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A DESCRIPTION OF THE CANADIAN SWORDFISH FISHERIES FROM 1988 TO 2012, AND CANDIDATE ABUNDANCE INDICES FOR USE IN THE 2013 STOCK ASSESSMENT

Andrushchenko[1] I., Hanke[1] A., Whelan[2] C. L., Neilson[1] J.D. and Atkinson[3], T.

SUMMARY

Indices of abundance for the north Atlantic swordfish stock, based on data from the Canadian pelagic longline fishery, were estimated. Nominal and standardized age aggregated catch time series were developed for round weight and number of swordfish caught per hook (1962 to 2012). Age and gender specific nominal series of swordfish number per hook are provided for 1999 to 2012. The standardization involved a mixed effects model with effects due to bait, hook type, quarter, shark and tuna caught, trip length and area.

RÉSUMÉ

Les indices d'abondance pour le stock d'espadon de l'Atlantique Nord, fondés sur les données originaires de la pêcherie palangrière pélagique du Canada, ont été estimés. Des séries temporelles de capture agrégée par âge nominales et standardisées ont été élaborées pour obtenir le poids vif et le nombre d'espadons capturés à l'hameçon (1962 à 2012). Les séries nominales spécifiques à l'âge et au sexe du nombre d'espadons par hameçon sont fournies pour la période 1999-2012. La standardisation a impliqué un modèle d'effets mixtes avec des effets dus à l'appât, type d'hameçon, trimestre, requins et thonidés capturés, longueur de la sortie et zone.

RESUMEN

Se estimaron los índices de abundancia para el stock de pez espada del Atlántico norte basándose en datos procedentes de la pesquería de palangre pelágico de Canadá. Se desarrollaron series temporales de captura agregadas por edad estandarizadas y nominales para obtener el peso vivo y el número de peces espada capturados por anzuelo (1962 a 2012). Se facilitan, para 1999 a 2012, series nominales específicas del género y la edad del número de peces espada por anzuelo. La estandarización implicaba un modelo de efectos mixtos con efectos debidos al cebo, tipo de anzuelo, trimestre, tiburones y túnidos capturados, duración de la marea y área.

KEYWORDS

Catch/effort, Swordfish, Pelagic fisheries, Mixed effects

[1] Fisheries & Oceans Canada, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9 CANADA. Email address of lead author: irene.andrushchenko@dfo-mpo.gc.ca.
[2] Fisheries & Oceans Canada, Fish Population Science Branch, 200 Kent Street, Ottawa, ON K1A 0E6 CANADA.
[3] Nova Scotia Swordfishermen's Association, NS Canada

1. Introduction

The International Commission for the Conservation of Atlantic Tunas (ICCAT) last assessed North Atlantic swordfish in 2009 using age-specific catch rate indices from the Canadian pelagic longline fleet from 1988 to 2008 (Anon. 2010). This manuscript updates the nominal catch rates (number per hook) for male and female swordfish aged 2-9+ and 5+ for the Canadian pelagic longline fishery by extending the series to 2012.

Canada also contributed a biomass index spanning the periods of 1963 – 1970 and 1979-2008 for use in a combined biomass index analysis in ASPIC. This document extends that series to 2012 and presents both nominal and standardized indices calculated in terms of number of fish per hook and round weight per hook. Recent fish size trends for the fishery are presented as well as the relationship of swordfish catch to changes in bait type, hook type, hook size and the number of other species caught. Consultations with the Canadian fishing industry were held throughout May 2013 and some of the views obtained are reflected in this document.

2. Description of the fishery

Annual swordfish landings of the Canadian pelagic longline fleet ranged from 800 to 2,200 mt between 1988 and 2012, with 39 to 77 actively fishing vessels. In 2012, 44 longliners landed 1,488 mt of swordfish, reaching the levels of catch last seen by the longline fleet in 2005 (**Figure 1**). In contrast, the harpoon fishery involved 34 active licenses and landed 98 mt of swordfish in 2012, the lowest annual catch for this fleet since 2004 (**Figure 1**). Representatives from the harpoon industry have attributed the low catch to fewer swordfish basking on the surface, reducing the chance of an encounter with a harpoon vessel. This change in behavior has been attributed to increasing water temperatures, allowing the swordfish to recover quickly from deep dives and/or removing the need to enter the surface layer altogether. Historically, for stock assessment purposes, the Canadian swordfish catch per unit effort (CPUE) index has been based exclusively on the longline fishery, as a harpoon-based CPUE can be often influenced by weather.

The Canadian longline fishery operates in waters from Georges Bank to the Flemish Cap (**Figure 2**), with highest catches along the edge of the Scotian Shelf. The fishing distribution of the fleet has contracted over the last decade, with fewer trips going east of the Grand Banks since 2006 (**Figure 3**). This shift has been attributed to unfavorable water conditions, high cost of fuel and abundance of catch along the Scotian Shelf. Since 2010, there has been a surge of activity in the Emerald Basin that was attributed to a decrease in shark encounters, an abundance of swordfish in this area and proximity to ports (pers. communication, industry representatives, May 2013). In a given year, fishing activity can begin as early as May, staying south of the Scotian Shelf and along the edge of the Gulf Stream (**Figure 4**). As the season progresses, the fishing distribution shifts north, encompassing Georges Bank, the Scotian Shelf and the Grand Banks. The fishing season generally finishes by mid-November, though December catches have been reported periodically.

Throughout the history of the pelagic longline fishery, the fishing patterns/behaviour of the fleet has been affected by changes in management regulations. Log submission for Canadian fisheries became mandatory in 1994, suggesting that records prior to this may provide an incomplete account of fleet activity. Some assurance that the absence of logbooks was largely random is provided in **Figure 5** which shows similar temporal patterns in fishing just before and after the implementation of mandatory reporting. Additional shifts in management structure came in the form of time closures and trip limits for swordfish-directed fishing between 1999 and 2001. Finally, the traditional competitive structure of the fishery was changed to an Individual Transferable Quota (ITQ) system in 2002. This change appears to restore the temporal pattern in fishing observed prior to 1994. From 1994 until 2001 the fishery was subject to a declining TAC **(Figure 1)** as well as further trip and area restrictions that resulted in an incremental decline in the length of the season (**Figure 5**).

Prior to the implementation of ITQ management, longline vessels targeted other tunas in the spring and fall, generally filling their annual swordfish quota during the summer months. Under the current ITQ system, the swordfish season extends from May until November (**Figure 5**) with longline vessels being able to either direct for swordfish or to target other tunas while catching swordfish as bycatch. Due to current quota levels, Canadian longline fishermen have reported primarily using swordfish quota for bycatch to target other tunas.

3. Environmental considerations

Swordfish are seasonal migrants into Canadian waters, spending the summer and fall months in the waters off southwestern Nova Scotia, in the Bay of Fundy, and along the Scotian Shelf to the Flemish Cap. As swordfish migrate north, they shift from a generalist to a specialist diet (Scott and Tibbo, 1968). Prey items found in the stomachs of swordfish can include species from a wide range of depths (Stillwell and Kohler, 1985). Volumetrically, the most important prey species found in swordfish stomach contents in the Northwest Atlantic are Atlantic mackerel, Atlantic herring and squid (Bigelow and Schroeder, 1953; Stillwell and Kohler, 1985; Tibbo *et al*., 1961; Scott and Tibbo, 1968). Atlantic cod, silver hake, haddock and redfishes have also been found, though less frequently and in smaller quantities. Some caution needs to be used when analyzing the frequency of Atlantic mackerel in stomach analysis since it is also used as bait; however, many samples included mackerel showing more advanced signs of digestion. The Canadian fishermen report a wide variety of prey consumed by swordfish including small pelagics, groundfish and invertebrates.

Landings of Atlantic mackerel in areas of swordfish abundance (NAFO subareas 3 and 4) increased substantially throughout the early 2000s to reach a high of 54,621 mt in 2005, before declining dramatically to 8,544 mt in 2011(**Figure 6**). Similar trends in landings were also seen in the United States. The index of spawning biomass (measured by egg surveys) declined between 1985 and 1998, before an increase attributed to a strong 1999 year class. Throughout the 2000s, the spawning biomass index declined again to levels seen prior to the 1999 year class (**Figure 6**, DFO 2012); a decline which has been attributed to unsustainable fishing levels and a lack of recruitment.

There are two stocks of Atlantic herring in Canadian waters: southern Gulf of St. Lawrence and southwestern Nova Scotia. Herring in the southern Gulf of St Lawrence does not currently spatially overlap with the Canadian distribution of swordfish, though historically there was a substantial inshore fishery for swordfish near the mouth of the Gulf of St Lawrence. More recently, a few individuals have been caught in this area though this is considered unusual.

