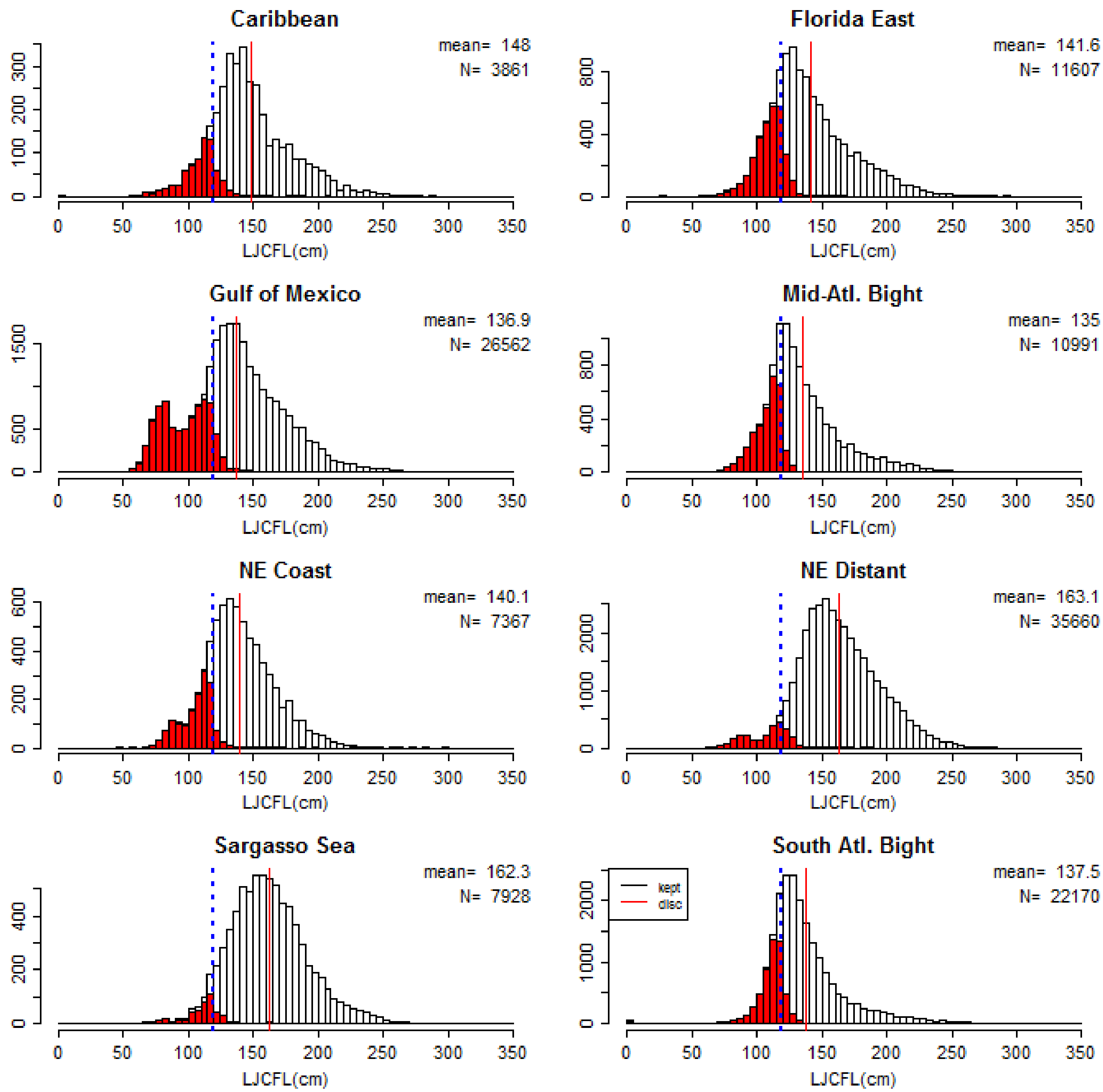

Figure 11. Size (cm lower jaw fork length) frequency distributions of swordfish measured by onboard observers of swordfish targeted trips during 1992 to 2015 by area. Red bars are discarded fish, dashed blue lines are size limits and red lines are the mean size in each year.