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UPDATED COMBINED BIOMASS INDEX OF ABUNDANCE OF NORTH ATLANTIC SWORDFISH STOCK 1963-2015

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SUMMARY

Surplus Production Models of North Atlantic swordfish have been used in addition to age structured virtual population analyses by ICCAT's SCRS to evaluate the status of the resource and to provide a basis for management advice. Production models require a standardized index of relative abundance in terms of biomass. The standardized biomass index of abundance developed for the 2006, 2008 and 2012 ICCAT SCRS meetings for North Atlantic swordfish was revised and updated with data through 2015. Generalized Linear Modeling (GLM) procedures were used to standardize swordfish catch (biomass) and effort (number of hooks) data from the major longline fleets operating in the North Atlantic; United States, EU-Spain, Canada, Japan, Morocco and EU-Portugal. As in past analyses, main effects included: year, area, quarter, a nation-operation variable accounting for gear and operational differences thought to influence swordfish catchability, and a target variable to account for trips where fishing operations varied according to the main target species. Interactions among main factors were also evaluated.

RÉSUMÉ

Le SCRS de l'ICCAT a utilisé des modèles de production excédentaire de l'espadon de l'Atlantique Nord en plus des analyses de population virtuelle structurée par âge afin d'évaluer l'état de la ressource et de fournir une base pour l'avis de gestion. Les modèles de production nécessitent un indice standardisé d'abondance relative en termes de biomasse. L'indice standardisé de l'abondance de la biomasse qui a été mis au point pour les réunions du SCRS de l'ICCAT de 2006, 2008 et 2012 pour l'espadon de l'Atlantique Nord a été révisé et actualisé avec des données allant jusqu'en 2015 y compris. Des procédures du modèle linéaire généralisé (GLM) ont été utilisées afin de standardiser les données de capture (biomasse) et d'effort (nombre d'hameçons) de l'espadon provenant des principales flottilles palangrières opérant dans l'Atlantique Nord : États-Unis, UE-Espagne, Canada, Japon, Maroc et UE-Portugal. Comme lors des analyses antérieures, les principaux effets incluaient : année, zone, trimestre, une variable nation-opération tenant compte des différences d'engins et d'opérations censées influencer la capturabilité de l'espadon, une variable cible pour tenir compte des sorties où les opérations de pêche ont varié en fonction des principales espèces cibles. Les interactions entre les principaux facteurs ont également été évaluées.

RESUMEN

El SCRS de ICCAT ha utilizado los modelos de producción excedente de pez espada en el Atlántico norte junto con los análisis de población virtual estructurados por edad para evaluar el estado del recurso y proporcionar una base para el asesoramiento en materia de ordenación. Los modelos de producción requieren un índice estandarizado de abundancia relativa en términos de biomasa. El índice de abundancia estandarizado en términos de biomasa desarrollado para las reuniones del SCRS de 2006, 2008 y 2012 para el pez espada del Atlántico norte fue revisado y actualizado con datos hasta 2015 inclusive. Se utilizaron los

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procedimientos de modelación lineal generalizados (GLM) para estandarizar los datos de captura (biomasa) y el esfuerzo (número de anzuelos) de pez espada de las principales flotas de palangre que operan en el Atlántico norte: Estados Unidos, UE-España, Canadá, Japón, Marruecos y UE-Portugal. Como en pasados análisis, los efectos principales incluían: año, área, trimestre, una variable nación-operación que refleja las diferencias de arte y operativas que se cree que influyen en la capturabilidad del pez espada y una variable objetivo para tener en cuenta las mareas en las que las operaciones pesqueras variaban en función de la principal especie objetivo. También se evaluaron las interacciones entre los principales factores.

KEYWORDS

Swordfish, Catch/effort, Longline, GLM, Biomass index

Introduction

The status of north Atlantic swordfish stock have been estimated using surplus production models in conjunction with age structured virtual population (VPA) models. These analyses provide a comprehensive picture of the status of the resource and provide a basis for management advice.

Prior to 1985, analyses examined standardized time series of swordfish abundance from the Japanese longline fishery (Kikawa and Honma 1981; Farber and Conser 1983). From 1985 to 1991 age structured virtual population analyses for North Atlantic swordfish (Conser et al. 1986, Anon 1988, 1989, 1992) provided the basis for management advice. However, suitable size frequency samples or age-length keys for estimating the catch at age has restricted these assessments to the time period from 1978 to the latest year available at the time of the analysis.

Interest in the use of stock-production models as a complimentary analysis reflected the availability of long time series of reported landings and Japanese CPUE data (Fonteneau 1991). Initial attempts to use non-equilibrium stock-production models for north Atlantic swordfish relied on data from 1974 through 1990 (Conser, et al. 1992; Anon. 1992, Praeger 1993) and provided estimates of maximum sustainable yield (MSY) ranging from 13,100 MT to 16,400 MT. These production models used a GLM standardized index based on combined U.S. and Spanish longline data (1974-1990).

Subsequent collaborative research among ICCAT scientists provided additional data for the standardized index of abundance from the Canadian and Japanese longline fisheries in the north Atlantic (Hoey et al. 1993), and more recently from the Portuguese and Moroccan longline fisheries. The Canadian data, in particular, allowed the time series to be extended into the 1960's, when longline gear was first introduced into temperate waters of the western north Atlantic. After the fishery expanded dramatically in the 1960's, western north Atlantic swordfish landings were significantly reduced in the early 1970's because of the mercury bioaccumulation. The revised database, included records since 1963, bracketing out the mercury closure period (1971-1978) (Hoey et al. 1995).

2. Materials and methods

2.1. Fishery Data

Data were obtained from the Spanish, Canadian, Portuguese, Moroccan and United States directed longline fisheries for swordfish and the Japanese longline fishery for tuna. These six nations account for 94% or more of the reported north Atlantic swordfish catch since 1990 (**Figure 1**). The biomass CPUE index is calculated in terms of kilograms live weight per 1,000 hooks. For the Canadian data trip records were revised and updated from 1963 through 2016. For the Spanish fishery there was an update of catch and effort from 1982 through 2015. For the Japanese fishery, data was revised and updated for the years 1975 to 2015; however, due to management regulations restrictions data from 2001 through 2003 were excluded. The US fishery data was reviewed and updated from 1979 through 2016, following the criteria for excluding/including data from areas where management measures have restricted the catch of swordfish (Walter et al. 2013). Portugal submitted swordfish catch and effort from their longline fishery from 1995 through 2016, and Morocco submitted swordfish catch data from 2005 through 2016. Because for 2016 not all major fisheries could provide catch and effort data, the standardization index was restricted to 1963 – 2015.

2.2. Catch and Effort Characteristics

The characteristics of the landings and effort data used in developing the biomass index are provided in Hoey et al. (1993, 1995, 1997, 2000 and 2003) and are summarized as follows:

A. Spanish, Canadian, United States and Portuguese data are based on individual vessel trips. Landed weight is measured at off-loading. Fishing area, fishing effort, and gear information is collected by logbooks, scientific records and interviews.

B. Japanese vessels report numbers caught by species, by month, by 5 degree squares of latitude and longitude, and by gear configuration (hooks per basket as described by Miyabe 1992). Size frequency samples are used to estimate weight. Records which accounted for fewer than 5,000 hooks within a month/five degree square were excluded.

C. Spanish data reported trip catch and effort data as number of sets with average hooks per set, and style of longline gear.

D. The variable of hooks per basket in the Japanese data distinguishes between deep and shallow rigged longline as described by Miyabe (1992). Sets with less than eleven (11) hooks per basket were classified as shallow gear-sets, while those with eleven or more hooks per basket were classified as deep gear-sets in the creation of nation-operation codes.

E. Differences in gear construction (multi-filament nylon vs. mono-filament), gear dimensions, and operating practices (set time and haul time, area, season, target species) are described in Hoey and Bertolino. (1988). These characteristics are incorporated into a classification variable for national-operation style (Scott et al. 1992, Scott and Bertolino 1991). This variable differentiates between multi-filament and mono-filament gear and the number of hooks between floats. The switch to mono-filament was consistently associated with other gear changes, including spacing, gangion length, and dropper length.

F. For the Morocco swordfish fishery, fishing effort was estimated base on a survey of the fleet as a constant of 1000 hooks per vessel/day times the days at sea. The survey also indicated that this fleet operates mainly between 20° and 25° North and 17° and 18° West, using exclusively monofilament longline gear.

G. Since gear and gear setting characteristics are often confounded within a nation fleet, the following nation-gear factor levels were defined:
    1) Japanese shallow rigged longline,
    2) Japanese deep rigged longline,
    3) Spanish multi-filament longline,
    4) Spanish mono-filament longline,
    5) Canadian traditional multi-filament longline,
    6) Canadian mono-filament longline,
    7) United States traditional multi-filament longline,
    8) United States mono-filament longline,
    9) Portuguese multi-filament longline,
    10) Portuguese mono-filament longline,
    11) Moroccan mono-filament longline.

