SCRS/2013/139 Collect. Vol. Sci. Pap. ICCAT, 70(4): 1912-1926 (2014)

AN UPDATED COMBINED BIOMASS INDEX OF ABUNDANCE FOR NORTH ATLANTIC SWORDFISH STOCK 1963-2012

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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 and 2008 ICCAT-SCRS meetings for North Atlantic swordfish was revised and updated with data through 2012. 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, Spain, Canada, Japan, Morocco and 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 et 2008 pour l'espadon de l'Atlantique Nord a été révisé et actualisé avec des données allant jusqu'en 2012 compris. Des procédures du modèle linéaire généralisé (GLM) ont été utilisées afin de standardiser les données de capture (biomasse) et d'effort (numéro d'hameçons) de l'espadon provenant des principales flottilles palangrières opérant dans l'Atlantique Nord : Etats-Unis, Espagne, Canada, Japon, Maroc et 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 en las reuniones del SCRS de 2006 y 2008 para el pez espada del Atlántico norte fue revisado y actualizado con datos hasta 2012 inclusive. Se utilizaron los 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, España, Canadá, Japón, Marruecos y Portugal. Como

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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 especie objetivo principal. También se evaluaron las interacciones entre los principales factores

KEYWORDS

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

1. 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 cooperative 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 U.S. mercury restrictions. 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 91% or more of the reported north Atlantic swordfish catch in recent years. 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 2012. For the Spanish fishery there was an update of catch and effort from 2004 through 2011. For the Japanese fishery, data was revised and updated for the years 1975 to 1999 and 2004 to 2012 only, due to management regulations restrictions data from 2001 through 2003 were excluded. The US fishery data was reviewed and updated from 1979 through 2012, criteria for excluding/including data from areas were management measures have restricted the catch of swordfish (Walter *et al.* 2013) was revised. Portugal submitted swordfish catch and effort from their longline fishery from 1995 through 2012, and Morocco submitted swordfish catch data from 2005 through 2012.

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 2002) 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 or 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 *et al.* (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 landings, fishing effort was estimated base in survey of the fleet as 10000 hooks per vessel-trip. 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 compare to the total landings by trip. This percent 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).

Reported fishing areas were aggregated into fourteen larger zones (**Figure 1**).

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). The later standardization methods assumed a delta model with a binomial error distribution for modeling the proportion of positive sets, 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 only 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 unbalance distribution of observations, as 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 as reference to define the factors and interactions for the final model selection.

In response to management regulations, some fisheries have experience different types of restrictions that may potentially affect catch rates of swordfish (Andrushchenko *et al.* 2013, Walter *et al.* 2013). The recommendations and data restriction 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 (bluesharks), has been revised and commented previously (Ref). In general it is recommended to have direct observations for identifying targeting in fisheries operations, based for example in gear configurations or direct indication by the fisher. However, in case when 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, 2001).

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 weighting factor. At the time of the analysis, task I data was available only up to 2011 calendar year, for 2012 it was used the same catch as 2011 for each flag. b) Replacing the NATOP factor by the flag and gear type factors. And, c) a sensitivity run including the Flag*Year as fixed factor to estimate indices trends for each country.

3. Results and Discussion

The available input data included over 84,000 records. The numbers of observations by nation were as follows: United States 28,950 trips; Spain 11,849 trips; Canada 7,126 trips; Portugal 1406 trips; Morocco 827 observations, and Japan 34,082 observations. The number of records used in the standardization of CPUE was 72,534. 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 2,** scaled to the average of the 1995-2011 period of each series. **Figure 3,** shows the annual trends of catch and effort represented in the input data by fleet. A scatter plot (**Figure 3** right plot) shows the expected correlated linear trends of catch and effort by fleet. **Figure 4** shows the distribution of observations per year and flag-gear combination in a mosaic plot. Noticeably few observations are available prior to 1985 and after 1992, and about half of the annual observations are from the US fleet using monofilament gear type. **Table 1** summarizes the number of observations, nominal CPUE, swordfish catch (t) included in the standardization, and fishing effort for the final input file, and the corresponding Task I longline annual catch used in the weighted standardization analyses. Analyses of deviance results (**Table 2**) indicate 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 25%). 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*zone, year*NATOP, zone*target, NATOP*target, and year*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 year*area interaction as random component. As in 2009, the base model included the catch and effort data from Canada, Japan, Spain, Portugal and US fisheries.

Table 4 presents the standardized index, standard errors, and upper and lower 95% confidence intervals (**Figure 5**). Annual abundance estimates are characterized by larger standard errors prior to 1985 and more constant thereafter, in part due to the low 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 **Figure 6.** These plots show a tail of low CPUE observations with high variance compared to the rest of the data for the positive observations. For the proportion of positives sub model, a high variance is observed for low nominal catch rates, likely associated with the non-target versus target operations. **Figure 7** shows the predicted mean catch rate for each factor and level from the positive sub-model in logarithm scale units. As expected, higher catch rates were predicted for the target swordfish fleets and monofilament gear type, while lower catch rates were predicted for the non-target and multifilament gear type (**Figure 7** plot NATOP). Predicted catch rates also vary by area (Zone) or quarter, albeit much less than the effects associated with gear o target effects. Model results coincided with the expected trends of the explanatory factors. For example, for the fleet-gear factor (NATOP) the model indicated a higher catch rates for all fleets operating with monofilament gear compared to the multifilament gear (**Figure 7**). And highest catch rates were predicted for fleets targeting swordfish (Canada, Spain, US and Portugal) while lower catch rates for non-targeting fleets (Japan).