Herring in southwestern Nova Scotia, the Bay of Fundy and along the Scotian shelf are an important prey assemblage for swordfish in Canadian waters and have seen a 32% reduction in spawning stock biomass, from an average of 551 000 mt (2001-2004) to 377 000 mt (2005-2010, **Figure 7**, DFO 2011). There is little or no sign of improvement from lower abundance levels observed in 2005-2010 and this lack of rebuilding is a cause for concern. Current science advice recommends caution, including catch restrictions on small fish. No observations suggesting a need to change the current management regime or causes for concern have been noted for the offshore Scotian shelf portion of this stock. Although not understood, the decline in southwest Nova Scotia and the Bay of Fundy herring coincides with an observed change in herring condition; 2010 had the lowest fish condition on record since 1974 for the southwest Nova Scotia herring (this was not observed in the Bay of Fundy or on the Scotian Shelf). There is also a trend of declining mean weight at age for the fish in this stock. The average weight at age value for 2000-2009 is lower than the long term averages from 1965 onwards. It has been reported that herring are staying in deeper, cooler waters where they are less vulnerable to purse seines and weirs, although presumably are still available to swordfish.

Squid was noted as a frequently occurring prey item in swordfish stomach content analysis (Bigelow and Schroeder, 1953; Stillwell and Kohler, 1985; Tibbo *et al*., 1961; Scott and Tibbo, 1968). More recently, squid has been found in stomach contents studies (Stillwell and Kohler, 1985), leading to speculation that this is linked to an increasing abundance of squid. Anecdotal information from Canadian fishermen indicate that squid was seen in very high numbers in 2012; unfortunately there is no stock assessment or research available for the status of squid in Canadian waters.

Human activities and changing environmental conditions have caused a structural shift in the Scotian Shelf ecosystem (Worcester and Parker, 2010). The ecosystem has seen a major increase in the abundance of small pelagic fish (except herring and mackerel), macroinvertebrates, seals and phytoplankton, accompanied by significant decreases in groundfish and zooplankton. More recently the abundance of phytoplankton and zooplankton seems to be returning to its long term average. It is unclear what impact these ecosystem shifts have had on swordfish. Southwestern Nova Scotia and the Scotian Shelf are areas of high human use and there are several ongoing activities or threats in this area (i.e. oil and gas development, impacts of aquatic invasive species, ocean acidification, contaminants) for which the impacts on the ecosystem and swordfish are unknown.

4. Methods

4.1 Data

Catch and effort data for the Canadian swordfish longline fishery were obtained from mandatory logbook submissions made to the Department of Fisheries and Oceans beginning in 1994; submissions prior to 1994 were entirely voluntary. The logbook database provides information about each species caught, such as total weight[3], number of fish caught, type and size of hook used, type of bait, surface temperature and effort (number of hooks) for each set. Intensive consultation with industry representatives over the past year allowed for recovery of some missing set-level data between 2003 and 2012, increasing the number of available trips with set-level information (**Table 1**). The set-level data were aggregated to trip level after excluding catches by the offshore fleet, which primarily targets other tunas, as its effort is not considered representative of the swordfish longline fleet.

Aggregating the data from set to trip level is often problematic when the variable of interest is not continuous and/or is missing for some sets within a trip. Prior to aggregating to trip level, the set level detail was restored to the highest degree possible. For example, the gear configuration can vary between sets of the same trip but is generally recorded by the fisherman in the logbook. In the case of hook type, only 72.7% of the set-level data between 2003 and 2012 was complete. However through Industry consultation, it was determined that the type of hook and manufacturer is generally associated with a certain hook sizing range/system (**Table 2**). As 88.1% of the set-level data had hook size information, the missing hook types were derived from available hook size using **Table 2**, resulting in 79.7% of the data having an associated hook type. Following aggregation, the trip-level dataset had hook type information for 84.1% of the trips between 2003 and 2012. Prior to 2003 no hook type data is available so hook size data was used to impute a hook type and, through industry consultation, it was determined that from 1962 to 1995 the fleet used J hooks.

Bait type data was available for 88.3% of set-level data and 93.4% of trip-level data from 2002 to 2012, and 100% of the data from 1988 to 2001.

Data on the number of swordfish caught was available for 98.9% of the trip-level data. A large proportion of the missing data (56 of the 82 missing trips) occurred in 2003. Swordfish weight data is provided by dockside monitors and was available for 100% of the trip-level records. Set-level detail on the number and weight of swordfish caught is available, but it is derived from estimates provided in fishermen's logbooks.

4.1.1. Nominal sex and age-specific CPUE (1999-2012)

Tally sheets obtained from the Dockside Monitoring program provide individual fish weights for approximately 90% of the landed swordfish catch. The sampling program has been in place since 1999 and provides individual round weights, which were used to generate lower jaw fork lengths (LJFL) using Turner (1978) conversion factors. The age and gender proportions (Ehrhardt *et al*. 1996, Ortiz *et al*. 2000) were applied against the numbers caught at length to generate age and gender specific nominal CPUE.

4.1.2 Standardized Age-aggregated CPUE (1963 – 2012)

The Canadian standardized index contains historic logbook records from the Canadian longline swordfish fishery from 1963-1970 and 1979-2012 (**Table 3**). Data is also available for 1962 but has been excluded in past assessments due to the low number of trips (11); however it was included in the current standardized index. High Canadian catch rates in the initial years of the 1963-1970 series were validated with paper log records and interviews[4]. Data was not available between 1971 and 1978 because fish were not landed in Canada due to export restrictions on mercury contaminated fish. The data for the early time series (pre-2003) were available on a trip-level, so the recent years (2003-2012) were also aggregated to trip level.

4.2 Variables

The current protocols for filtering and aggregating the data and constructing factors used in the standardization are described.

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[3]Weight and number from logs are values estimated by the fisherman. Accurate weight and number data come from dockside monitor records and are available on trip-level only.
[4]It was recommended during the 2009 stock assessment that these high values be checked.

4.2.1 Gear filter

Canadian pelagic longline vessels can use longline, tended line and harpoon gear concurrently on a given trip, but the resulting sets are all recorded as 'longline' in the log system. This is thought to have a confounding effect on CPUE (Paul and Neilson 2010a), and was addressed in Hanke *et al*. (2012) by excluding suspected harpoon and tended line sets based on effort, weight of swordfish and presence of other species. Sets with fewer than 300 hooks were considered a mixture of gears (likely tended line and harpoon), while those with equal to or greater than 300 hooks were strictly longline. Sets with only one hook were considered harpoon, unless more than one species was identified or the total weight for the set exceeded the maximum known weight of a single fish (537 kg). This filter was applied to the set-level data and its effect on set-level data is summarized in **Table 4**. It should be noted that the effect of the harpoon filter on 1988-2001 data would exclude 3 trips, but it was not applied.

4.2.2 Targeting, bait and hook effects

As the fishery evolved from targeting exclusively swordfish to a mixed fishery targeting swordfish and other tunas, a variable had to be introduced into the model that would control for an effect due to targeting. Historically, this was achieved by only considering trips where the weight of the swordfish exceeded the weight of the other species (Paul and Neilson 2007). Following a review of other potential targeting variables (bait type and sea surface temperature), Paul and Neilson (2010b) recommended continued use of the traditional weight-based targeting, citing poor data availability for the other factors and lack of data for the earlier part of the series (1988 – 1993). However, a weight-based targeting variable involving swordfish is strongly correlated with both catch in numbers and in weight and its inclusion may remove time trends in the catch rate which should be attributed to the year effect (Maunder and Punt 2004). Consequently, other variables were considered in the present analysis such as bait type, hook size/type and their interaction. The availability of sharks and tunas in a given time and place was not thought to be closely related to that of swordfish, so their combined count per trip was adopted as a variable which would reflect an aspect of targeting but also a gear saturation effect.

The bait type on a given set was grouped into one of four categories: a mixture of pelagic fish (alewife, herring, mackerel and silver hake), a mixture of squid with one type of pelagic fish, a mixture of squid with two pelagic species, and squid alone. As the fleet generally targets swordfish using pelagic fish and tunas using squid, the bait type for the trip was expressed as the mean proportion of pelagic fish for all sets on the trip. Each bait-type was assigned a pelagic fish proportion (P_{pel}) based on the number of bait types identified: all pelagic fish (1), all squid (0), squid and one type of pelagic fish (0.5), squid and two types of pelagic fish (0.667). The P_{pel} was averaged for all sets of a single trip, to provide a mean pelagic fish proportion for the trip. Where set-level bait information was not available for the older data (1962-2002), the specified trip-level bait type recorded was converted to one of the four P_{pel} values (0, 0.5, 0.667 or 1).

If the trip level data did not have a bait value (P_{pel}), a suitable substitution was made using the mean bait value in the same area-quarter-year stratum. When this failed, the mean bait value from the dataset was substituted. The continuous bait values were then converted into discrete bait categories when it was realized that the distribution of bait values had 3 modes corresponding with a proportion pelagic fish of 0, .5 and 1. The bait values were binned into three groups, *Squid*, *Mix* and *Fish* respectively, by breaking the data at bait values of 0.33 and 0.66.

A mixture of hook types was used by industry and could be classified into three main groups. The variety of styles were reclassified to '*C*', '*J*' or '*unknown*' based on consultation with Industry and knowledge of the corresponding hook sizes and the year. Aggregation of set-level data to trip resulted in any trips with both *J-hook* and *Circle-hooks* used on different sets being coded as '*C*'.