H. Differences in fishing strategy reflect the increased economic importance of tuna and mixed species (tuna/shark) trips among the fleets which previously targeted swordfish almost exclusively. Changes in target species were incorporated into the model by using a proxy based on the percentage of swordfish landings compared to the total landings by trip. This percentage was categorized into four levels based on percentile catch of swordfish ($0 \leq 0.25$, $0.25 \leq 0.50$, $0.50 \leq 0.75$, and $0.75 \leq 1.0$). This target definition was applied to the data from U.S., Canada and Japan. In the case of Spain, Morocco and Portugal the target proxy was based on the percentage of catch of swordfish and the combined swordfish and blue shark landings (Mejuto and De la Serna 2000).

I. Reported fishing areas were aggregated into fourteen larger zones (**Figure 2**).

1) South East Atlantic. - Between 5° N and 30° N and east of 30° W,
2) South. Central Atlantic. - Between 5° N and 30° N and between 30° W and 50° W,
3) South West Atlantic. (Caribbean) - Between 5° N and 20° N and west of 50° W,
4) Gulf of Mexico - Between 20° N and 30° N and west of 80° W,
5) Southeast U.S. - Between 20° N and 35° N and between 70° W and 80° W,
6) Central West Atlantic. - Between 20° N and 35° N and between 50° W and 70° W,
7) Northeast U.S. - Between 35° N and 50° N and west of 65° W,
8) Nova Scotia - Between 35° N and 50° N and between 55° W and 65° W,
9) Grand Banks - Between 40° N and 50° N and between 35° W and 55° W,
10) North Azores - Between 40° N and 50° N and between 20° W and 35° W,
11) Northwest Spain - Between 40° N and 50° N and east of 20° W,
12) South West Iberia - Between 30° N and 40° N and between 0° W and 20° W,
13) Azores - Between 30 N and 40° N and between 20° W and 40° W,
14) West Azores - Between 30° N and 40° N and between 40° W and 50° W and 5° degree square 35° N 50°W (lower right coordinate).

2.3. Model Development

In earlier analyses, the standardized combined biomass index was developed using linear models (GLM) with trips that reported positive catch of swordfish only (Hoey et al. 2003, 1993, 1995, 1997). Since 2006, the combined index has been estimated using generalized linear models (GLMs) with distributions that included observations with zero swordfish catch (Ortiz et al. 2007, 2010, 2014). The later standardization methods assumed a delta model with a binomial error distribution for modeling the proportion of positive catches, and a lognormal error distribution for modeling the mean catch rate of successful (positive swordfish catch) trips. Albeit, the proportion of zero observations is relatively low (≤ 30%) there has been changes in target strategies for some fisheries, mainly in response to market conditions particularly between swordfish and sharks. In addition, there are also fisheries, like the Japan longline fleet, for which swordfish is a non-targeted species and the proportions of zero catch are much higher. The probability of zero catch of swordfish is negligible or minor in most of the targeting fleets when trip data is considered.

For the present standardization analysis, the delta lognormal model with a binomial distribution for the proportion of positives was adopted; for the positive catch observations, a normal distribution for the log-transformed nominal CPUE (kg/1000 hooks) was assumed. The standardization model evaluated all available common factors among the different fleets including; year, calendar quarter, zone, a nation-operation (NATOP) factor, gear type, flag, and a target variable as main effects and all 1st level interaction terms. As NATOP and gear-flag are correlated factors, in a given model only NATOP or gear and flag were evaluated. In the case of the proportion of positives sub model, the NATOP and target factors were not included because of the unbalanced distribution of zero observations, that is in some instances for a given NATOP all observations have positive catch. Once a set of factors was identified as main explanatory variables, all significant interactions were evaluated and considered as random effects in the final model to allow generation of annual estimates (Maunder and Punt 2004). Deviance explained, statistical significance and Akaike information criteria types were used to define the factors and interactions for the final model selection.

In response to management regulations, some fisheries have experienced different types of restrictions that may potentially affect catch rates of swordfish (Andrushchenko *et al*. 2014, Walter *et al*. 2014). The recommendations and data restrictions from these studies have been also applied to the data input for the present standardization. For example, approaches to address the implementation of ICCAT minimum size regulations in the US longline fleet were applied to the input data, based on these, the current model uses only the U.S. time series of swordfish catch greater than the minimum size/weight equivalent of 33 lbs. dressed weight.

The use of a proxy for target in the model, a ratio of the swordfish catch to total or other target species catch (blue sharks), has been revised and described previously (Anon, 2001a). In general it is recommended to have direct observations for identifying targeting in fisheries operations, based for example on gear configurations or direct indication by the fisher. However, in case where this information is lacking, expert reviewers concluded that "*Of the different proxy methods simulated by the Working Group the use of catch ratios was found to perform best, on average, and remained the preferred proxy, although this method may not necessarily provide the best performance in all cases*" (Anon, 2001a).

As recommended in past analyses, sensitivity runs were also performed to evaluate the influence of assumptions in the modeling exercise. The cases considered as sensitivity runs included: a) using the annual longline catch by nation (Task I LL north Atlantic swordfish) as a weighting factor, b) replacing the NATOP factor by the flag and gear type factors, c) including the Flag*Year as a fixed factor to estimate indices trends for each country, and d) including the records of Morocco with the updated fishing effort estimates.

3. Results and Discussion

The available input data included over 93,000 records. The numbers of observations by nation were as follows: United States 46,280 trips; Spain 10,846 trips; Canada 8,130 trips; Portugal 1966 trips; Morocco 1311 observations, and Japan 26,675 observations. The number of records used in the standardization of CPUE was 87,714. Records without gear, month, area, or effort information from each flag fishery were excluded. Nominal annual trends of catch rates by fleet are shown in **Figure 3,** scaled to the average of the 1995-2015 period of each series. **Figure 4,** shows the annual trends of catch and effort in the input data by fleet and compared to the information provided in 2013. **Table 1** summarizes the number of observations, nominal CPUE, swordfish catch (kg) included in the standardization, and fishing effort for the final input file. **Figure 5** shows that the annual trends of successful observations with swordfish catch, for targeting fleets are very high; however, in recent years due to a variety of reasons, the proportion of observations with positive catch has varied. **Figure 6** contrasts the nominal mean CPUE by flag and NATOP. Analyses of deviance results (**Table 2**) indicated that the model for the positive observations was significant and accounted for over 75% of the overall variability. The deviance explained by the binomial model on the proportion of positive trips was much lower (about 23%). The relative annual index of abundance was estimated as the product of the year factor least square means (LSMeans) from the binomial and the lognormal components. LSMeans estimates were weighted proportional to observed margins in the input positive data, and for the lognormal estimates, a log-back transformed bias correction was applied (Lo et al. 1992).

The deviance table indicated that for the positive observation sub model, the NATOP factor was by far the most important in explaining the observed variability in the data, followed by the geographical area (zone) and target factors (**Table 2**). The interactions year*area, year*NATOP, and area*target were also statistically significant (**Table 3**). The base model, for the positive observations sub model included the factors year area target quarter NATOP and the interactions year*area year*NATOP and area*target as random effects. For the proportion of positives, the base model included year, quarter, area and the year*area and year*quarter interactions as random component. Following the prior standardizations, the base model included the nominal CPUEs of Canada, Spain, Portugal, Japan and U.S.

Table 4 presents the standardized index, standard errors, and upper and lower 95% confidence intervals (**Figure 7**). Annual abundance estimates are characterized by larger standard errors prior to 1985 and more constant thereafter, mainly due to the limited number of observations prior to 1985. Diagnostic plots from the lognormal positive observations and proportion of positives of the delta-lognormal CPUE standardization model are shown in **Figures 8** and **9.** For the proportion of positives sub model (**Figure 8**), a high variance is observed for low nominal catch rates, likely associated with the non-target versus target operations. Diagnostic plots also show a tail of low CPUE observations with high variance compared to the rest of the data for the positive observations. **Figure 10** shows the estimates of the random coefficients for the binomial and lognormal components of the final model.

The standardized relative index shows a rapid decline of catch rates from the highest point in 1963 to average values in the 1960’s. After the domestic mercury restrictions (1971-1974) catch rates increased until 1979 followed by a slow decrease afterwards. By the mid 1990’s the catch rates reached low values (1996), followed by a slight recovery until 2000. Throughout the 2000s catch rates remained at low levels until 2006 when a recovery period started. Nominal catch rates for fleets operating mainly in the western north Atlantic (Canada, USA, Japan) have shown a decreasing trend in recent years, while fleets operating in the eastern north Atlantic (Spain, Portugal and Morocco) show an increasing trend in the same period (**Figures 3, 15**).

The standardized relative biomass index was consistent with the one calculated in 2006, 2009, and 2013 showing similar trends up to 1999 (**Figure 11**). After 1999 the trends of the standardized indices varied; showing a cyclical pattern with higher values in 2002 and 2010/11, and lower values in 2005,and 2013/14 (**Figure 11** insert).

The level of aggregation of catch and effort information is not consistent among the different fleets; hence the number of observations is quite variable among fleets. A sensitivity run was explored where the model was weighted by the total annual catch (Task I NC LL), considering that total catch would partially account for the differences in data aggregation and reflected better the overall stock trends. Overall, trend of the standard index did not differ substantially between the base and the weighted - catch models (**Figure 14**).