The standard relative index show a rapid decline of catch rates from the 1963 highest point to average values in the 1960’s. After the mercury period, 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 recover until 2000, throughout the 2000s catch rates remained at low levels until 2006 when a recovery period started. Nominal catch rates for several fleets including US, Spain and Portugal have shown an increase trend in the last 3 years (**Figure 2**); only the Canadian nominal CPUE shows a declining trend since 2010.

The standardized relative biomass index was consistent with the one calculated in 2006 and 2009, showing similar trends up to 1999 (**Figure 8**). After 1999 the trends of the standardized indices varied; in 2006/09 indices show an increase in 2000's compared to 1994-98 years, instead in the current index, the period of 2000 to 2005 shows low population trends, while the recovery started only after 2005/06 forwards (**Figure 8** right plot).

In general, 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 9**). In the latest case, more different trends are observed since 2000 forwards. However, the estimated confidence intervals do substantially overlapped in this period (**Figure 9**). **Figure 10** shows the estimated standardized CPUEs by flag. In this scenario, the model was modified to introduce the year*flag as fixed factor and the estimated CPUEs are the LSMeans of 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 would reflect the trend of the overall population, and that the interaction year*flag likely reflect the combination of the population trend and trends or effect particular to each flag fishery(ies), like changes in targeting or selectivity, that would need to be account for in the overall assessment evaluation.

References

Andrushchenko, I., A. Hanke, Whelan, Neilson and Atkinson. 2013. A description of the Canadian swordfish fisheries from 1988 to 2012, and candidate abundance indices for use in the 2013 stock assessment. SCRS/2013/059.

Anon. 1988. Report of the ICCAT Swordfish Workshop - Madrid, Spain - October 6-13, 1987 ICCAT. Col. Vol. Sci. Pap. Vol. 27: 1-126.

Anon. 1989. Second ICCAT Swordfish Workshop. ICCAT. Col. Vol. Sci. Pap. Vol. 29:71-83.

Anon. 1992. Reference Paper on 1991 Swordfish Stock Assessments. ICCAT. Col. Vol. Sci. Pap. Vol. 39(2):397-476.

Anon. 2000. Detailed report on Swordfish: report of the ICCAT Swordfish Stock Assessment Session, Madrid, Spain, Sept. 27 - Oct. 4, 1999. ICCAT. Col. Vol. Sci. Pap. Vol. 51: 1001-1209.

Anon. 2001. Executive Summary - Atlantic swordfish. Report for the biennial period, 2000-01. Part 1 (2000) - Vol. 2: 85-94.

Anon, 2001. Report of the ICCAT working group on stock assessment methods (Madrid, Spain - May 8 to 11, 2000). ICCAT Col. Vol. Sci. Pap. 52(5): 1569-1662.

Conser, R.J., Phares, P, Hoey, J.J. and Farber, M. 1986. An assessment of the status of stocks of swordfish in the northwest Atlantic Ocean. ICCAT. Col. Vol. Sci. Pap. Vol. 25:218-245.

Conser, R.J., Porter, and Hoey. 1992. Casting the Shepherd stock-production model in a statistical framework suitable for swordfish stock assessment and management advice. ICCAT. Col. Vol. Sci. Pap. Vol. 39(2):593-599.

Farber, M.I. and R. Conser. 1983. Swordfish indices of abundance from the Japanese longline fishery data for various areas of the Atlantic Ocean. ICCAT. Col. Vol. Sci. Pap. Vol.18:629-644.

Fontaneau, A. 1991. Open letter to the SCRS Chairman. Appendix 7 of the SCRS report. In. Report of the Biennial Period, 1990-1991. Part I (1990). ICCAT. Madrid, Spain.

Hoey, J.J., Mejuto, Porter, Paul, and Yokawa. 2003. An update biomass index of abundance for North Atlantic swordfish, 1963-1001. ICCAT. Col. Vol. Sci. Pap. Vol. 55(4):1562-1575.

Hoey, J.J. and Bertolino. 1988. Review of the U.S. fishery for swordfish, 1978 to 1986. ICCAT. Col. Vol. Sci. Pap. Vol. 27:256-266.

Hoey, J.J., Mejuto, Porter, and Uozumi. 1993. A Standardized Biomass Index of Abundance for North Atlantic Swordfish. ICCAT. Col. Vol. Sci. Pap. Vol. 40(1):344-352.

Hoey EY, J.J., Mejuto, Porter, and Uozumi. 1995. An Updated Biomass Index of Abundance for North Atlantic Swordfish, 1963-1993. ICCAT. Col. Vol. Sci. Pap. Vol. 44(2): 187-196.

Hoey, J.J., Mejuto, Porter, and Uozumi. 1997. An Updated Biomass Index of Abundance for North Atlantic Swordfish, 1963-1995. ICCAT. Col. Vol. Sci. Pap. Vol. 46(3): 354-361.

Lo, N.C., Jacobson, and Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

Kikawa, S. and Honma. 1981. Overall fishing effort and catch with comment on the status of stocks for the swordfish in the Atlantic Ocean. ICCAT. Col. Vol. Sci. Pap. Vol. 15:381-386.

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

Mejuto, J., Garcia, and de la Serna. 2002. Preliminary Standardized Catch rates for the North Atlantic Swordfish (*Xiphias gladius*) from the Spanish Longline Fleet for the Period 1983-2000. ICCAT. Col. Vol. Sci. Pap. Vol 54 (5): 1550-1554.

Miyabe, N. 1992. Trend in CPUE for swordfish caught by the Japanese longline fishery in the Atlantic Ocean. ICCAT. Col. Vol. Sci. Pap. Vol. 39(2):484-496.

Ortiz, M. 2010. An updated biomass index of abundance for north Atlantic swordfish (*Xiphias gladius*) for the period 1963-2008. ICCAT. Col. Vol. Sci. Pap. Vol. 65(1):171-184.