Following the data restoration and trip-level aggregation described earlier for hook type and size, the categories of each were simplified. Hook sizes between 0 and 8 were converted to '*JR*' (ringed), sizes 9 to 12 were coded as '*JnR*' (not ringed), sizes 13 to 15 were coded to '*SmallC*' and sizes larger than 15 were coded as '*BigC*' (**Table 2**).

The total number of sharks and tuna caught was simply determined by summing the set-level data. In some instances only the weight caught was given but this information was used to calculate the number caught by dividing the weight caught by the average weight of that species caught in the same area-quarter stratum.

4.2.3 Area effect

Each set was identified to a NAFO statistical unit area but an entire trip could span several of these areas. This made trip level aggregation of area information problematic. A protocol was developed to identify a trip with a representative area when more than one area was fished. This involved creating area complexes based on the aggregate of unique areas fished. This process resulted in a trip with fishing in area 4V, 4W and 5Z being identified with area complex 4VW5Z, for example. In total 59 areas were identified, not all of which were area complexes. This large number was rationalized to 16 based on areas that the complexes had in common. Simple areas generally remained distinct.

4.2.4 Management effect

The years of the time series were identified with changes that occurred in the fishery and this factor was termed the management effect. The management effect was not included in the model because it was collinear with the year effect; however it was useful for exploring the results from the model and to document the changes to the fishery. The phases of the fishery are as follows: Phase 1, 1962:1970 (unrestricted fishing); Phase 2, 1979:1993 (post export restrictions on mercury contaminated fish, introduction of quotas); Phase 3, 1994:1998 (mandatory logbook submissions); Phase 4, 1999:2001 (trip and area restrictions) and Phase 5, 2002:2012 (switch from competitive fishery to individual transferable quotas).

4.3 Nominal age and sex-specific CPUE (1999-2012)

Age and sex specific nominal CPUEs were calculated based on individual size data from the Canadian dockside swordfish sampling program which was instituted in 1999. Currently, the series is based on the 1999 to 2012 period. The sex ratio at length key (Ortiz *et al*. 2000) was applied to the numbers at length and split the population into male and female components. Gender specific growth curves (Ehrhardt *et al*. 1996) were applied against the respective genders and provided ages by gender, month and aggregated lower jaw fork lengths (5cm bin). Annual CPUE (total annual number of swordfish/total annual number of hooks) was calculated for each gender for ages 2 through 8; CPUE was also generated for a 9+ and a 5+ group (**Figure 8**).

4.4 Standardized age-aggregated CPUE (1963-2012)

Standardized age-aggregated indices of swordfish abundance were developed from trip-level data for the period 1962 – 1970 and 1979 – 2012 using both the number and weight of swordfish caught. The models were identical except for the choice of response variable. Rather than model the rate, fishing effort was included as an explanatory variable (Maunder and Punt 2004). Both catch and effort were log transformed to account for the non-linearity in their relationship. This log-log model was not assumed to have normally distributed errors. A mixed effects model was adopted with random intercept and slope and a ‘power of the covariate’ variance structure (Pinheiro and Bates 2000; Pinheiro *et al*. 2013; Zuur *et al*. 2009). More formally the model was as follows:

$$
\begin{aligned}
Ln(NSwo)_{ij} &= \alpha + \beta_1 \times Ln(Hooks)_{ij} + \beta_2 \times Year_{ij} + \beta_3 \times Bait_{ij} + \beta_4 \times HookType_{ij} + \beta_5 \times Quarter_{ij} + \\
&\beta_6 \times Ln(NSets)_{ij} + \beta_7 \times Ln(NSharkTuna_{ij}) + \beta_8 \times Year_{ij} \times Ln(NSets)_{ij} + \beta_9 \times Bait_{ij} \times HookType_{ij} + \\
&\beta_{10} \times Bait_{ij} \times Quarter_{ij} + \beta_{11} \times Quarter_{ij} \times HookType_{ij} + \beta_{12} \times Ln(NSets)_{ij} \times Ln(NSharkTuna_{ij}) + \\
&\beta_{13} \times Ln(NSets)_{ij} \times Quarter_{ij} + \beta_{14} \times Quarter_{ij} \times Ln(NSharkTuna_{ij}) + b_{i1} + b_{i2} + \varepsilon_{ij}
\end{aligned}
$$

where $Ln(NSwo)_{ij}$ is the natural log transformed number of swordfish caught for observation *j* in NAFO area *i*. $Year_{ij}$, $Quarter_{ij}$, $Bait_{ij}$ and $HookType_{ij}$ are all nominal variables with 43, 3, 3 and 3 levels respectively. $Ln(Hooks)_{ij}$, $Ln(NSets)_{ij}$ and $Ln(NSharkTuna_{ij})$ are natural log transformed continuous variables. The between $Area$ variation and the $Ln(NSets) \times Area$ interaction are modeled with a random intercept b_{i1} and random slope b_{i2}, respectively, and are represented by 16 groups. The distribution of the intercept and slope is given by

$$\binom{b_{i1}}{b_{i2}} \sim N(0,D) \text{ where } D = \begin{pmatrix} d_{11}^2 & d_{12}^2 \\ d_{21}^2 & d_{22}^2 \end{pmatrix}$$

Here the variance d_{11}^2 determines the amount of variation around the population intercept α in the areas and the variance d_{22}^2 determines the amount of variation around the population slope in the areas. The correlation between the random intercept and slopes is represented by d_{21}^2. The residual ε_{ij} is assumed to be normally distributed with mean 0 and variance increasing with the power of the absolute value of the variance covariate $Hooks$. The structure for the residuals is

$$\varepsilon_{ij} \sim N(0, \sigma^2 x \left| Hooks_{ij} \right|^{2\delta})$$

Both the ε_{ij} and b_i terms are assumed to be independent of each other.

The model selection process followed the method of Diggle *et al*. (2002) and began by specifying a model where the fixed component had all explanatory variables and as many interactions as possible so that the optimal structure of the random component could be found. The selection of the optimal component was accomplished using REML estimation and the likelihood ratio test. After selecting the optimal random component the optimal fixed structure was determined using ML estimation and a stepwise backwards and forwards search for the model with the lowest AIC (Venables and Ripley 2002). The final model was estimated using REML to generate unbiased estimates of the parameters. The final model for number of swordfish caught was determined first and this became the starting point for the development of a model based on weight of swordfish caught. The rationale for the inclusion of main effects and interactions was the same for both response variables and it remained for the forward and backwards selection process to decide which terms would be retained.

The year effects were represented by their population level estimates (not within area) and were extracted from the model by setting the continuous predictors to their median value and by setting the categorical variables to their most common value in the dataset ($Quarter$ *=3rd*, $Bait$ *=fish* and $HookType$*=J* (not ringed)) (Maunder and Punt 2004). These choices also reflect the levels most likely associated with swordfish directed fishing over the entire time series. Year effects, standard errors and 95% confidence intervals were back transformed to the original scale (Jørgensen and Pedersen 1998) and, when appropriate, scaled by the median number of hooks for comparison with nominal catch rates.

5. Results and discussion

5.1 Catch characteristics

The Canadian pelagic longline swordfish fishery catches individuals with a mean lower jaw fork length (LJFL) of 181 cm (**Figure 9**) and the size distribution of its catch has been historically skewed to the left (**Figure 10**). In 2011 the longline fishery saw an increase of larger fish (>180cm LJFL, **Figure 10**), with the annual mean exceeding the series mean for the first time since 2005 (**Figure 9**). The strong year class of large fish continued to move through the 2012 fishing season (>210 cm), but was also supplemented by an influx of fish with a LJFL <150 cm (**Figure 10**). The high occurrence of both small and large fish resulted in an unusually flat-topped catch-size distribution for 2012 (**Figure 10**). In recent years, the weight of swordfish catch per set has been highest towards the end of the season (**Figure 11**).

5.2 Bait and hook effects

Bait is used as a targeting variable for the pelagic longline fishery. In general, fish bait is used when the target species is swordfish, while squid bait is used to target other tunas (**Figure 12**). From 1962 until 1990, pelagic fish was the predominant bait type used by the Canadian pelagic longline fishermen (**Figure 13**). Throughout the 1990s and the early 2000s, mixed bait and squid bait saw a steady increase in popularity, with squid becoming the predominant bait type in 2007 (**Figure 13**). More recently, the use of mixed bait has increased to rival the use of squid (**Figure 13**). As indicated above, there have been recent declines in herring and mackerel biomass which may affect the availability of these species for use as bait.

Following data recovery efforts and industry consultation, the Canadian pelagic longline fishery is thought to have used a combination of ringed and non-ringed J-hooks until the early 2000s (**Figure 14)**. Detailed log information shows the use of circle hooks beginning in 2002, but the actual introduction of circle hooks may have occurred several years earlier. Following the introduction into the fishery, the use of circle hooks was encouraged and steadily increased until 2012, when their use became mandatory as part of the bycatch reduction initiative (**Figure 14**). The use of non-ringed J hooks appears to yield the highest proportion of swordfish, while the ringed J-hooks and the circle hooks yields a mixture of swordfish and tuna (**Figure 15**). It was noted by Industry that J hooks in general catch more swordfish through foul hooking and consequently hook type is not entirely indicative of the species targeted. The higher CPUE for swordfish when using J hooks is supported by the literature (Read 2007, Foster *et al*., 2012, **Figure 16**).