In the latest assessment of north Atlantic swordfish, it was noted the contrary trends of fleet independent indices of abundance (Anon 2014). This feature was also observed with the nominal and predicted by fleet standardized catch rates (**Figure 3**, **Figure 15**). It was postulated that there appears to be a different trend of stock distribution or availability in the western versus the eastern north Atlantic, likely associated with environmental factors and oceanographic conditions. Analysis of catch and mean size by areas indicated a northern displacement of fish in response to changes in the distribution patterns of warm waters in the north Atlantic basin (Schirripa *et al.* 2017). This may affect biomass catch rates as different age-groups may be available for the different fleets operating through the north Atlantic, F**igures 12** and **13** shows the annual trends of the available size sampling data (Task 2 SZ) from longline gear for NATL swordfish separated into western (zones 3 to 9 and 14 (Fig 1)) and eastern (zones 1, 2, and 10 -13) components. First, there is a wide range of swordfish sizes caught by most longline fisheries, with large overlapping among fleets and years. Nevertheless, the mean trends (**Figure 13)** shows some consistent increasing trends in mean size for most of the eastern north Atlantic fleets since 2009 (excluding last year for Japan fleet). Instead, on the western side, for the fleets of US, Spain and Portugal in general the mean size has remained stable or decrease, although for the Canadian fleet the mean size has consistently increased since 2000 and in the Japan fleet since 2008. In summary, trends of mean size of caught swordfish by main fleets tend to coincide with the general trends of catch rates for the eastern and western regions in the north Atlantic.

The results from the sensitivity runs indicated similar trends of the index when using the total annual longline catch as weighting factor, or when the NATOP factor was replaced by the flag gear type factors in the model (**Figure 14**). In the latest case, more different trends are observed since 2000 forwards. However, the estimated confidence intervals do overlap substantially during this period (**Figure 11**). **Figure 15** shows the estimated standardized CPUEs by flag. In this scenario, the model was modified to introduce the year*flag as a fixed factor and the estimated CPUEs are the LSMeans including this interaction. In this case, the estimated trends follow more closely the nominal observations. It is important to note that the year component in the model reflects the trend of the overall population, and that the year*flag interaction likely reflects the combination of the population trend and trends or effects particular to each flag's fishery (ies), like changes in targeting or selectivity, that would need to be accounted for in the overall assessment evaluation.

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Table 1. North Atlantic swordfish biomass index catch and effort input for standardization process. Nominal catch rates (kg/1000 hooks) by flag, catch of swordfish (kg) and total fishing effort (hooks) by flag.

		Effort N hooks						Catch kg						Nominal CPUE kg/1000 hooks					
Year	N Obs	CAN	JPN	MOR	POR	SPA	USA	CAN	JPN	MOR	POR	SPA	USA	CAN	JPN	MOR	POR	SPA	USA
1963	95	459,720						1,573,678						3,534.4					
1964	247	1,839,857						2,161,598						1,210.2					
1965	192	2,236,398						1,689,306						764.3					
1966	197	2,101,837						1,639,656						752.7					
1967	208	2,443,308						2,327,054						966.6					
1968	286	3,606,096						2,342,563						664.6					
1969	263	3,441,914						2,167,989						616.9					
1970	182	2,618,026						1,992,236						738.7					
1975	510		33,500,635						1,801,597						46.9				
1976	424		24,910,710						1,060,339						35.9				
1977	282		15,789,510						683,956						40.1				
1978	321		15,236,787						824,481						63.6				
1979	629	351,548	19,984,389				60,513	399,215	497,280				155,118	1,257.4	31.4				2,518.3
1980	1045	692,769	27,150,422				331,872	805,537	1,112,852				335,499	1,125.2	45.0				1,418.1
1981	773	374,077	39,601,476				5,110	374,554	1,213,273				14,629	905.1	31.4				2,828.2
1982	913	314,974	31,051,135			291,400	181,590	255,360	1,447,049			114,388	236,041	798.9	47.4			958.3	2,219.0
1983	648	361,755	17,127,298			2,988,982	283,168	218,209	441,604			889,663	333,954	726.1	29.2			330.1	1,158.9
1984	807	377,435	20,986,548			3,992,692	372,720	165,083	596,674			1,280,628	546,445	443.6	29.7			318.8	1,187.3
1985	1048	324,970	24,946,443			4,814,070	345,144	203,657	804,215			1,510,951	562,418	621.9	33.7			332.4	1,295.1
1986	1291	244,295	22,691,040			14,542,950	679,636	204,649	720,170			4,800,038	808,447	1,082.2	31.5			325.0	905.6
1987	1507	320,895	18,860,890			10,027,330	1,765,118	162,967	484,387			3,261,733	1,588,925	563.9	28.7			332.9	785.0
1988	1723	317,600	23,894,453			9,884,850	2,234,629	182,977	745,581			2,508,351	2,478,497	531.8	35.2			268.4	835.3
1989	2026	392,699	35,017,486			12,037,600	2,193,340	223,938	1,316,760			3,034,266	2,126,363	567.8	38.3			254.5	747.5
1990	2102	351,739	30,921,568			16,438,900	2,494,005	347,582	912,407			3,931,811	2,016,194	914.0	33.8			253.4	625.7
1991	2568	1,030,663	32,215,636			15,564,796	3,345,339	588,296	1,009,382			3,600,261	2,082,165	638.1	43.0			240.5	494.3
1992	3036	940,592	27,730,082			16,268,780	5,600,324	594,576	780,194			3,586,826	2,381,402	625.7	34.1			233.6	418.4
1993	3413	1,963,449	26,564,918			15,779,456	7,079,796	994,531	910,817			3,229,217	2,692,455	499.0	36.2			212.9	381.4
1994	4106	3,725,432	25,893,801			20,124,074	7,651,079	1,583,528	809,336			3,820,106	2,451,361	408.5	33.5			194.1	357.7
1995	4529	3,112,938	29,733,299		75,200	25,879,110	8,295,941	1,320,044	964,092		35,703	4,862,051	2,509,424	443.1	32.1		380.5	196.6	374.0
1996	4058	2,449,862	45,654,721		83,200	25,017,900	7,335,590	628,835	1,432,427		26,262	4,431,869	2,270,928	259.6	32.0		350.5	183.6	301.6
1997	3898	2,411,971	42,349,272		367,500	23,734,819	7,230,457	947,155	1,127,698		74,438	3,639,232	2,312,887	377.7	30.3		201.0	155.6	338.6
1998	3443	1,622,980	44,514,947		494,400	15,864,264	6,046,375	821,404	1,265,186		127,990	2,508,226	2,137,048	542.3	28.2		261.4	156.1	382.2
1999	2970	1,638,427	35,391,407		918,800	12,007,791	5,707,083	1,156,215	979,410		254,296	2,214,089	1,807,663	676.9	28.8		270.3	186.4	356.5
2000	3264	1,971,466	36,326,454		1,418,610	6,520,150	6,522,502	850,552	-		529,677	2,259,025	2,195,990	501.2	-		385.5	389.3	307.4
2001	3454	1,673,520	34,891,756		1,034,908	8,756,145	6,702,404	969,008	-		375,272	3,898,653	1,977,471	767.9	-		372.1	429.0	289.0
2002	2890	1,601,484	24,381,036		783,850	5,990,089	6,640,988	968,397	-		202,040	2,733,887	2,341,564	836.3	-		264.0	433.5	353.8
2003	2742	1,514,981	24,212,869		851,102	6,523,229	6,730,889	1,216,063	-		286,995	3,011,027	2,402,343	790.2	-		339.8	432.8	397.5
2004	3147	1,777,757	38,643,216		876,482	5,415,248	6,910,371	1,541,009	485,133		426,450	2,097,116	2,198,599	760.4	12.7		508.9	390.8	385.6
2005	3101	2,070,959	42,013,783	853,000	1,048,178	5,101,258	5,836,061	1,934,649	593,704	501,266	380,703	2,240,959	1,993,618	925.1	15.4	662.3	350.2	410.4	376.7
2006	2735	2,092,851	32,546,676	1,605,000	522,917	5,954,072	5,457,303	1,626,791	578,984	455,873	202,049	2,121,412	1,704,954	833.5	16.2	283.9	377.5	332.2	376.6
2007	2548	1,798,310	22,242,067	1,162,000	567,790	4,851,280	5,998,701	1,484,361	708,411	245,256	247,156	2,243,589	1,986,705	746.3	35.6	217.0	426.2	420.1	369.0
2008	2460	1,266,970	25,236,852	986,000	640,946	4,174,145	6,331,801	1,418,864	775,191	297,767	259,486	2,065,591	2,012,512	1,056.4	29.9	306.6	380.9	463.0	335.8
2009	2447	1,363,411	27,127,973	1,045,000	730,782	4,138,853	6,708,446	1,320,594	760,359	297,339	328,101	1,942,729	2,391,836	1,114.1	30.2	307.1	476.4	475.8	369.3
2010	2474	1,274,364	29,150,312	1,429,000	817,542	4,601,757	5,670,065	1,304,380	1,047,968	627,856	349,553	1,355,041	1,955,160	1,256.4	31.8	454.5	460.4	297.4	356.5
2011	2248	1,703,930	18,832,831	1,404,000	482,839	4,118,231	5,945,020	1,452,192	519,098	414,234	218,442	1,703,746	2,265,427	1,026.2	27.8	314.3	456.1	410.6	367.1
2012	2523	1,672,588	16,431,233	1,407,000	712,567	4,982,898	7,734,522	1,672,511	525,827	440,214	420,762	2,286,135	3,021,073	1,099.0	28.9	324.9	623.2	499.9	406.0
2013	2447	1,591,688	17,782,831	1,993,000	973,168	3,010,478	7,319,850	1,395,542	188,414	648,539	610,688	1,230,349	2,561,816	888.9	11.5	326.7	641.2	448.7	337.4
2014	2272	1,984,363	17,048,290	1,827,000	515,191	3,873,496	6,805,166	1,626,458	344,747	451,423	266,806	1,759,856	1,627,016	765.5	17.7	256.2	563.9	472.7	224.5
2015	1996	2,329,291	16,055,657	1,817,000	541,854	3,831,353	5,792,081	1,679,735	271,661	497,501	352,712	1,778,588	1,409,818	739.7	15.1	276.3	709.0	551.2	222.6
2016	1450	2,502,732		1,295,000	747,120		5,114,543	1,616,309		409,554	456,659		1,249,548	594.7		360.6	649.1		227.0