Ortiz, M. 2007. Update of standardized catch rates by sex and age for swordfish (*Xiphias gladius*) from the U.S. longline fleet 1981-2005. ICCAT. Col. Vol. Sci. Pap. Vol. 60(6):2048-2058.

Praeger, M.H. 1993. A Nonequilibrium Production Model of Swordfish: Data Reanalysis and Possible Further Directions. ICCAT. Col. Vol. Sci. Pap. Vol. 40(1):433-437.

Scott, G.P. and Bertolino. 1991. Standardized catch rates for swordfish (*Xiphias gladius*) from the U.S. longline fleet through 1989. ICCAT. Col. Vol. Sci. Pap. Vol. 35 (2):397-404.

Scott, G.P., Restrepo, and Bertolino. 1992. Standardized catch rates for swordfish (*Xiphias gladius*) from the U.S. longline fleet through 1990. ICCAT. Col. Vol. Sci. Pap. Vol. 39(2):554-571.

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 (t) and total fishing effort (million hooks) by flag.

		Effort Hooks					Catch Kg					Nominal CPUE Swo Kg/ thousand hooks				
YEAR	N Obs	CAN	JPN	POR	SPA	USA	CAN	JPN	POR	SPA	USA	CAN	JPN	POR	SPA	USA
1963	95	459,720					1,573,678					3,534.43				
1964	247	1,839,857					2,161,598					1,210.24				
1965	192	2,236,398					1,689,306					764.27				
1966	197	2,101,837					1,639,656					752.70				
1967	208	2,443,308					2,327,054					966.62				
1968	286	3,606,096					2,342,563					664.62				
1969	263	3,441,914					2,167,989					616.86				
1970	182	2,618,026					1,992,236					738.66				
1975	510		33,500,635					1,801,597					46.86			
1976	424		24,910,710					1,060,339					35.93			
1977	282		15,789,510					683,956					40.07			
1978	321		15,236,787					824,481					63.56			
1979	489	351,548	19,984,389			32,888	399,215	497,280			92,744	1,257.42	31.39			3,038.08
1980	730	692,769	27,150,422			98,182	805,537	1,112,852			96,178	1,125.17	45.05			1,514.97
1981	765	374,077	39,601,476				374,554	1,213,273				905.11	31.39			
1982	845	314,974	31,051,135		291,400	5,330	255,360	1,447,049		114,388	10,177	798.95	47.43		958.33	1,898.03
1983	559	361,755	17,127,298		2,988,982	21,823	218,209	441,604		889,663	22,644	726.08	29.23		330.05	1,021.67
1984	725	377,435	20,986,548		3,992,692	144,321	165,083	596,674		1,280,628	245,763	443.62	29.73		318.76	1,410.54
1985	976	324,970	24,946,443		4,814,070	148,013	203,657	804,215		1,510,951	252,507	621.95	33.74		332.38	1,449.13
1986	1122	244,295	22,691,040		14,542,950	330,585	204,649	720,170		4,800,038	401,932	1,082.19	31.52		324.98	1,127.28
1987	1108	320,895	18,860,890		10,027,330	767,753	162,967	484,387		3,261,733	791,333	563.90	28.73		332.86	1,028.14
1988	1238	317,600	23,894,453		9,884,850	1,146,364	182,977	745,581		2,508,351	1,303,427	531.79	35.25		268.37	1,019.78
1989	1642	392,699	35,017,486		12,037,600	1,014,445	223,938	1,316,760		3,034,266	975,414	567.76	38.33		254.49	892.06
1990	1638	351,739	30,921,568		16,438,900	1,287,469	347,582	912,407		3,931,811	1,158,551	914.00	33.77		253.42	789.80
1991	1954	1,030,663	32,215,636		15,564,796	2,087,568	588,296	1,009,382		3,600,261	1,447,746	638.05	43.00		240.54	631.96
1992	2248	940,592	27,730,082		16,268,780	3,452,358	594,576	780,194		3,586,826	1,750,734	625.66	34.12		233.58	489.10
1993	2564	1,963,449	26,564,918		15,779,456	4,584,007	994,531	910,817		3,229,217	1,991,332	498.99	36.21		212.88	423.71
1994	3318	3,725,432	25,893,801		20,124,074	5,393,684	1,583,528	809,336		3,820,106	1,939,568	408.46	33.52		194.09	408.66
1995	3672	3,112,938	29,733,299	75,200	25,879,110	5,617,685	1,320,044	964,092	35,703	4,862,051	1,679,423	443.11	32.06	380.53	196.58	381.82
1996	3458	2,449,862	45,654,721	83,200	25,017,900	5,395,621	628,835	1,432,427	26,262	4,431,869	1,655,472	259.59	32.01	350.49	183.64	319.16
1997	3458	2,411,971	42,349,272	367,500	23,734,819	6,003,357	947,155	1,127,698	74,438	3,639,232	1,761,472	377.65	30.34	201.00	155.55	340.54
1998	3137	1,622,980	44,514,947	494,400	15,864,264	5,327,704	821,404	1,265,186	127,990	2,508,226	1,923,652	542.28	28.21	261.36	156.09	401.53
1999	2700	1,638,427	35,391,407	918,800	12,007,791	4,844,333	1,156,215	979,410	254,296	2,214,089	1,669,341	676.93	28.78	270.34	186.45	381.78
2000	3011	1,971,466	36,326,454	1,418,610	6,520,150	5,597,602	850,552		529,677	2,259,025	2,039,361	501.16		385.47	389.32	332.42
2001	3105	1,673,520	34,891,756	1,034,908	7,328,904	6,121,761	969,008		375,272	3,464,268	1,799,412	767.91		372.10	461.84	295.15
2002	2636	1,400,920	24,381,036	783,850	5,676,009	6,136,926	912,162		202,040	2,636,089	2,171,997	900.66		264.02	439.51	370.61
2003	2579	1,387,441	24,212,869	851,102	6,159,929	6,475,262	1,046,408		286,995	2,902,621	2,288,372	811.03		339.77	439.07	398.92
2004	2971	1,487,115	38,643,216	876,482	5,244,098	6,724,382	1,047,546	485,133	426,450	2,022,305	2,150,399	717.66	12.75	508.92	386.97	380.04
2005	2775	1,446,302	42,013,783	1,048,178	5,026,558	5,438,940	1,271,210	593,704	380,703	2,200,711	1,878,726	888.27	15.45	350.19	407.40	388.34
2006	2294	1,422,070	32,546,676	522,917	5,930,672	5,144,825	1,168,237	578,984	202,049	2,114,287	1,633,834	820.37	16.23	377.50	332.29	402.18
2007	2127	1,193,994	22,242,067	566,740	4,851,280	5,376,289	966,899	708,411	247,156	2,243,589	1,886,245	725.90	35.56	430.73	420.11	397.91
2008	2013	982,993	25,236,852	602,012	4,126,095	5,605,052	988,350	775,191	259,486	2,040,663	1,846,051	973.78	29.85	412.31	461.32	364.71
2009	2011	849,052	27,127,973	650,286	4,059,653	5,936,109	924,163	760,359	328,101	1,917,058	2,222,475	1,282.68	30.24	529.96	479.30	398.69
2010	2007	825,930	29,150,312	791,564	4,601,757	5,014,785	1,036,924	1,047,968	349,553	1,355,041	1,668,972	1,370.02	31.83	480.91	297.36	363.44
2011	1689	1,060,993	18,832,831	475,009	4,118,231	4,677,020	1,203,464	519,098	218,442	1,703,746	1,807,291	1,234.87	27.79	475.06	410.57	385.50
2012	1602	1,135,810	16,431,233	712,567		5,826,126	1,277,788	525,827	420,762		2,320,079	1,062.12	28.88	623.19		447.23