The longline fishery has evolved in response to quota limitations and the implantation of individual quotas from strictly targeting swordfish, to targeting other tunas and reserving their swordfish quota for bycatch or for a swordfish directed portion of a trip. Industry representatives have indicated that some captains have been targeting swordfish towards the end of a trip. This change in behaviour makes the set-level detail for a trip increasingly more important for identifying the alternative modes of catching swordfish and may be called upon for sorting sets and then splitting trips into the respective modes prior to aggregation. We do wish to note that the data does not substantiate the claim that more swordfish are caught towards the end of a trip for the fleet in general. Vessels which catch more swordfish than tunas have a generally lower average weight of swordfish for the last two sets than for the preceding sets. Clearly there are potential area and seasonal considerations that must be taken into account when testing for the presence of these modes.

5.3 Indices

5.3.1 Nominal age-specific CPUE (1999-2012)

The nominal age-specific CPUE for female swordfish has shown a general increase from 1999 to 2012 for all ages except the 9+ group. There was also a notable short-term increase in CPUE of female swordfish aged 2 and 3 from 2011 to 2012, while older females (ages 4 through 8) all showed a decline from 2011 to 2012 (**Figure 8**). Males constitute a smaller fraction of the population, so trends in their abundance are less evident by comparison. It was noted, however, that males ages 2 through 4, as well as the 9+ group, did show a net increase from 1999 to 2012. In comparison, male swordfish aged 5 through 8 remain consistently low (**Figure 8**).

Although the harpoon filter removed 79 sets between 2003 and 2012 (**Table 4**), the change had minimal effect on the nominal CPUE. Some of the data-recovery procedures applied to the data may have downplayed the impact of the harpoon filter, but future efforts to improve the accuracy of the set-level log data may minimize the need for data recovery assumptions and increase the impact of this filter. It was also be noted that the harpoon filter could be expanded to include any sets where the total catch was only one swordfish (weight <537 kgs) with no other species, regardless of whether the effort amount exceeded 300 hooks. The same filter can be elevated to trip level and applied to pre-2002 data.

5.3.2 Nominal age-aggregated CPUE (1963 – 2012)

The nominal CPUE (weight of swordfish per 1000 hooks) for the time series (1963 – 1970 and 1979 – 2012) was calculated as the annual average of the individual trip CPUEs for each year (**Figure 17**). The high catch rate in 1963 was validated with original paper log records, and thus continues to be included in this time series. The weight-based CPUE for the later series shows that the catch rate in 2010 surpassed the catch rates seen throughout the 1980s, though it was followed by a slight decrease in 2011 and 2012.

5.3.3 Standardized age-aggregated CPUE (1963 – 2012)

A test of the marginal sum of squares for the fixed terms in the final model for both numbers and weight caught is given in **Table 5** and a summary of the estimates of the model coefficients for the fixed effects of the numbers model is provided in **Table 6**. **Table 7** and **Table 8** provide the predicted catch in each year when bait is *fish*; hook type is *J* (not ringed), quarter is *3rd* and the continuous variables are held at their median on the original scale for both the numbers and weight based models respectively. These catch estimates are expressed as a rate by dividing by median number of hooks (6,594) so that they can be compared with the nominal estimates on the same scale. The transformed CV and 95% CI for the standardized catch rate are also provided.

The estimated variation around the population intercept and slope in the numbers model was 0.3892319^2 and 0.1343626^2 respectively while the correlation between the random intercepts and slopes was -0.71. The residual variance was estimated as 5.3393695^2 and the estimate of δ for the power of the covariate variance structure is -0.254863. Similar estimates for the weight based model were 0.29435821^2, 0.03141687^2, -0.01, 11.73938627^2 and -0.3352946 respectively.

Scatter plots of the standardized residuals versus the fitted values from the final numbers based model conditioned on management periods (**Figure 18**) indicate that the residuals are centered on zero and seem to have similar variability across periods. The outcome was similar for the final weight based model. The periods differ with respect to the number of observations and seasonal coverage **(Figure 5**) and account for some of the visual differences. Normal plots of the standardized residuals from the fixed component of the final numbers based model conditioned on management period indicate that assumptions of normality were not violated (**Figure 19**) and fitted values are in fairly good agreement with the observed catches (**Figure 20**). The normal plots for the final weight based model indicated that the residuals had a slightly heavier left tail while the fitted values were in good agreement with the observed catches (not shown). Finally, normal residual plots for the random components of the final numbers based model were reasonably normal for both the intercept and slope (**Figure 21**) and this was true for the weight based model as well (not shown).

The trend in the standardized catch in numbers is given in **Figure 22** for the case where bait is *fish* (hook type *J* (not ringed), quarter *3rd)*. Given that fish is the bait preferred by swordfish and that the use of squid has increased in recent times as fishermen target other species, there is an obvious divergence of the standardized index of abundance from the nominal series beginning around 2001 that corresponds with the change in bait. The effect of bait choice on the index is clearly shown in **Figure 23**. The predicted year effects for squid as bait are similar to the nominal values post 2001 when squid became more widely used but are below the nominal values when bait like mackerel and herring were the dominant bait choice.

The shift in bait choice corresponds with the introduction of individual quotas (ITQ) beginning in 2002 and is likely an expression of the fisherman's attempt to manage all his fishing options in a way that maximizes his profit. This includes managing options when swordfish are targeted. Catch rates for swordfish were generally higher in the 4th quarter than the 3rd which was higher than the 2nd, regardless of bait. Also beginning around 2002 is the increase in the use of circle hooks which have been shown to reduce the catch rate for swordfish (Read 2007, Foster *et al*., 2012, **Figure 16**).

The abundance prior to the implementation of export restrictions on mercury contaminated fish in 1971 is lower than after it was lifted in 1979. The restrictions account for the lack of data between 1971 and 1978. The index declines estimated for 1990 to 1996 correspond with a period when the fishery was competitive and the TAC was being incrementally reduced (**Figure 1, Figure 5**). The net effect on the fishing was to have the seasons shorten incrementally as indicated in **Figure 5**. Also coincident with these events is a sharp decline in mackerel biomass, a principal prey of swordfish **(Figure 6**). The index responds positively in conjunction with both the introduction of an ITQ system and a partial recovery of mackerel biomass. However, the recovery began while mackerel abundance was low, the fishery was competitive and strict area and trip restrictions were being imposed. These apparent inconsistencies suggest that this period in the history of the fishery requires further study. Since the last assessment in 2009, the stock experienced an increase to 2010 and decline in 2011 which was arrested in 2012. However, the general trend since 1996 has been an increase in abundance to levels consistent with what was observed historically.

The trend in the standardized catch in weight closely resembles that for catch in numbers (**Figure 24**) and differences are only evident when the series are overlaid on each other as in **Figure 25**. This figure shows the relationship between the weight and numbers based nominal and standardized data. The scatterplots show that there is a strong linear relationship between the nominal estimates of catch as well as the standardized estimates of catch. The time series plots of the standardized catch indicate that there is good agreement between the weight and numbers based series from 1998 to 2011. Between 1993 and 1997 the weight based index shows the stock as being more abundant while from 1979 to 1992 the weight based index shows the stock as being less abundant. From 1962 to 1970 the indices either match or the weight based index is more optimistic. The discrepancies between the two indices maybe a function of shifts in stock structure in the areas being fished. Harvesting smaller fish may require more effort to maintain a given level of catch than larger fish, for example.

6. Conclusions and recommendations

1. Bait, hook and gear saturation effects (number of sharks and tuna) accounted for trends in the catch unrelated to changes in abundance. Catch rates were highest when using fish for bait and in the 4th quarter. Non-ringed J-hooks had the highest catch and trips while low numbers of sharks and tuna caught tended to have the highest swordfish catches. Because of the significant influence of these factors on catch and the changing bait and hook use over time, it is important to incorporate these factors in the catch standardization.

2. Standardized indices based on weight and numbers caught were generally in close agreement with discrepancies related to periods where there might be data issues that need to be resolved. There is also a possibility that catch rates based on weight are sensitive to size of the fish being caught and consequently the differences in the two series reflect shifts in the size composition of the catch.

3. The trend in the index between 1990 and 2000 is coincident with major changes in the management of the fishery and significant changes in the abundance of an important prey species that could impact the index. It is important to determine if the model properly accounts for these events and accurately reflects stock abundance in this period.

4. The period prior to mandatory logbook submissions require additional consideration to determine if the trends are sensitive to the nature of the voluntary reporting and omission of zero-catch trips.

5. The age and gender key is used to produce the nominal age and gender specific indices. This key needs to be updated because it is now more than 12 years old and may no longer reflect the stock composition by month, length and gender.

6. The dockside monitoring program that provides the individual size data used in the age and gender specific indices began collecting samples in 1999. Prior to this, individual records were obtained from the buyers. Given that the age and gender specific indices currently start in 1999 it is recommended that they be extended to 1988 if possible.

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Table 1. Change in the number of available trips with set information from 2003 to 2008 before (original) and after (updated) data recovery efforts.