Table 2. Deviance analysis table of explanatory variables in the delta lognormal model for swordfish biomass catch rates North Atlantic fisheries. Percent of total deviance refers to the deviance explained by the full model; *p* values refer to the Chi-square probability between consecutive models.

Swordfish biomass CPUE Index 1962-2016

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	193858.6			
Year	49	177076.1	16782.4	11.5%	< 0.001
Year Zone	13	137830.6	39245.6	27.0%	< 0.001
Year Zone Qtr	3	136844.0	986.6	0.7%	< 0.001
Year Zone Qtr NATOP	9	81978.4	54865.6	37.7%	< 0.001
Year Zone Qtr NATOP Target	3	53919.7	28058.7	19.3%	< 0.001
Year Zone Qtr NATOP Target Qtr*Natop	25	53587.5	332.2	0.2%	< 0.001
Year Zone Qtr NATOP Target Zone*Qtr	39	53336.6	583.2	0.4%	< 0.001
Year Zone Qtr NATOP Target Year*Qtr	139	53033.3	886.4	0.6%	< 0.001
Year Zone Qtr NATOP Target Zone*Natop	64	52994.3	925.4	0.6%	< 0.001
Year Zone Qtr NATOP Target Year*Target	123	52934.3	985.4	0.7%	< 0.001
Year Zone Qtr NATOP Target Zone*Target	39	50704.4	3215.3	2.2%	< 0.001
Year Zone Qtr NATOP Target Natop*Target	27	50621.2	3298.6	2.3%	< 0.001
Year Zone Qtr NATOP Target Year*Natop	163	49943.6	3976.2	2.7%	< 0.001
Year Zone Qtr NATOP Target Year*Zone	522	48514.0	5405.7	3.7%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	65656.4			
Year	49	62506.8	3149.6	25.6%	< 0.001
Year Qtr	3	62045.7	461.1	3.8%	< 0.001
Year Qtr Zone	13	59044.7	3001.0	24.4%	< 0.001
Year Qtr Zone Year*Qtr	139	58274.2	770.5	6.3%	< 0.001
Year Qtr Zone Qtr*Zone	39	57518.4	1526.3	12.4%	< 0.001
Year Qtr Zone Year*Zone	527	53374.5	5670.2	46.2%	< 0.001

Table 3. Evaluation of the 1st level interactions as random effect in the delta lognormal model for swordfish biomass catch rates North Atlantic fisheries. The random effects were evaluated using the AIC, Bayesian IC and the likelihood ratio test. * indicates the final model factors and interactions in each of the sub models component.

	Swordfish GLMixed Model	-2 REM Log likelihood	Akaike's Information Criterion	Bayesian Information Criterion	Likelihood Ratio Test	
	Proportion Positives					
	Year Qtr Area	38856.3	38858.3	38865.2		
	Year Qtr Area *Year*Area*	38731.8	38735.8	38744.6	124.5	0.0000
*	Year Qtr Area *Year*Area Year*Qtr*	38701.5	38707.5	38720.7	30.3	0.0000
					38701.5	0.0000
	Positives catch rates					
	Year Area Target Qtr NATOP	192057.6	192059.6	192068.8		
	Year Area Target Qtr NATOP *Year*Area*	185748	185752	185760.8	6309.6	0.0000
	Year Area Target Qtr NATOP *Year*Area Year*NATOP*	184678.7	184684.7	184697.8	1069.3	0.0000
*	Year Area Target Qtr NATOP *Year*Area Year*NATOP Area*Target*	181053.2	181061.2	181078.7	3625.5	0.0000
	Positives catch rates					
	Year Area Target Qtr Flag Gear	196799.2	196801.2	196810.4		
	Year Area Target Qtr Flag Gear *Year*Area*	190177.9	190181.9	190190.7	6621.3	0.0000
	Year Area Target Qtr Flag Gear *Year*Area Year*Flag*	188977.7	188983.7	188996.6	1200.2	0.0000
	Year Area Target Qtr Flag Gear *Year*Area Year*NATOP Area*Target*	185124.2	185132.2	185149.6	3853.5	0.0000
*	Year Area Target Qtr Flag Gear *Year*Area Year*NATOP Area*Target*	185105.9	185115.9	185137.8	18.3	0.0000

Table 4. Nominal and standard swordfish biomass CPUE index from combined logline fisheries in the North Atlantic 1963-2016.

Year	N Obs	Nominal CPUE	Standard	Low	Upp	coeff var	std error
1963	95	3534.4	1164.2	586.3	2311.8	35.3%	411.4
1964	247	1210.2	409.4	207.8	806.9	34.9%	143.0
1965	192	764.3	252.7	128.4	497.4	34.8%	88.1
1966	197	752.7	255.1	129.8	501.4	34.8%	88.7
1967	208	966.6	299.1	152.3	587.2	34.7%	103.8
1968	286	664.6	238.3	120.4	471.7	35.1%	83.8
1969	263	616.9	217.2	110.5	426.6	34.7%	75.4
1970	182	738.7	246.9	125.6	485.3	34.8%	85.9
1971							
1972							
1973							
1974							
1975	510	46.9	433.4	232.7	807.4	31.9%	138.1
1976	424	35.9	354.6	190.3	660.9	31.9%	113.1
1977	282	40.1	409.4	219.1	764.8	32.0%	131.1
1978	321	63.6	467.2	266.4	819.7	28.7%	133.9
1979	628	1227.3	357.9	241.9	529.4	19.8%	70.7
1980	1036	728.1	359.0	243.0	530.1	19.7%	70.7
1981	773	102.2	329.7	220.1	493.9	20.4%	67.3
1982	899	283.0	321.5	225.8	457.7	17.8%	57.2
1983	624	289.0	258.0	181.9	365.8	17.6%	45.4
1984	794	338.7	232.7	165.9	326.2	17.0%	39.6
1985	1038	298.3	266.3	190.9	371.5	16.8%	44.6
1986	1288	427.2	258.9	185.6	361.0	16.7%	43.3
1987	1496	554.4	209.2	150.1	291.5	16.7%	35.0
1988	1710	605.2	218.0	156.7	303.2	16.6%	36.2
1989	2012	404.0	189.4	138.0	259.7	15.9%	30.1
1990	2095	409.9	214.2	156.5	293.1	15.8%	33.8
1991	2566	374.9	215.2	157.7	293.6	15.6%	33.6
1992	3036	331.9	179.3	131.1	245.2	15.7%	28.2
1993	3413	311.2	175.4	128.5	239.4	15.7%	27.5
1994	4106	279.2	144.6	104.4	200.4	16.4%	23.7
1995	4529	283.0	156.9	114.3	215.5	16.0%	25.0
1996	4058	197.4	117.3	85.1	161.6	16.2%	18.9
1997	3898	223.1	132.3	97.5	179.5	15.4%	20.3
1998	3443	237.8	153.2	112.8	208.1	15.4%	23.6
1999	2970	261.8	166.9	123.2	226.2	15.3%	25.5
2000	2221	341.8	167.3	121.8	229.7	16.0%	26.7
2001	2441	374.2	171.9	121.5	243.2	17.5%	30.0
2002	2202	417.6	181.5	128.8	255.7	17.3%	31.4
2003	2077	441.7	185.8	132.3	261.1	17.1%	31.8
2004	3138	318.5	149.0	109.5	202.9	15.5%	23.1
2005	3016	303.7	134.2	98.5	182.8	15.5%	20.9
2006	2598	328.1	137.4	100.3	188.2	15.8%	21.8
2007	2458	345.4	177.7	130.1	242.8	15.7%	27.9
2008	2375	332.4	201.8	147.8	275.4	15.6%	31.6
2009	2352	356.7	215.6	157.7	294.9	15.8%	34.0
2010	2348	347.1	224.1	164.1	306.1	15.7%	35.1
2011	2131	367.6	218.7	159.6	299.6	15.8%	34.6
2012	2418	429.4	241.9	176.9	330.8	15.7%	38.1
2013	2307	354.1	158.8	115.7	217.8	15.9%	25.3
2014	2145	271.9	188.2	137.0	258.5	16.0%	30.1
2015	1868	303.1	177.4	129.1	243.8	16.0%	28.4