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 1962-2012

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	638092.1			
Year	45	596694.8	41397.3	6.9%	< 0.001
Year Zone	13	428311.6	168383.2	28.0%	< 0.001
Year Zone Qtr	3	427506.3	805.4	0.1%	< 0.001
Year Zone Qtr NATOP	9	59903.2	367603.0	61.1%	< 0.001
Year Zone Qtr NATOP Target	3	40290.6	19612.6	3.3%	< 0.001
Year Zone Qtr NATOP Target Qtr*Natop	25	40182.7	107.9	0.0%	< 0.001
Year Zone Qtr NATOP Target Zone*Qtr	39	39877.8	412.8	0.1%	< 0.001
Year Zone Qtr NATOP Target Year*Qtr	127	39554.0	736.7	0.1%	< 0.001
Year Zone Qtr NATOP Target Zone*Natop	58	39439.7	851.0	0.1%	< 0.001
Year Zone Qtr NATOP Target Year*Target	111	39398.1	892.5	0.1%	< 0.001
Year Zone Qtr NATOP Target Natop*Target	24	38621.4	1669.2	0.3%	< 0.001
Year Zone Qtr NATOP Target Zone*Target	39	38520.9	1769.7	0.3%	< 0.001
Year Zone Qtr NATOP Target Year*Natop	151	37938.7	2351.9	0.4%	< 0.001
Year Zone Qtr NATOP Target Year*Zone	469	36798.1	3492.5	0.6%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1		59366.3			
Year	45	53620.1	5746.1	37.9%	< 0.001
Year Qtr	3	53467.4	152.7	1.0%	< 0.001
Year Qtr Zone	13	50892.9	2574.5	17.0%	< 0.001
Year Qtr Zone Year*Qtr	127	50147.6	745.2	4.9%	< 0.001
Year Qtr Zone Qtr*Zone	39	48970.6	1922.2	12.7%	< 0.001
Year Qtr Zone Year*Zone	476	44210.6	6682.3	44.1%	< 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	35968.6	35970.6	35977.4		
*	Year Qtr Area *Year*Area*	35258.5	35262.5	35271.1	710.1	0.0000
	Year Qtr Area *Year*Area Qtr*Area*	36390	36396	36408.8	-1131.5	N/A
	Positives catch rates					
	Year Area Target Qtr NATOP	149697.7	149699.7	149708.8		
	Year Area Target Qtr NATOP *Year*Area*	145600.7	145604.7	145613.2	4097	0.0000
	Year Area Target Qtr NATOP *Year*Area Year*NATOP*	144477.2	144483.2	144496.1	1123.5	0.0000
*	Year Area Target Qtr NATOP *Year*Area Year*NATOP Area*Target*	142031.2	142040.2	142057.3	2446	0.0000

Table 4. Nominal and standard swordfish biomass CPUE index from combined logline fisheries in the North Atlantic 1963-2012.