Year	2002	2003	2004	2005	2006	2007	2008	2009
Original	217	191	229	239	253	200	153	-
Updated	217	198	239	239	258	210	165	153
Net	0	+7	+10	0	+5	+10	+12	-

Table 2. Hook type, size and main species caught by the Canadian pelagic longline fleet (Per. Comm. Industry Representatives).

Hook Size	Hook Type	Main species caught
3.3, 3.4, 3.6, 3.8, 4.2, 5.5, 7[5],8	Japanese Ringed Tuna Hook	Other Tuna
9/0, 10/0, 11/0, 12/0	J- Hook (Not ringed)	Swordfish
16/0, 18/0	Circle Hook (Big)	Swordfish and other tunas
13/0, 14/0, 15/0	Circle Hook (Small)	Mahi-Mahi and small tunas

Table 3. Catch and effort data available for the age-aggregated Canadian biomass index. 1962 has been excluded from the index due to the low number of trips.

Year	Number of Trips	Number of Sets	Number of Fish	Weight (MT round)	N Hooks (millions)	Nominal CPUE (kgs/1000 hooks; set-based)	Nominal CPUE (kgs/1000 hooks; trip-based)
1962	11	96	814	113	0.04	2,730	2,692
1963	95	618	14,527	1,574	0.46	3,423	3,534
1964	256	2,106	24,064	2,298	1.90	1,209	1,249
1965	197	1,895	21,474	1,729	2.27	761	773
1966	202	1,885	21,474	1,669	2.14	779	751
1967	212	1,950	35,093	2,347	2.47	952	971
1968	292	2,757	38,362	2,362	3.64	648	661
1969	273	2,523	37,549	2,194	3.50	627	609
1970	189	1,801	38,219	2,023	2.68	756	730
1979	39	315	5,031	399	0.35	1,136	1,257
1980	75	583	9,717	806	0.69	1,163	1,125
1981	36	283	5,527	375	0.37	1,001	905
1982	34	264	3,501	255	0.31	811	799
1983	30	270	3,551	218	0.36	603	726
1984	33	274	3,048	165	0.38	437	444
1985	34	253	3,477	204	0.32	627	622
1986	30	189	3,444	205	0.24	838	1,082
1987	35	252	3,531	163	0.32	508	564
1988	36	268	3,600	183	0.32	576	532
1989	44	352	4,084	224	0.39	570	568
1990	45	376	5,603	348	0.35	988	914
1991	117	1,077	9,189	588	1.03	571	638
1992	117	1,019	9,801	595	0.94	632	626
1993	218	1,986	16,668	995	1.96	507	499
1994	427	3,855	24,601	1,584	3.73	425	408
1995	405	3,252	19,168	1,320	3.11	424	443
1996	330	2,639	9,139	629	2.45	257	260
1997	272	2,571	13,749	947	2.41	393	378
1998	210	1,732	13,340	821	1.62	506	542
1999	202	1,671	19,438	1,156	1.64	706	677

[5]Size 7 and 8 hooks have been included in the ringed category even though they are not ringed.

2000	187	1,814	17,263	851	1.97	431	501
2001	234	1,926	12,977	969	1.67	579	768
2002	217	1,350	12,651	915	1.41	649	898
2003	198	1,396	9,140	1,048	1.40	750	806
2004	239	1,475	14,197	1,048	1.49	704	716
2005	239	1,527	18,491	1,271	1.45	879	887
2006	258	1,539	15,437	1,168	1.42	821	820
2007	210	1,364	12,865	967	1.20	808	707
2008	165	1,099	13,351	988	0.98	1,005	972
2009	153	1,031	12,282	924	0.85	1,088	1,283
2010	178	972	13,206	1,037	0.83	1,254	1,360
2011	180	1,253	13,919	1,206	1.06	1,133	1,190
2012	188	1,299	15,953	1,277	1.13	1,126	1,057

Table 4. Change in set–level information for 2003 – 2012 before and after applying a gear filter that excludes suspected harpoon records.

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
No Filter	1,350	1,396	1,475	1,527	1,539	1,364	1,099	1,031	972	1,253	1,299
With Filter	1,350	1,380	1,469	1,524	1,535	1,351	1,092	1,031	963	1,234	1,297
Net	0	-16	-6	-3	-4	-13	-7	0	-9	-19	-2

Table 5. Marginal sum of squares for each term in the final model (numbers and weight caught) with degrees of freedom for the numerator, denominator and F-values and p-values for a Wald test. These test the effect of adding a term with all other terms already in the model.

Terms: Numbers model	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	7001	7.1322	0.0076
LNhook	1	7001	333.6361	<.0001
YEAR	42	7001	6.4874	<.0001
log(N_SETS)	1	7001	3.0988	0.0784
BAIT	2	7001	23.2125	<.0001
HOOK_SIZE	4	7001	8.084	<.0001
Qtr	2	7001	3.4499	0.0318
NSharkTuna	1	7001	5.8878	0.0153
YEAR:log(N_SETS)	42	7001	4.0601	<.0001
BAIT:HOOK_SIZE	8	7001	9.4648	<.0001
BAIT:Qtr	4	7001	6.6499	<.0001
HOOK_SIZE:Qtr	8	7001	6.9403	<.0001
log(N_SETS):NSharkTuna	1	7001	3.9119	0.048
log(N_SETS):Qtr	2	7001	10.0647	<.0001
Qtr:NSharkTuna	2	7001	6.6752	0.0013
Terms: Weight model	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	7001	0.48636	0.4856
LNhook	1	7001	224.3266	<.0001

YEAR	42	7001	7.67704	<.0001
log(N_SETS)	1	7001	3.26628	0.0708
BAIT	2	7001	44.42235	<.0001
HOOK_SIZE	4	7001	7.82615	<.0001
Qtr	2	7001	11.54988	<.0001
NSharkTuna	1	7001	14.99286	0.0001
YEAR:log(N_SETS)	42	7001	5.76482	<.0001
BAIT:HOOK_SIZEg	8	7001	8.01305	<.0001
BAIT:Qtradj	4	7001	12.21417	<.0001
HOOK_SIZE:Qtr	8	7001	3.65945	0.0003
log(N_SETS):NSharkTuna	1	7001	13.40202	0.0003
log(N_SETS):Qtr	2	7001	7.16219	0.0008
Qtr: NSharkTuna	2	7001	13.35417	<.0001

Table 6. A summary of the model coefficients for the different fixed effects for the numbers caught model. ‘Value’, ‘Std. Error’, ‘DF’, ‘t-value’, and ‘p-value’ represent respectively the fixed effects estimates, their approximate standard errors, the denominator degrees of freedom, the ratios between the estimates and their standard errors, and the associated p-value from a t distribution.

Terms: Numbers model	**Value**	**Std.Error**	**DF**	**t-value**	**p-value**
(Intercept)	-3.43	1.29	7001	-2.67	0.01
LNhook	0.55	0.03	7001	18.27	0.00
YEAR1963	2.05	1.30	7001	1.57	0.12
YEAR1964	0.76	1.28	7001	0.59	0.55
YEAR1965	0.65	1.30	7001	0.50	0.62
YEAR1966	0.45	1.29	7001	0.35	0.73
YEAR1967	1.17	1.30	7001	0.90	0.37
YEAR1968	1.03	1.29	7001	0.80	0.42
YEAR1969	0.45	1.29	7001	0.35	0.73
YEAR1970	1.55	1.31	7001	1.19	0.23
YEAR1979	2.68	1.38	7001	1.95	0.05
YEAR1980	0.78	1.32	7001	0.60	0.55
YEAR1981	0.18	1.34	7001	0.13	0.89
YEAR1982	1.16	1.36	7001	0.85	0.40
YEAR1983	1.11	1.41	7001	0.79	0.43
YEAR1984	1.27	1.41	7001	0.91	0.36
YEAR1985	0.88	1.34	7001	0.65	0.51
YEAR1986	2.31	1.33	7001	1.73	0.08
YEAR1987	1.95	1.33	7001	1.47	0.14
YEAR1988	1.00	1.35	7001	0.75	0.46
YEAR1989	0.68	1.32	7001	0.51	0.61
YEAR1990	0.62	1.34	7001	0.46	0.64
YEAR1991	1.38	1.29	7001	1.07	0.28
YEAR1992	1.71	1.30	7001	1.31	0.19
YEAR1993	0.64	1.28	7001	0.50	0.62