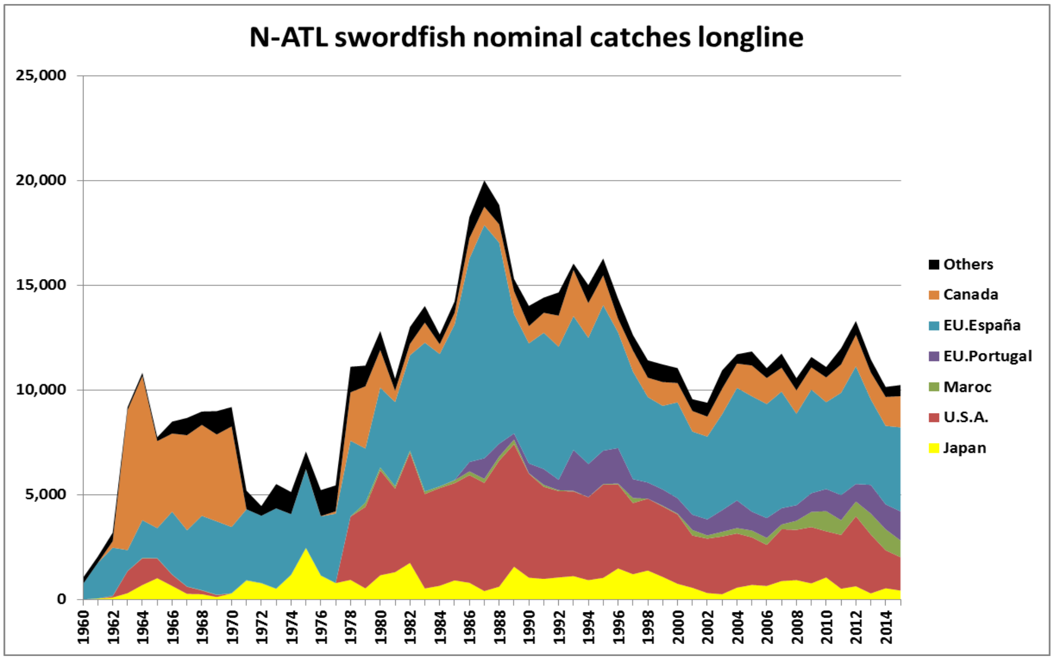

Figure 1. Annual trends of north Atlantic swordfish catch by longline fleets since 1960. The flags included correspond to those submitting catch and effort data for the biomass index excluding the others category.

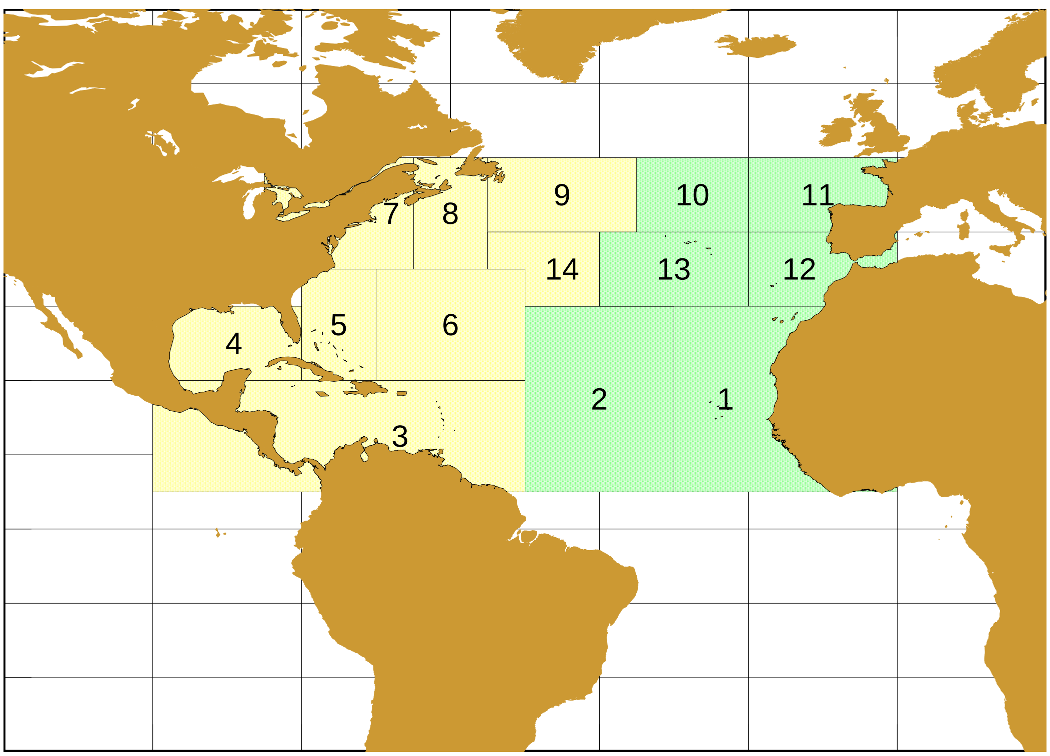

Figure 2. Geographical zones used for standardizing swordfish catch and effort data from major longline fisheries in the North Atlantic. Zones 3, 4, 5, 6, 7, 8, 9 and 14 are denominated western north ATL while zones 1, 2, 10, 11, 12 and 13 are eastern north ATL.

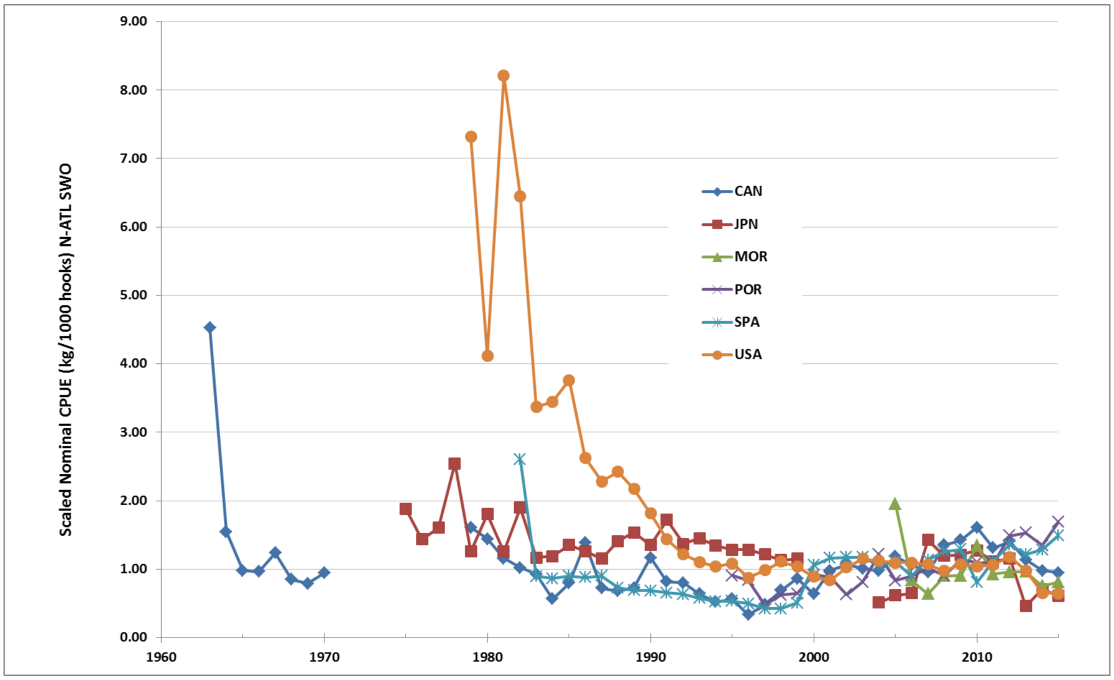

Figure 3. Annual trends of nominal CPUE north Atlantic swordfish by fleet. The series are scaled to the mean CPUE for the 1995 -2015 period for comparison purposes.

Figure 4. Annual trends of catch (kg) and effort (hooks deployed) by main flag. Lines show the input values from 2013 index versus the 2017 index.

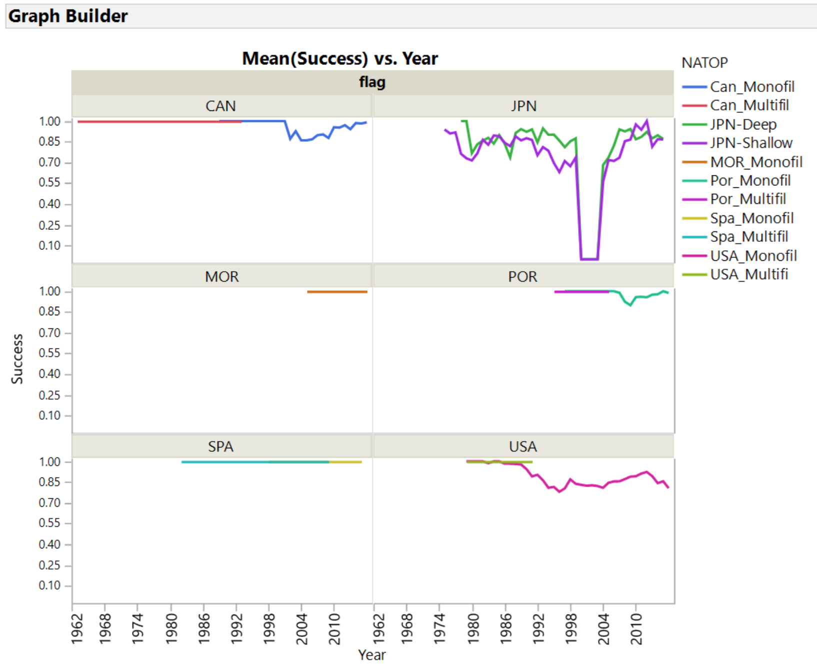

Figure 5. N-SWO mean annual trend of successful observations with catch of swordfish by flag and fleet-gear type (NATOP).