Year	N Obs	Nominal CPUE	Standard	Low	Upp	coeff var	std error
1963	95	3534.4	3054.3	1686.7	5530.7	30.4%	927.1
1964	247	1210.2	1083.3	604.1	1942.7	29.8%	323.2
1965	192	764.3	663.7	370.7	1188.5	29.8%	197.5
1966	197	752.7	677.3	378.9	1210.7	29.7%	200.9
1967	208	966.6	798.5	447.2	1425.8	29.6%	236.4
1968	286	664.6	625.1	346.9	1126.7	30.1%	188.2
1969	263	616.9	579.8	324.5	1035.8	29.6%	171.8
1970	182	738.7	659.9	369.1	1180.1	29.7%	195.9
1971							
1972							
1973							
1974							
1975	510	46.9	1156.2	686.8	1946.7	26.5%	306.4
1976	424	35.9	931.9	552.2	1572.6	26.6%	248.1
1977	282	40.1	1080.1	639.0	1825.8	26.7%	288.4
1978	321	63.6	1212.3	736.8	1994.5	25.3%	306.5
1979	489	928.5	945.1	665.1	1342.9	17.7%	167.3
1980	730	419.8	925.2	649.2	1318.3	17.8%	165.1
1981	765	72.5	641.9	437.9	941.1	19.3%	123.9
1982	845	26180.7	803.4	577.1	1118.5	16.7%	133.8
1983	559	86874.5	668.5	488.2	915.4	15.8%	105.7
1984	725	77135.0	619.1	460.7	831.9	14.9%	92.0
1985	976	74073.8	717.8	537.2	959.1	14.6%	104.6
1986	1122	150513.2	685.5	513.4	915.3	14.5%	99.6
1987	1108	99782.5	591.5	442.3	791.1	14.6%	86.5
1988	1238	68688.4	567.7	426.9	755.0	14.3%	81.3
1989	1642	61296.5	524.8	398.5	691.1	13.8%	72.6
1990	1638	75446.8	596.8	454.2	784.3	13.7%	81.9
1991	1954	58276.7	601.1	459.0	787.3	13.6%	81.5
1992	2248	47662.5	489.1	372.0	642.9	13.7%	67.2
1993	2564	35556.6	480.2	366.2	629.7	13.6%	65.4
1994	3318	32246.1	410.1	309.5	543.4	14.1%	58.0
1995	3672	36577.5	442.2	335.4	583.0	13.9%	61.4
1996	3458	33925.3	326.7	246.6	432.9	14.1%	46.2
1997	3458	27260.3	374.0	285.7	489.6	13.5%	50.6
1998	3137	21058.1	425.9	325.9	556.7	13.4%	57.3
1999	2700	23787.1	463.8	355.7	604.7	13.3%	61.8
2000	3011	43250.3	303.3	214.5	428.9	17.4%	52.9
2001	3105	71151.5	330.5	233.1	468.7	17.6%	58.2
2002	2636	53125.6	333.1	235.8	470.6	17.4%	58.0
2003	2579	43530.4	290.6	203.2	415.5	18.0%	52.4
2004	2971	32701.6	392.0	298.6	514.8	13.7%	53.6
2005	2775	34170.4	361.2	275.1	474.3	13.7%	49.4
2006	2294	32304.7	372.4	283.1	490.0	13.8%	51.3
2007	2127	35277.6	494.8	377.5	648.6	13.6%	67.3
2008	2013	36052.4	531.2	406.0	695.2	13.5%	71.8
2009	2011	31569.7	577.5	440.4	757.4	13.6%	78.6
2010	2007	29813.8	599.6	457.5	785.8	13.6%	81.5
2011	1689	41921.2	578.6	439.9	761.1	13.8%	79.7
2012	1602	448.0	599.5	447.4	803.1	14.7%	88.1

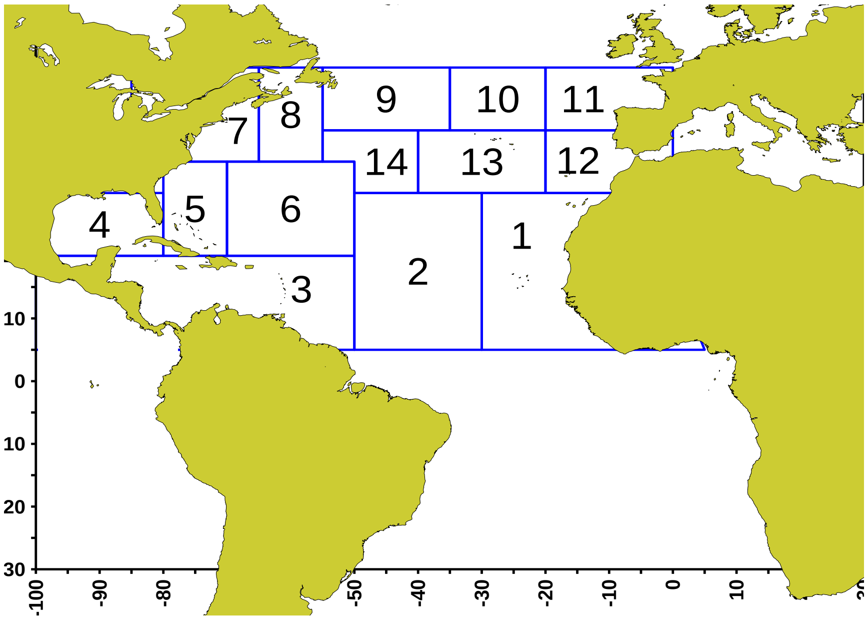

Figure 1. Geographical zones used for standardizing swordfish catch and effort data from major longline fisheries in the North Atlantic [Canada, Japan, Spain, Portugal and US fisheries].