YEAR1994	-0.22	1.27	7001	-0.17	0.86
YEAR1995	0.33	1.27	7001	0.26	0.80
YEAR1996	-0.33	1.27	7001	-0.26	0.80
YEAR1997	-0.49	1.28	7001	-0.38	0.70
YEAR1998	0.78	1.28	7001	0.61	0.54
YEAR1999	0.75	1.28	7001	0.59	0.56
YEAR2000	1.16	1.28	7001	0.91	0.36
YEAR2001	0.47	1.28	7001	0.37	0.71
YEAR2002	1.09	1.28	7001	0.85	0.39
YEAR2003	0.74	1.28	7001	0.58	0.56
YEAR2004	0.50	1.27	7001	0.40	0.69
YEAR2005	0.73	1.27	7001	0.57	0.57
YEAR2006	0.72	1.27	7001	0.57	0.57
YEAR2007	0.48	1.28	7001	0.37	0.71
YEAR2008	0.72	1.28	7001	0.56	0.58
YEAR2009	0.87	1.28	7001	0.68	0.50
YEAR2010	0.95	1.28	7001	0.75	0.46
YEAR2011	0.99	1.28	7001	0.78	0.44
YEAR2012	0.57	1.28	7001	0.45	0.65
log(N_SETS)	1.01	0.58	7001	1.76	0.08
BAITMix	0.22	0.12	7001	1.88	0.06
BAITFish	0.61	0.09	7001	6.60	0.00
HOOK_SIZEBigC	-0.21	0.10	7001	-2.06	0.04
HOOK_SIZEJapJ	0.07	0.08	7001	0.84	0.40
HOOK_SIZEJapJ2	-0.33	0.10	7001	-3.24	0.00
HOOK_SIZESmallC	-0.41	0.25	7001	-1.67	0.10
Qtr3	0.32	0.13	7001	2.52	0.01
Qtr4	0.36	0.16	7001	2.25	0.02
NSharkTuna	-0.07	0.03	7001	-2.43	0.02
YEAR1963:log(N_SETS)	-0.59	0.59	7001	-1.00	0.32
YEAR1964:log(N_SETS)	-0.31	0.58	7001	-0.53	0.60
YEAR1965:log(N_SETS)	-0.34	0.59	7001	-0.58	0.56
YEAR1966:log(N_SETS)	-0.24	0.58	7001	-0.41	0.68
YEAR1967:log(N_SETS)	-0.43	0.58	7001	-0.73	0.47
YEAR1968:log(N_SETS)	-0.45	0.58	7001	-0.78	0.44
YEAR1969:log(N_SETS)	-0.21	0.58	7001	-0.37	0.71
YEAR1970:log(N_SETS)	-0.57	0.59	7001	-0.97	0.33
YEAR1979:log(N_SETS)	-1.02	0.62	7001	-1.64	0.10
YEAR1980:log(N_SETS)	-0.14	0.60	7001	-0.23	0.82
YEAR1981:log(N_SETS)	0.15	0.61	7001	0.24	0.81
YEAR1982:log(N_SETS)	-0.42	0.62	7001	-0.67	0.50
YEAR1983:log(N_SETS)	-0.45	0.63	7001	-0.71	0.48

YEAR1984:log(N_SETS)	-0.60	0.64	7001	-0.94	0.35
YEAR1985:log(N_SETS)	-0.29	0.61	7001	-0.47	0.64
YEAR1986:log(N_SETS)	-0.91	0.61	7001	-1.49	0.14
YEAR1987:log(N_SETS)	-0.84	0.60	7001	-1.39	0.16
YEAR1988:log(N_SETS)	-0.38	0.61	7001	-0.62	0.53
YEAR1989:log(N_SETS)	-0.31	0.60	7001	-0.52	0.60
YEAR1990:log(N_SETS)	-0.06	0.61	7001	-0.10	0.92
YEAR1991:log(N_SETS)	-0.63	0.58	7001	-1.08	0.28
YEAR1992:log(N_SETS)	-0.70	0.59	7001	-1.19	0.24
YEAR1993:log(N_SETS)	-0.31	0.58	7001	-0.53	0.59
YEAR1994:log(N_SETS)	-0.10	0.57	7001	-0.17	0.86
YEAR1995:log(N_SETS)	-0.30	0.57	7001	-0.53	0.60
YEAR1996:log(N_SETS)	-0.26	0.57	7001	-0.46	0.65
YEAR1997:log(N_SETS)	0.02	0.58	7001	0.03	0.97
YEAR1998:log(N_SETS)	-0.36	0.58	7001	-0.62	0.53
YEAR1999:log(N_SETS)	-0.24	0.58	7001	-0.41	0.68
YEAR2000:log(N_SETS)	-0.49	0.58	7001	-0.84	0.40
YEAR2001:log(N_SETS)	-0.27	0.58	7001	-0.48	0.63
YEAR2002:log(N_SETS)	-0.45	0.58	7001	-0.78	0.44
YEAR2003:log(N_SETS)	-0.17	0.58	7001	-0.29	0.77
YEAR2004:log(N_SETS)	-0.04	0.58	7001	-0.07	0.95
YEAR2005:log(N_SETS)	-0.07	0.58	7001	-0.12	0.90
YEAR2006:log(N_SETS)	-0.09	0.58	7001	-0.16	0.87
YEAR2007:log(N_SETS)	0.04	0.58	7001	0.07	0.94
YEAR2008:log(N_SETS)	0.05	0.58	7001	0.09	0.93
YEAR2009:log(N_SETS)	-0.07	0.58	7001	-0.12	0.91
YEAR2010:log(N_SETS)	-0.03	0.58	7001	-0.05	0.96
YEAR2011:log(N_SETS)	-0.16	0.58	7001	-0.28	0.78
YEAR2012:log(N_SETS)	0.05	0.58	7001	0.09	0.93
BAITMix:HOOK_SIZEBigC	0.19	0.11	7001	1.76	0.08
BAITFish:HOOK_SIZEBigC	0.17	0.08	7001	2.04	0.04
BAITMix:HOOK_SIZEJapJ	-0.24	0.10	7001	-2.34	0.02
BAITFish:HOOK_SIZEJapJ	-0.22	0.08	7001	-2.87	0.00
BAITMix:HOOK_SIZEJapJ2	0.01	0.11	7001	0.07	0.94
BAITFish:HOOK_SIZEJapJ2	0.03	0.09	7001	0.37	0.71
BAITMix:HOOK_SIZESmallC	-0.12	0.28	7001	-0.43	0.67
BAITFish:HOOK_SIZESmallC	0.14	0.27	7001	0.52	0.60
BAITMix:Qtr3	0.26	0.07	7001	3.61	0.00
BAITFish:Qtr3	-0.03	0.07	7001	-0.37	0.71
BAITMix:Qtr4	0.05	0.11	7001	0.46	0.64
BAITFish:Qtr4	-0.24	0.10	7001	-2.40	0.02
HOOK_SIZEBigC:Qtr3	0.17	0.09	7001	1.79	0.07

HOOK_SIZEJapJ:Qtr3	0.31	0.05	7001	5.74	0.00
HOOK_SIZEJapJ2:Qtr3	0.40	0.09	7001	4.75	0.00
HOOK_SIZESmallC:Qtr3	0.50	0.28	7001	1.74	0.08
HOOK_SIZEBigC:Qtr4	-0.16	0.11	7001	-1.39	0.16
HOOK_SIZEJapJ:Qtr4	0.15	0.06	7001	2.38	0.02
HOOK_SIZEJapJ2:Qtr4	0.17	0.11	7001	1.51	0.13
HOOK_SIZESmallC:Qtr4	0.05	0.40	7001	0.14	0.89
log(N_SETS):NSharkTuna	0.02	0.01	7001	1.98	0.05
log(N_SETS):Qtr3	-0.10	0.05	7001	-1.87	0.06
log(N_SETS):Qtr4	0.06	0.06	7001	1.02	0.31
Qtr3:NSharkTuna	-0.05	0.02	7001	-2.97	0.00
Qtr4:NSharkTuna	-0.02	0.02	7001	-0.76	0.45

Table 7. Nominal catch rates (total number caught/total hooks), standardized numbers caught (relative to the median number of hooks) and the coefficient of variation and 95% CI for the standardized catch of north Atlantic swordfish caught in the Canadian pelagic longline fishery.

Year	Nominal	Standard	CV	Low	High
1962	0.02	0.01	22.95	0.007	0.016
1963	0.031	0.023	10.15	0.019	0.028
1964	0.012	0.012	8.45	0.01	0.014
1965	0.009	0.01	8.8	0.008	0.011
1966	0.01	0.01	8.34	0.008	0.012
1967	0.014	0.014	8.32	0.011	0.016
1968	0.011	0.011	8.09	0.01	0.013
1969	0.011	0.01	8.17	0.009	0.012
1970	0.014	0.015	8.67	0.012	0.017
1979	0.014	0.018	11.17	0.014	0.022
1980	0.014	0.017	9.49	0.014	0.02
1981	0.015	0.017	11.31	0.013	0.021
1982	0.011	0.014	11.74	0.011	0.017
1983	0.01	0.012	12.26	0.01	0.015
1984	0.008	0.011	11.52	0.008	0.013
1985	0.011	0.014	11.69	0.011	0.017
1986	0.014	0.016	13.26	0.012	0.02
1987	0.011	0.013	11.75	0.01	0.016
1988	0.011	0.013	11.59	0.01	0.016
1989	0.01	0.011	10.94	0.009	0.013
1990	0.016	0.017	10.91	0.013	0.021
1991	0.009	0.011	8.92	0.009	0.013
1992	0.01	0.013	8.92	0.011	0.016
1993	0.008	0.01	8.13	0.009	0.012
1994	0.007	0.007	7.69	0.006	0.008
1995	0.006	0.008	7.77	0.006	0.009
1996	0.004	0.004	7.85	0.004	0.005
1997	0.006	0.007	8.09	0.006	0.008
1998	0.008	0.011	8.21	0.009	0.012
1999	0.012	0.013	8.22	0.011	0.016
2000	0.009	0.012	8.53	0.01	0.014

2001	0.008	0.009	8.13	0.008	0.011
2002	0.009	0.012	8.5	0.01	0.014
2003	0.011	0.015	8.73	0.013	0.018
2004	0.01	0.016	8.51	0.013	0.018
2005	0.013	0.018	8.6	0.015	0.022
2006	0.011	0.017	8.54	0.015	0.02
2007	0.011	0.018	8.76	0.015	0.021
2008	0.014	0.023	9.11	0.019	0.028
2009	0.014	0.021	9.18	0.018	0.025
2010	0.016	0.025	9.51	0.021	0.03
2011	0.013	0.02	8.92	0.016	0.023
2012	0.014	0.02	9.1	0.017	0.024

Table 8. Nominal catch rates (total weight caught/total hooks), standardized weight caught (relative to the median number of hooks) and the coefficient of variation and 95% CI for the standardized catch of north Atlantic swordfish caught in the Canadian pelagic longline fishery.