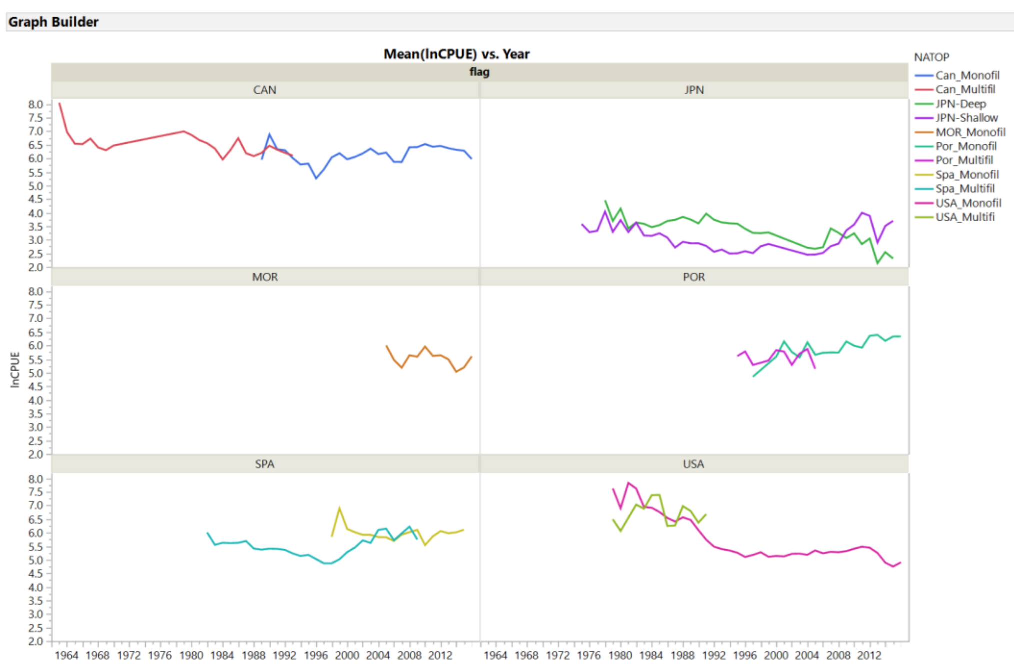

Figure 6. N-SWO mean annual trend of nominal lnCPUE (kg per 1000 hooks) by flag and fleet-gear type (NATOP) positive observations only.

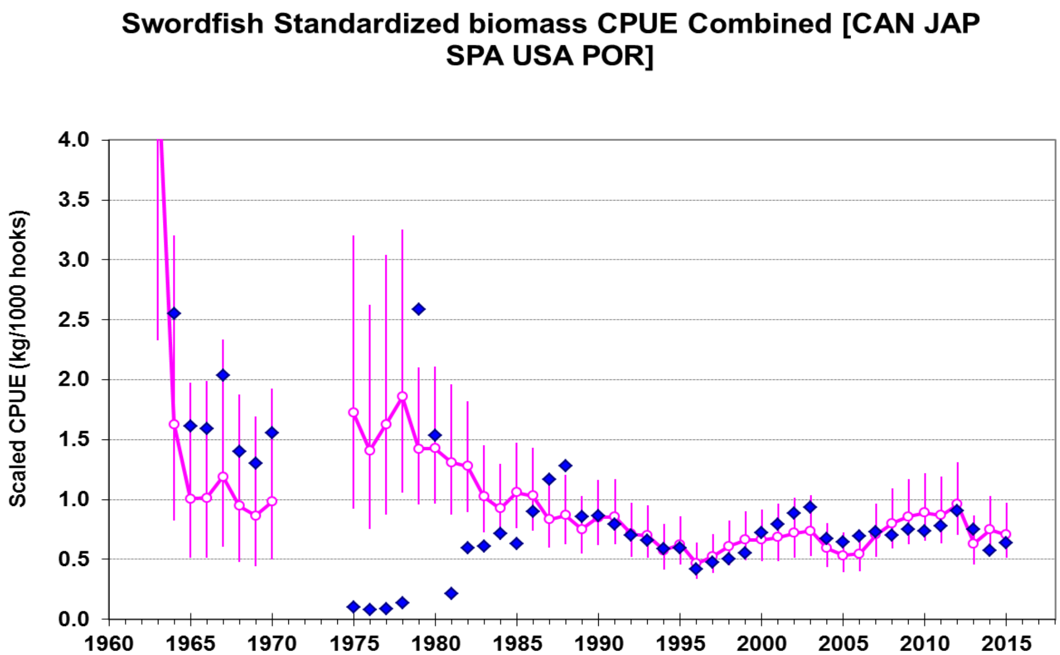

Figure 7. Nominal (diamond mark) and standardized biomass index (open circle) for North Atlantic swordfish from the main fisheries Canada, Japan, Spain and US. Bars represent upper and lower 95% estimated confidence intervals.

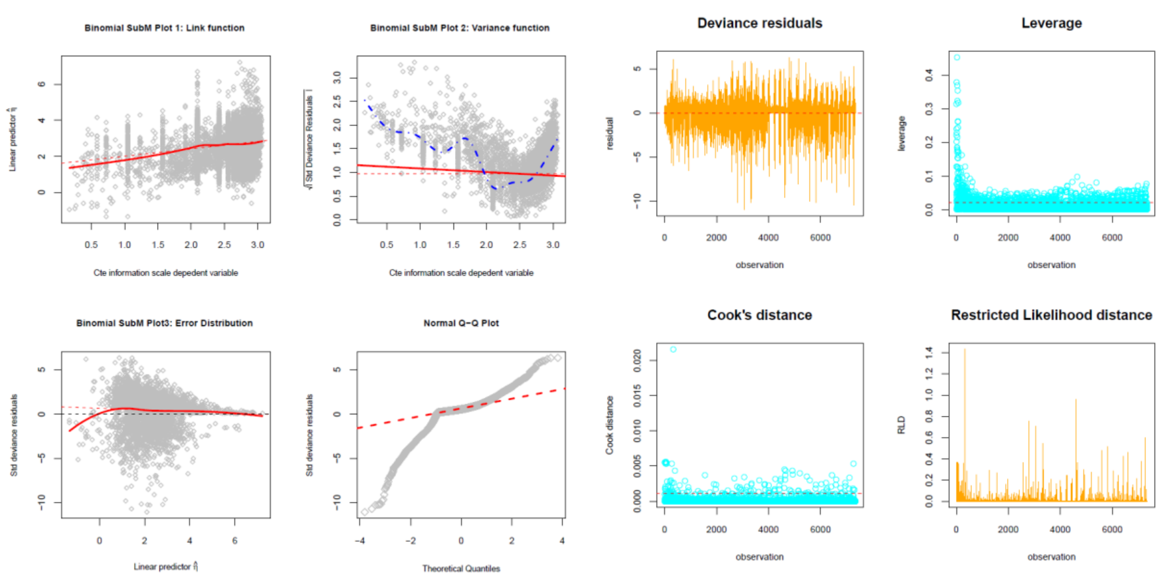

Figure 8. Diagnostic plots from the proportion of positives binomial component of the delta-lognormal CPUE standardization model.