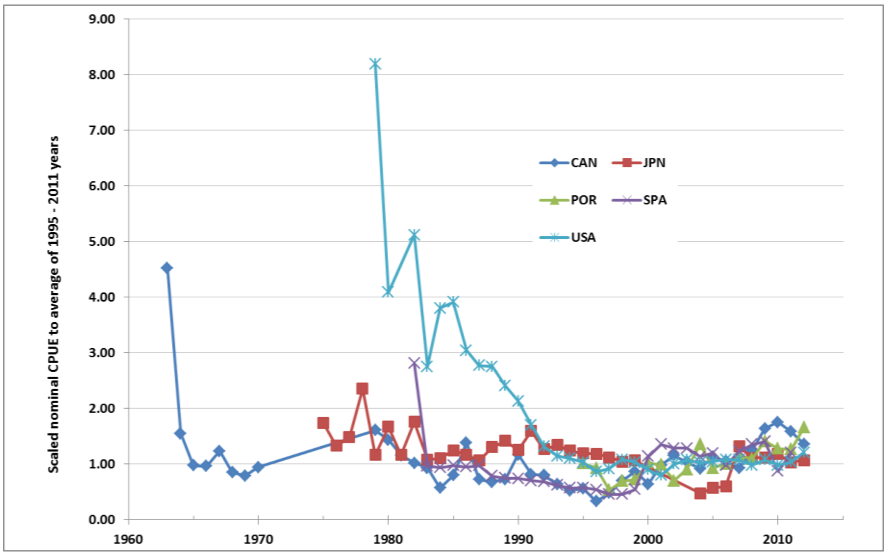

Figure 2. Annual trends of nominal CPUE north Atlantic swordfish by fleet. The series are scaled to the mean CPUE for the 1995 -2011 period for comparison purposes.

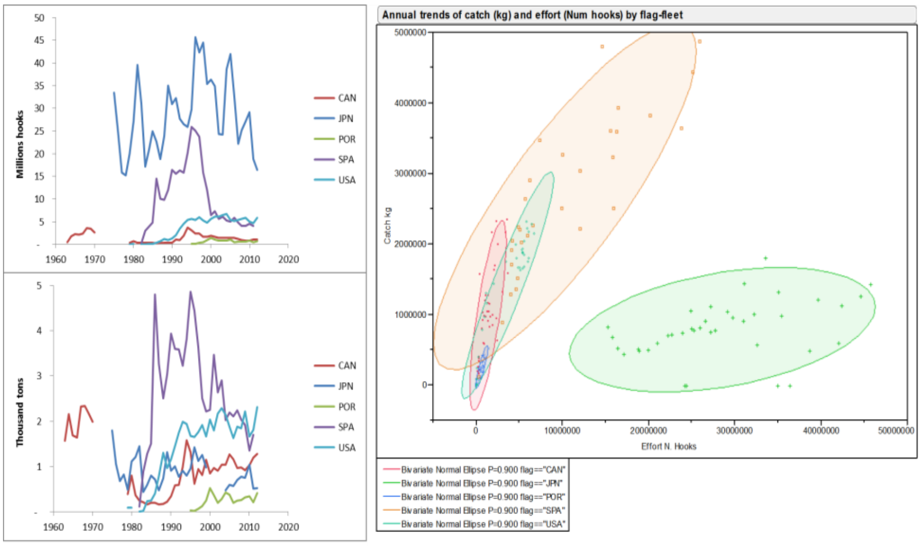

Figure 3. Annual trends of effort (number of hooks) and catch (tons) by main flag (left column) and bivariate normal ellipse (p=0.90) for the catch against effort linear relationships by flag.

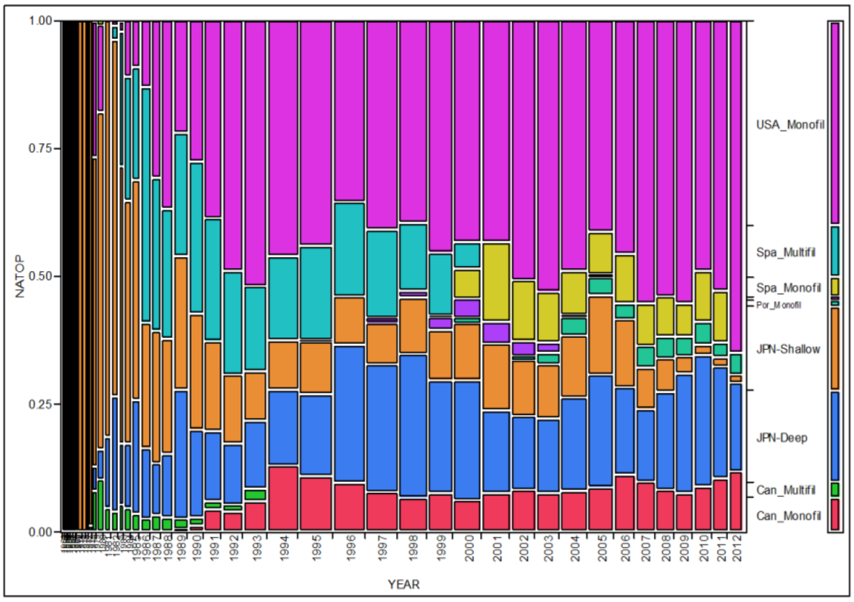

Figure 4. Mosaic plot of the biomass catch rate of north Atlantic swordfish by year and fleet-gear (NATOP) base model input data. The wide and high are proportional to the number of observations in each cell.

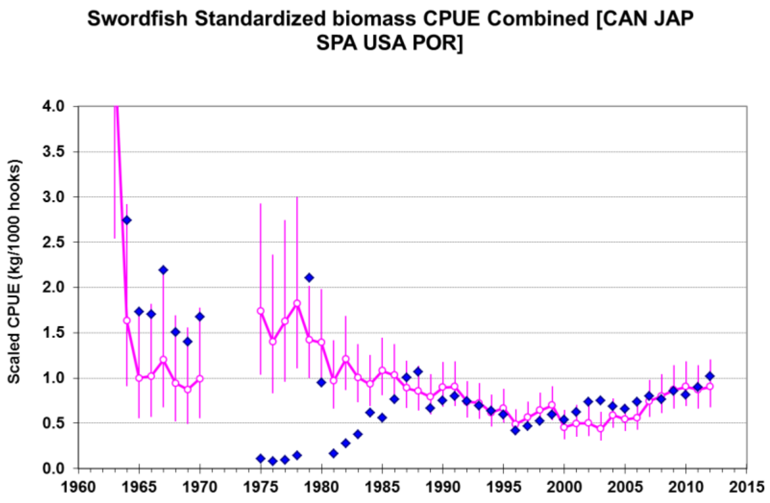

Figure 5. Nominal (diamond mark) and standard biomass catches rates (open circle) for North Atlantic swordfish from the main fisheries Canada, Japan, Spain and US combined. Bars represent upper and lower 95% estimated confidence intervals.