Year	Nominal	Standard	CV	Low	High
1962	2.73	1.147	26.18	0.67	1.838
1963	3.288	2.322	10.8	1.87	2.852
1964	1.173	1.08	8.93	0.903	1.281
1965	0.754	0.788	9.35	0.653	0.942
1966	0.781	0.727	8.87	0.609	0.862
1967	0.946	0.882	8.82	0.739	1.044
1968	0.647	0.725	8.59	0.611	0.855
1969	0.628	0.633	8.65	0.533	0.747
1970	0.761	0.778	9.16	0.647	0.926
1979	1.136	1.407	11.8	1.11	1.759
1980	1.163	1.345	9.99	1.101	1.627
1981	1.001	1.104	11.86	0.87	1.382
1982	0.811	0.977	12.37	0.761	1.234
1983	0.603	0.757	13.05	0.582	0.968
1984	0.437	0.565	12.08	0.443	0.71
1985	0.627	0.83	12.2	0.649	1.045
1986	0.838	0.95	13.8	0.719	1.232
1987	0.508	0.617	12.26	0.482	0.778
1988	0.576	0.647	12.14	0.507	0.815
1989	0.57	0.587	11.61	0.465	0.732
1990	0.988	0.985	11.6	0.78	1.228
1991	0.571	0.724	9.52	0.599	0.869
1992	0.632	0.861	9.5	0.712	1.032
1993	0.507	0.62	8.64	0.521	0.731
1994	0.425	0.415	8.16	0.353	0.485
1995	0.424	0.489	8.23	0.415	0.573
1996	0.257	0.278	8.32	0.235	0.326
1997	0.393	0.446	8.61	0.375	0.525
1998	0.506	0.681	8.71	0.572	0.804
1999	0.706	0.805	8.73	0.676	0.951
2000	0.431	0.735	9.06	0.613	0.874
2001	0.579	0.677	8.64	0.569	0.798
2002	0.649	0.865	8.98	0.723	1.027

2003	0.754	1.099	9.21	0.914	1.311
2004	0.704	1.194	8.99	0.997	1.418
2005	0.879	1.338	9.1	1.115	1.592
2006	0.822	1.337	9.04	1.115	1.588
2007	0.81	1.404	9.29	1.166	1.676
2008	1.005	1.911	9.66	1.575	2.297
2009	1.088	1.777	9.75	1.462	2.14
2010	1.255	2.132	10.12	1.74	2.585
2011	1.134	1.81	9.46	1.498	2.168
2012	1.125	1.768	9.66	1.457	2.126

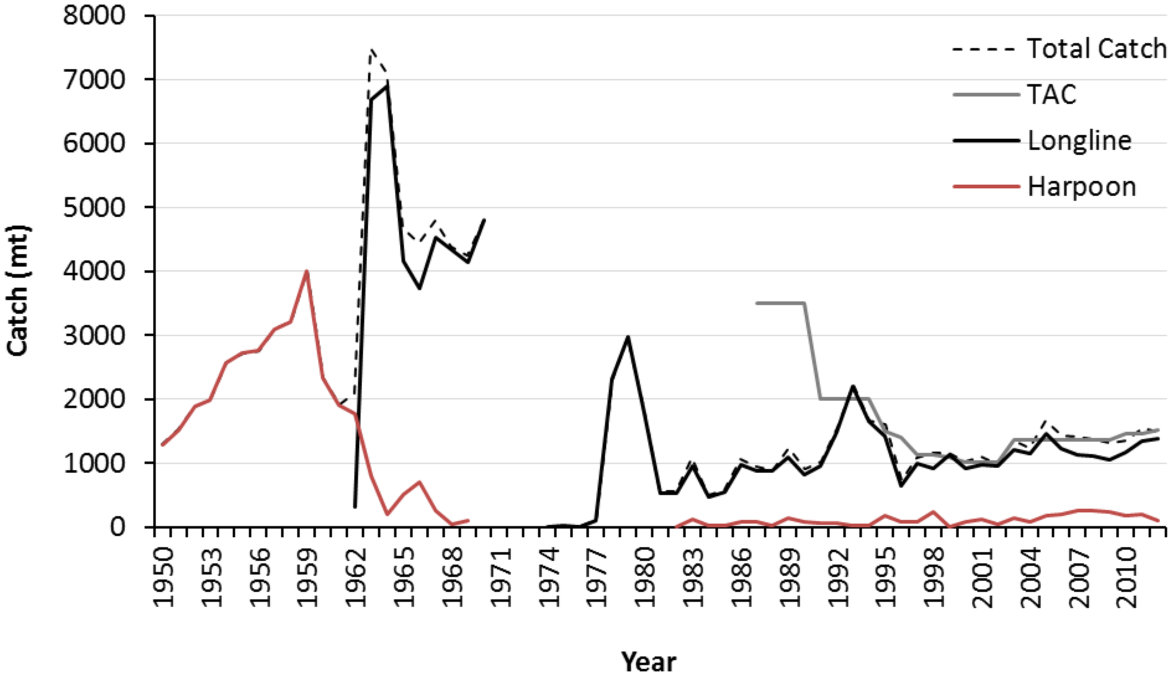

Figure 1. Total annual historic landings (metric tonnes) of North Atlantic swordfish caught in Canadian waters by longline (solid black) and all gears (harpoon and longline; dashed black). Grey line represents total TAC allocated to Canada by ICCAT and includes transfers from other countries (US, Senegal, Chinese Taipei and Japan). TAC excludes annual over or underage adjustments, but does account for dead discard estimates in all years except 2012.

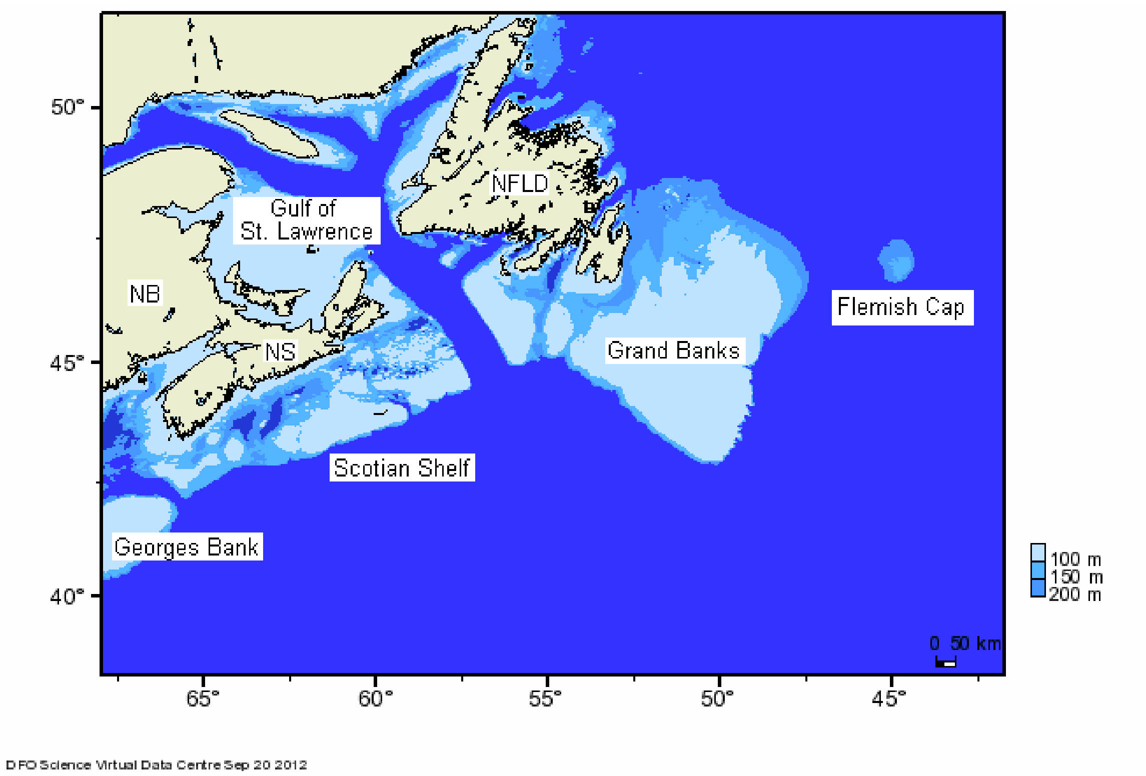

Figure 2. Geographic locations off the Canadian Atlantic coast spanning the longline swordfish fishery.