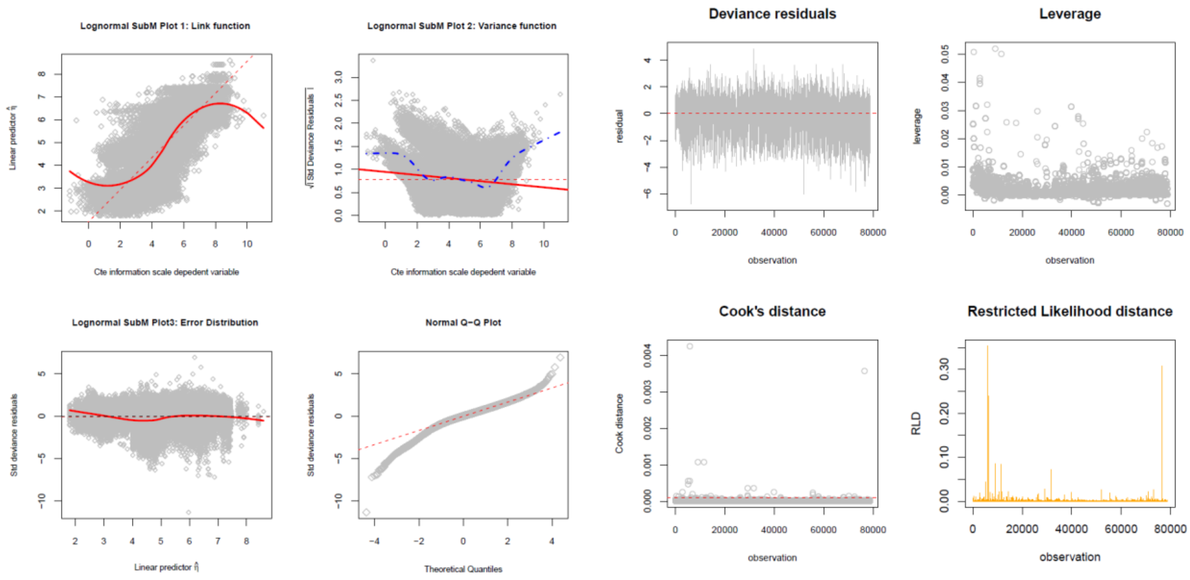

Figure 9. Diagnostic plots from the positive observations of the delta-lognormal CPUE standardization model.

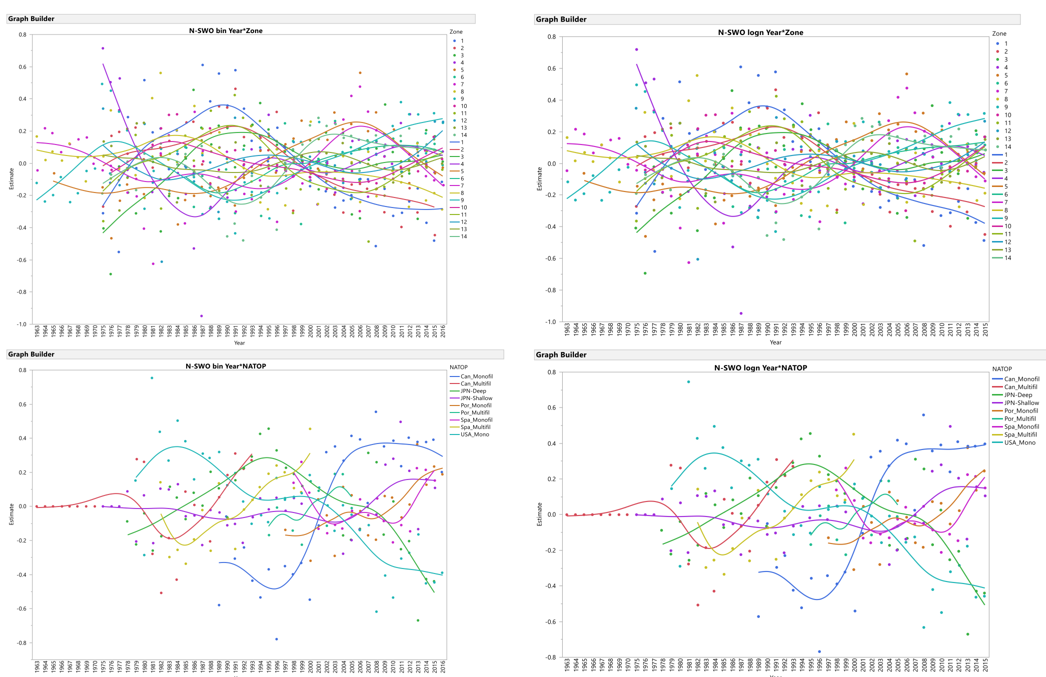

Figure 10. Diagnostic plots for the random interactions of the models. Left binomial component, right lognormal positive observations.

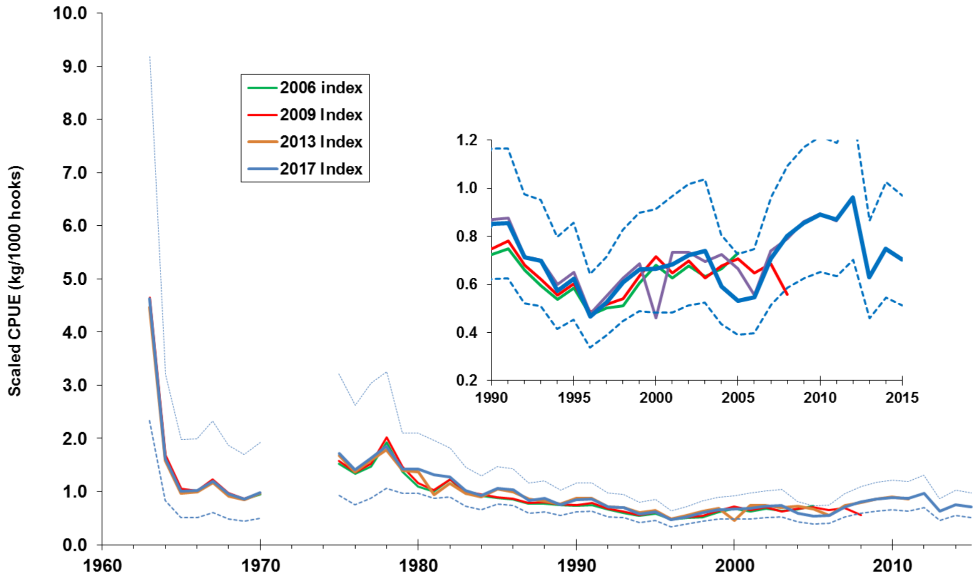

Figure 11. Comparison of the standardized CPUE series of North Atlantic swordfish estimated in 2006, 2009, 2013 and 2017.

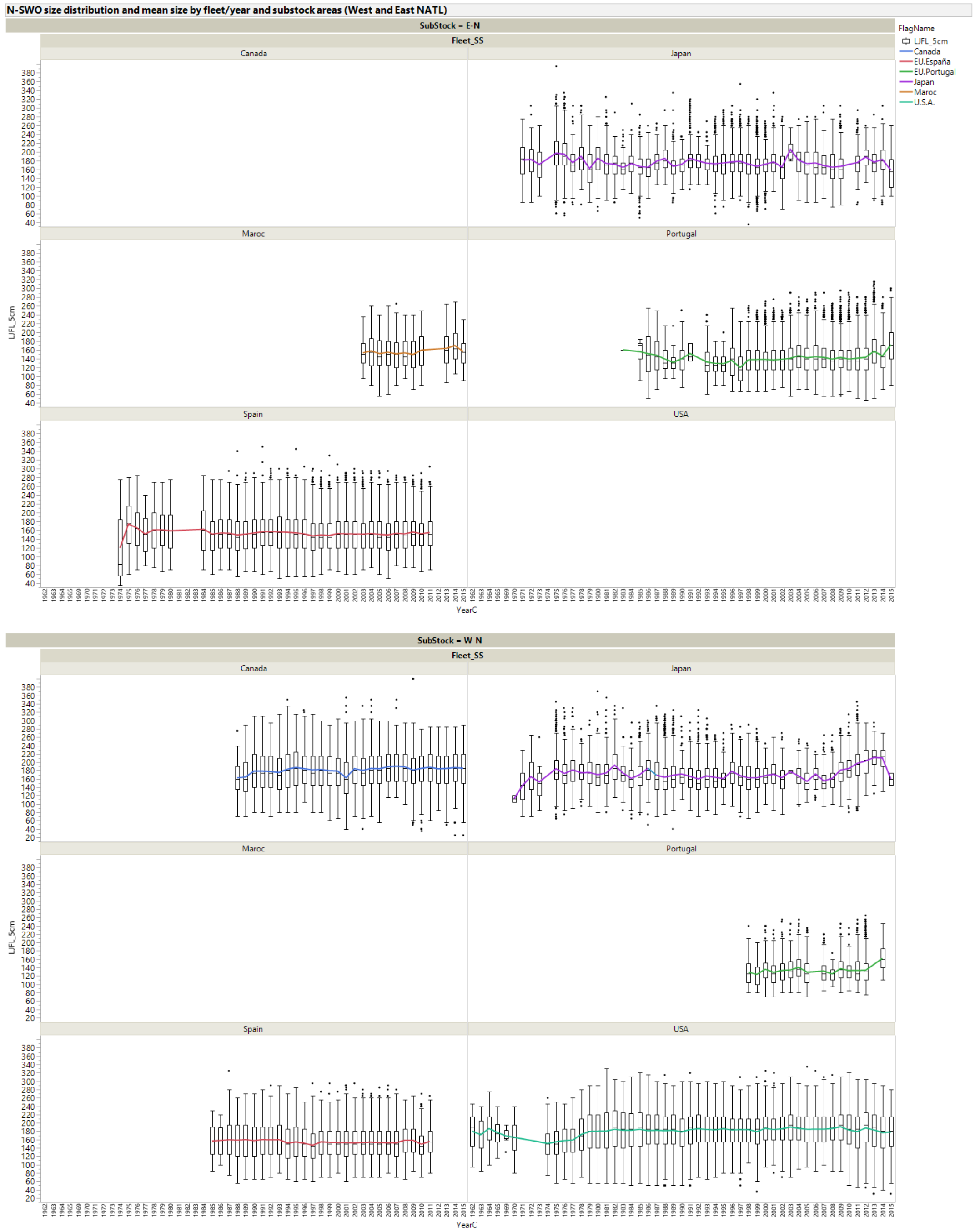

Figure 12. N-SWO longline size samples task II-sz (LJFL cm) by Flags and sub-areas east and west north Atlantic.