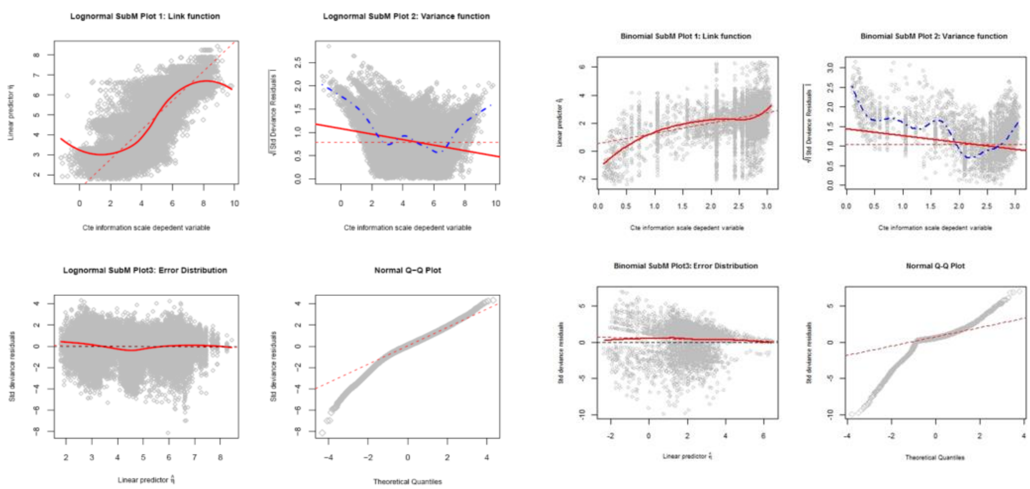

Figure 6. Diagnostic plots from the lognormal positive observations (2 left columns) and proportion of positives (2 right columns) of the delta-lognormal CPUE standardization model.

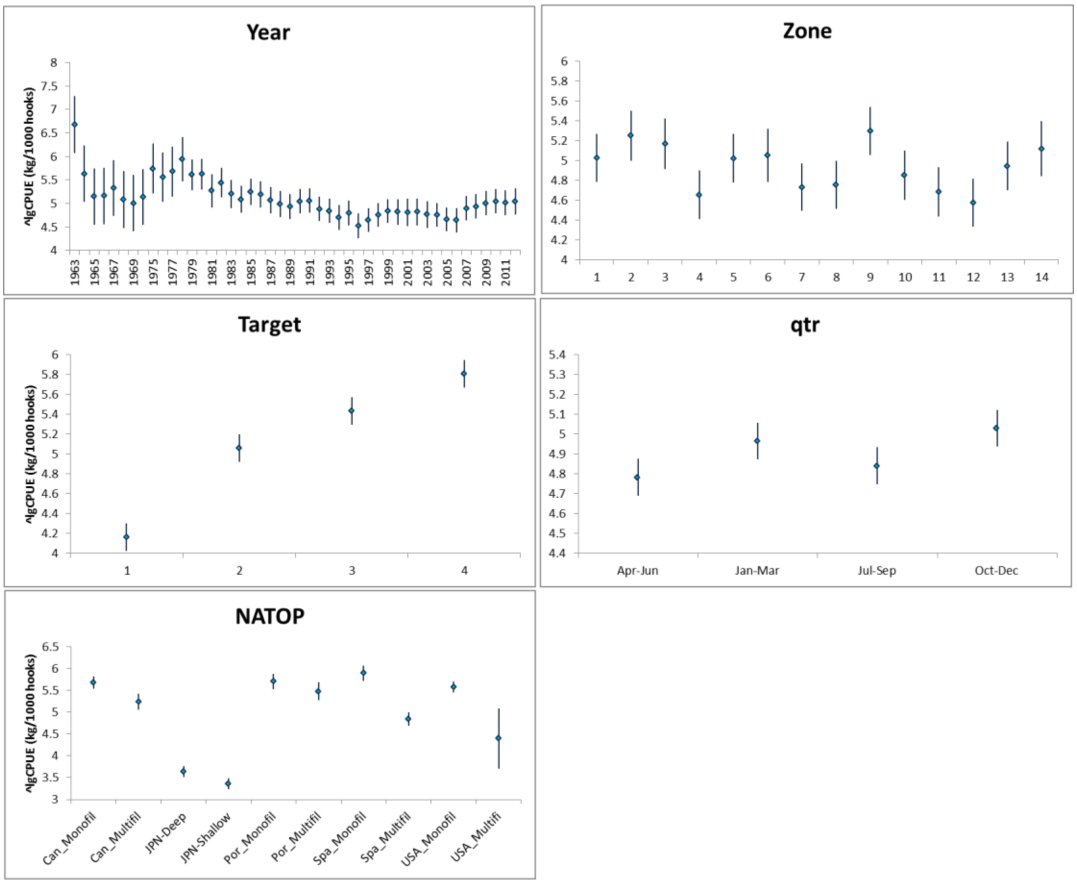

Figure 7. Plots of the predicted mean catch rate by factor-level in the base model of the log-transformed positive observations. Error bars indicated estimated 95% confidence bounds.