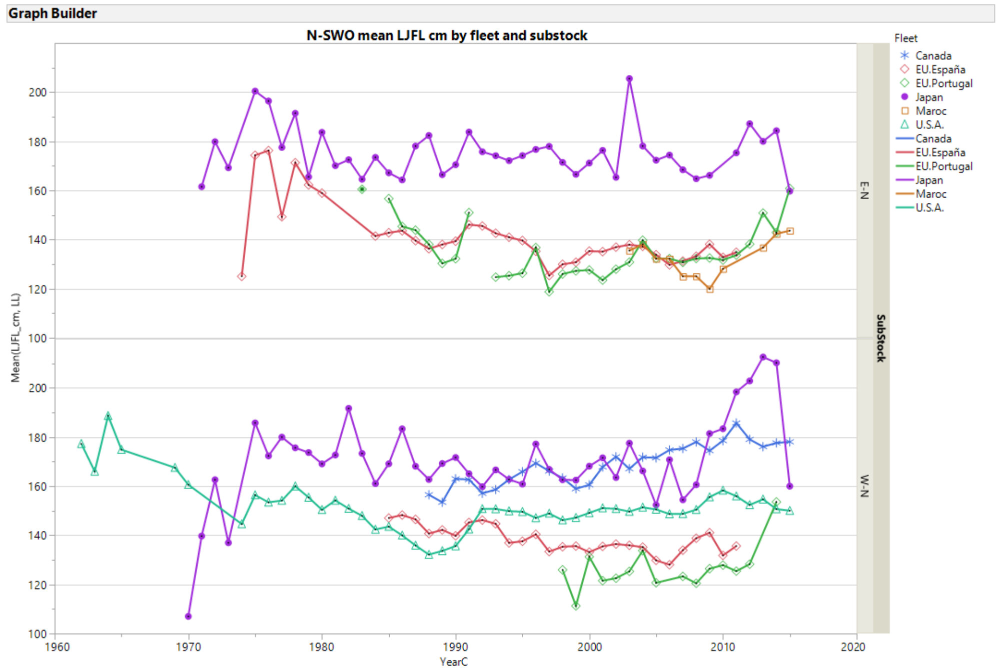

Figure 13. SWO NATL annual trends of mean size (LJFL cm) of the size data from longline fisheries by main fleet and substock West and East north Atlantic.

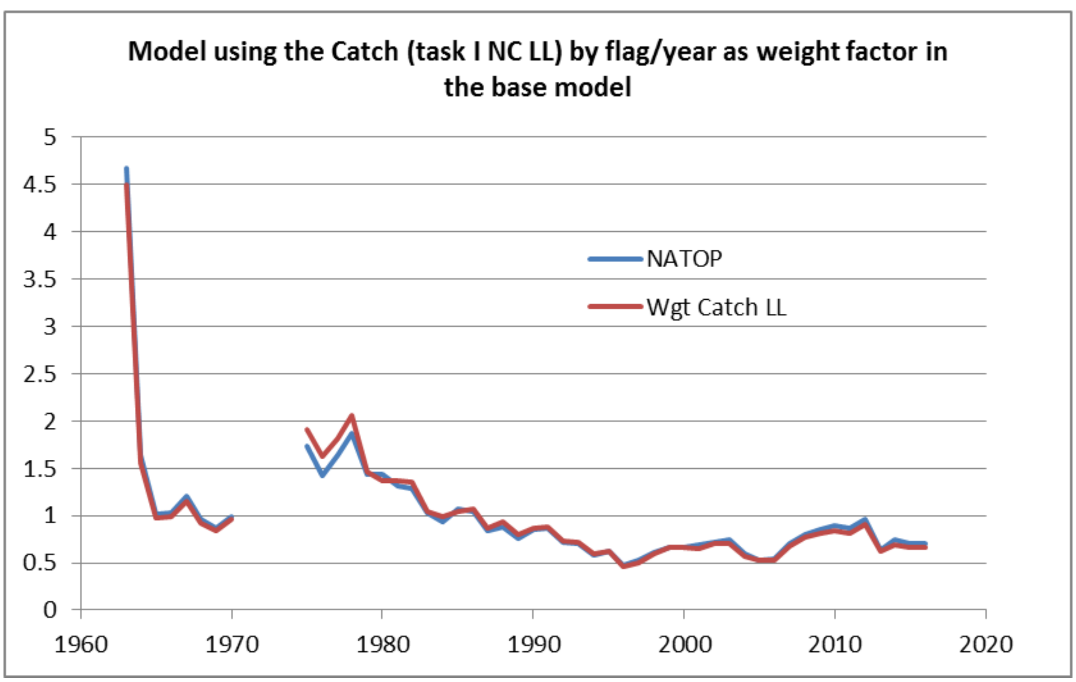

Figure 14. Sensitivity runs: Comparison of the standard index between model using the NATOP factor, and using the catch task I longline as weighting factor in the model (base model proposal).

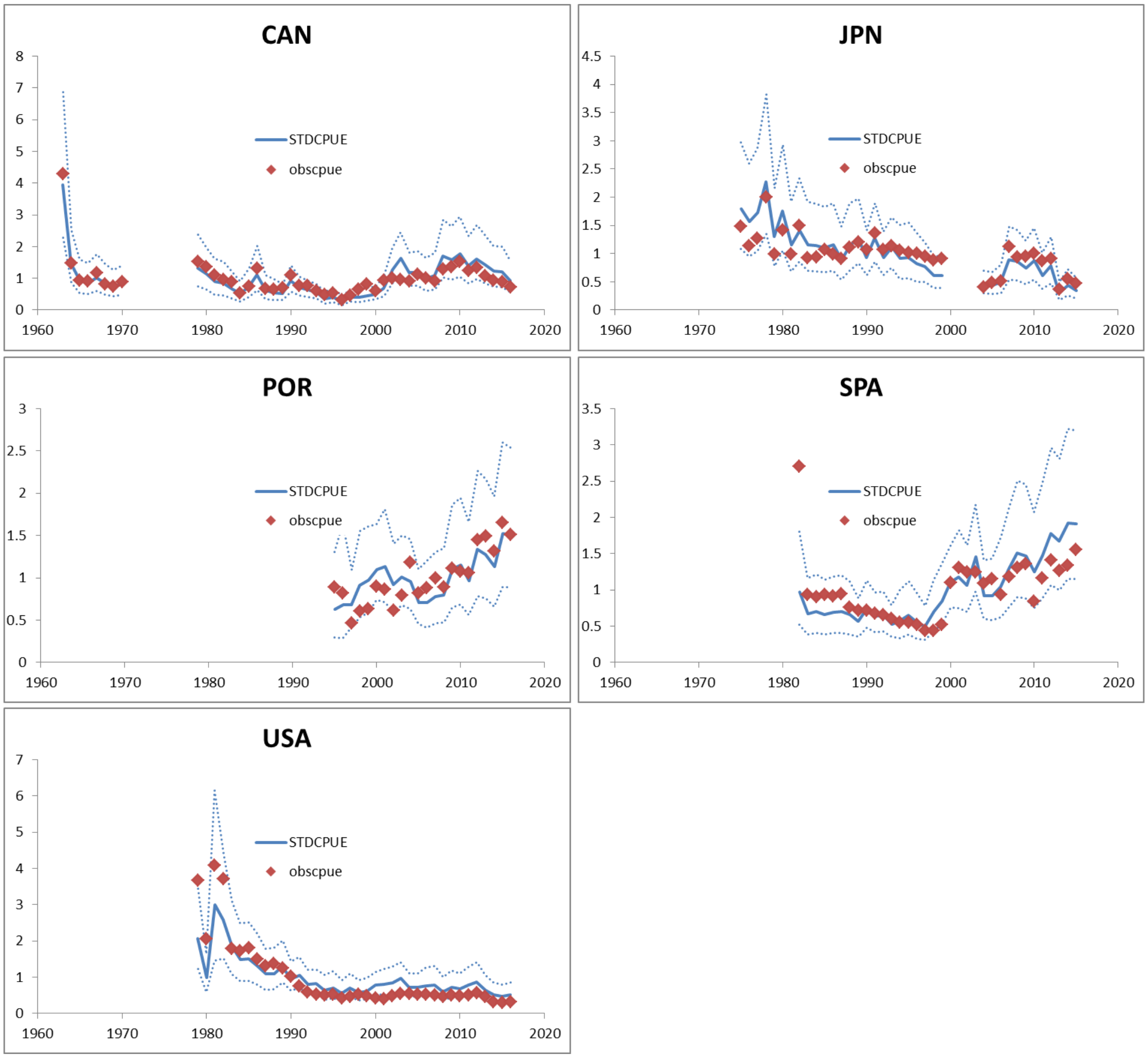

Figure 15. Sensitivity run: Estimated standardized N-SWO CPUE by flag with estimated 95% confidence intervals.