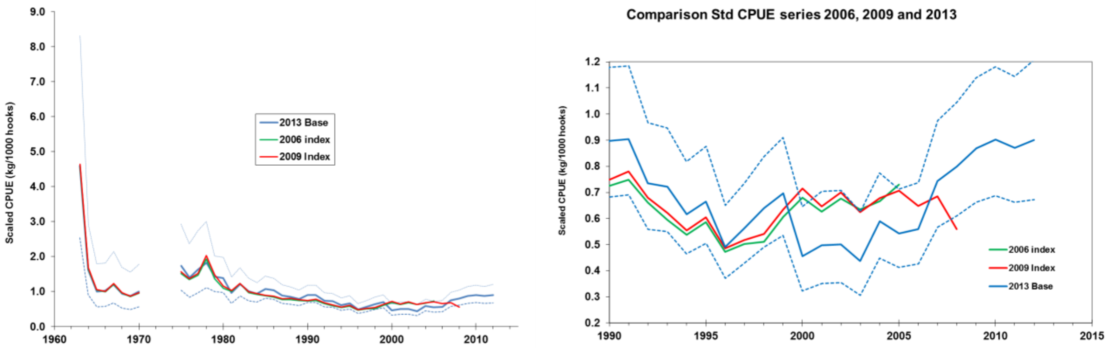

Figure 8. Comparison of the standardized CPUE series of North Atlantic swordfish estimated in 2006, 2009 and 2013 (left).

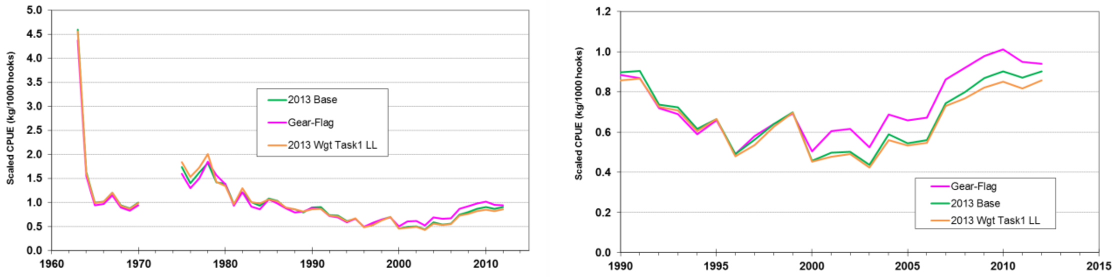

Figure 9. Sensitivity runs: Comparison of the standard index between base model, using gear and flag factors instead of NATOP, and using the catch task I longline as weighting factor in the model.

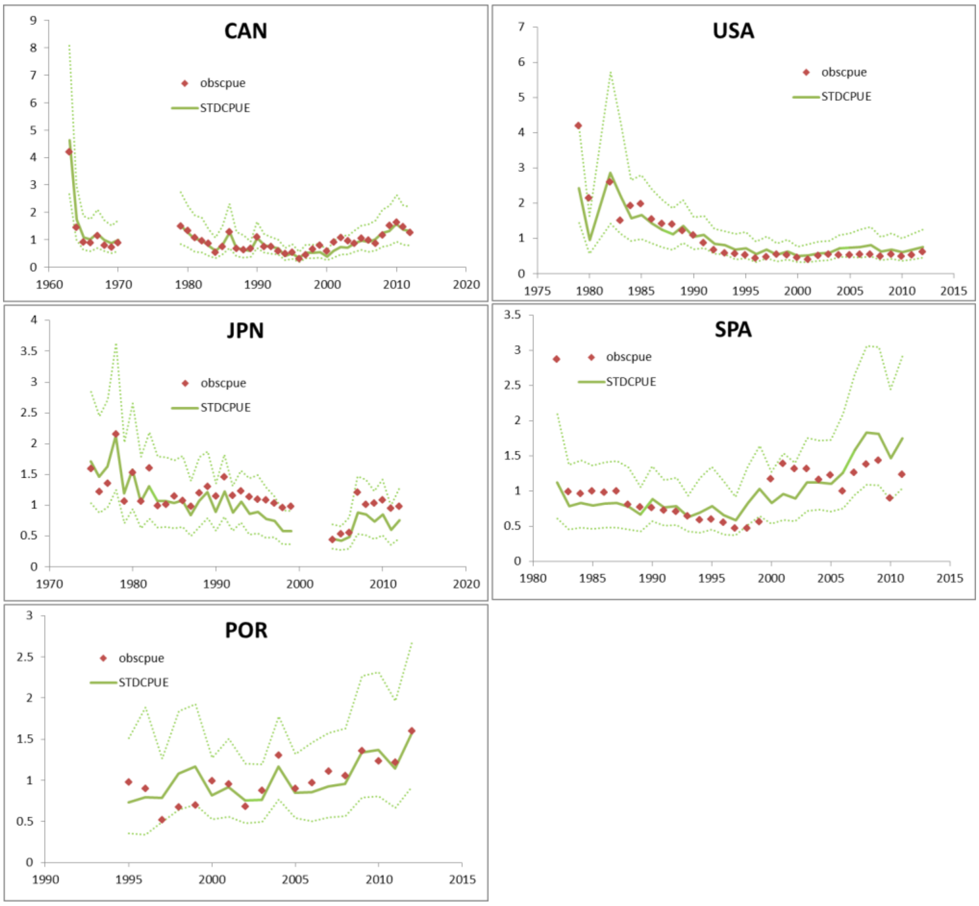

Figure 10. Sensitivity run: Estimated standardized N-SWO CPUE by flag with estimated 95% confidence intervals.