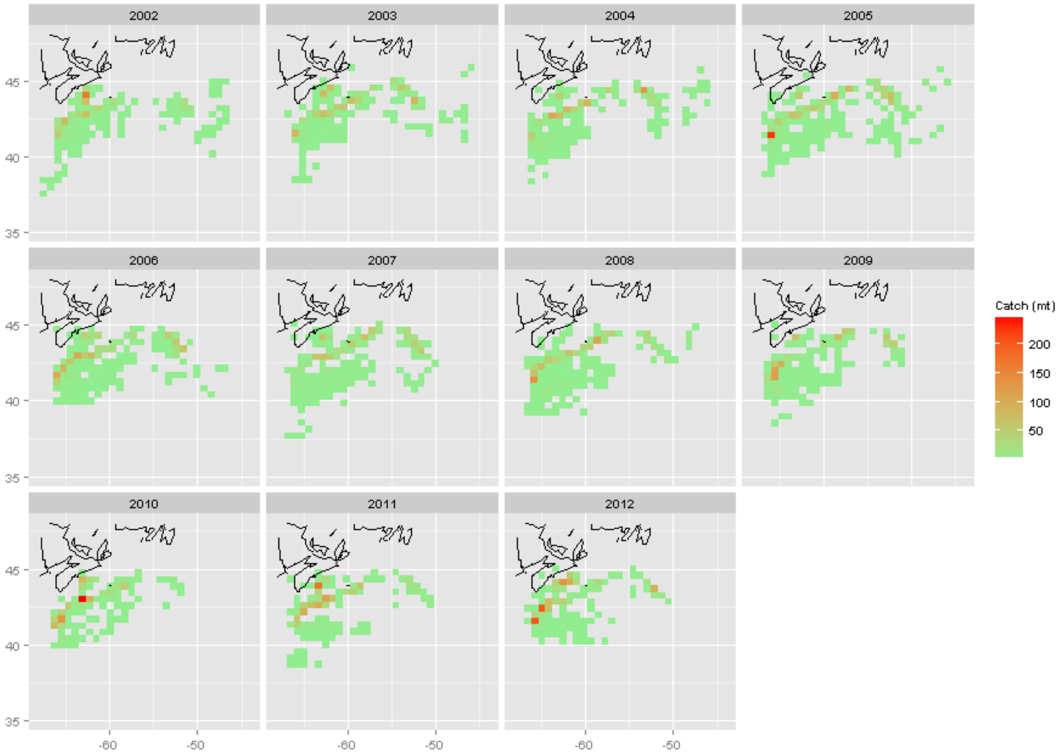

Figure 3. Recent annual distribution of the Canadian pelagic longline fishery between 2002 and 2012. Colors represent aggregated catch (metric tonnes) for a given square.

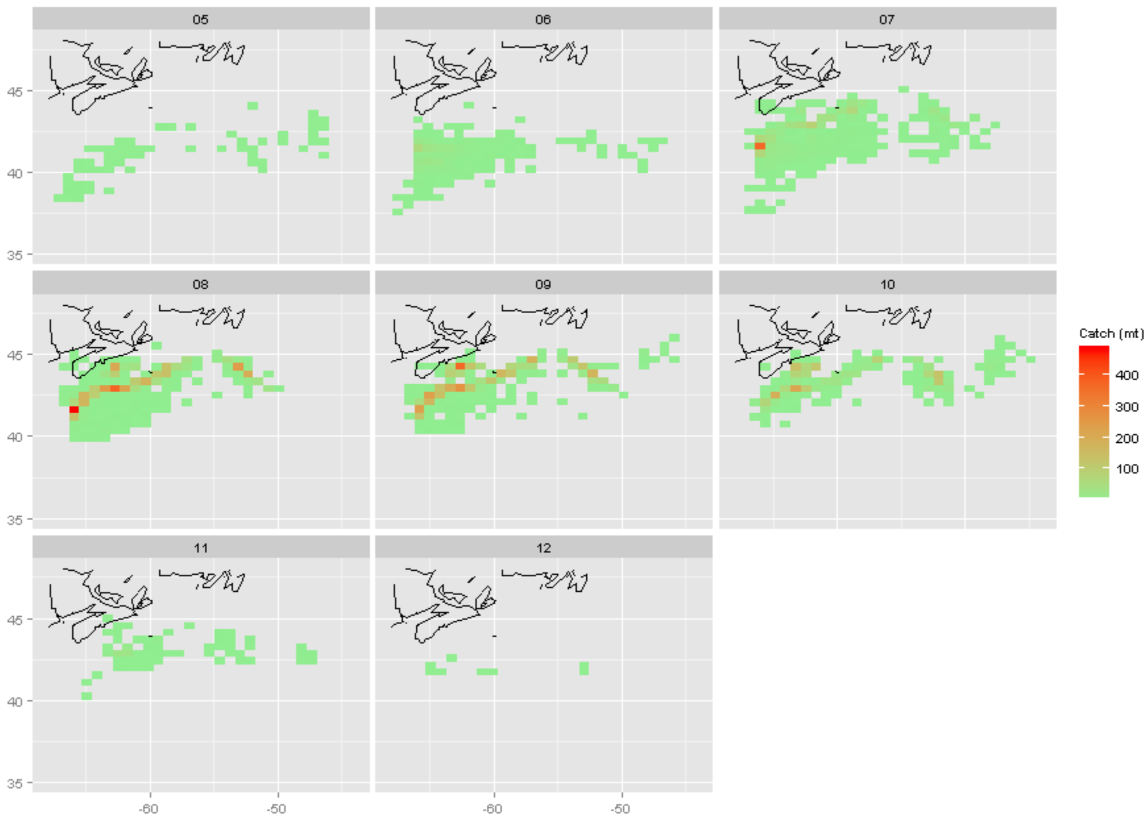

Figure 4. Monthly distribution of Canadian pelagic longline fishery catches between 2002 and 2012. Colors represent aggregated catch (metric tonnes) for a given square.

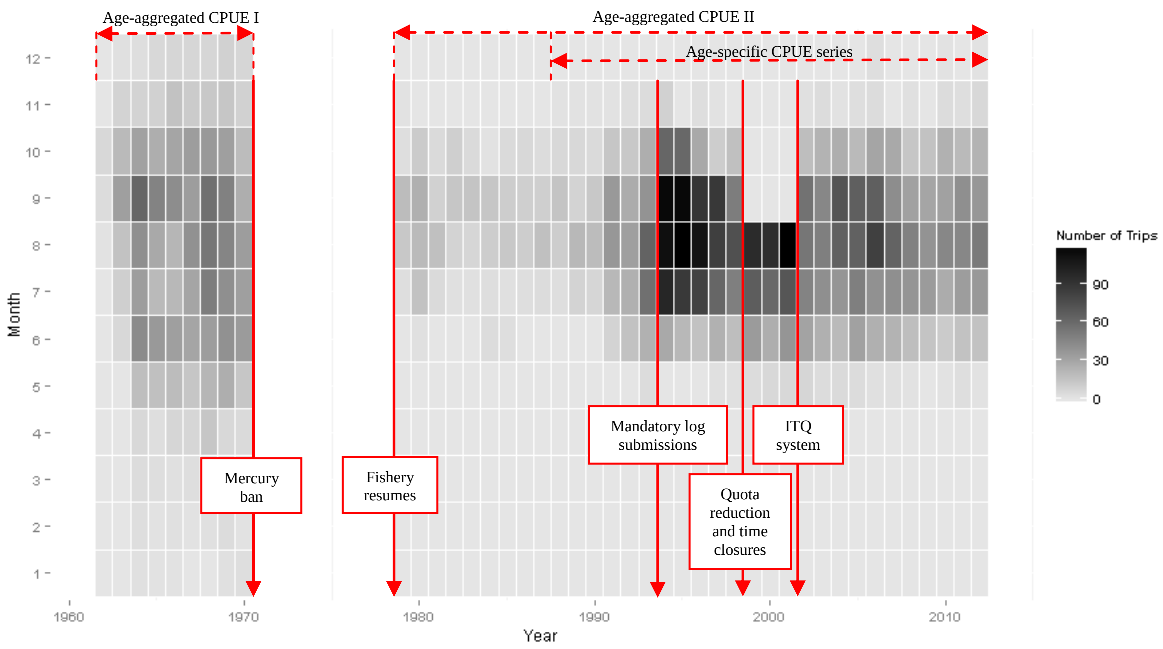

Figure 5. Number of reported trips made in a given month by the Canadian pelagic longline fishery between 1962 and 2012. Solid lines identify years in which changes in fishing opportunity and introduction of management actions occurred. Dotted lines indicate span of current ASPIC and VPA series.

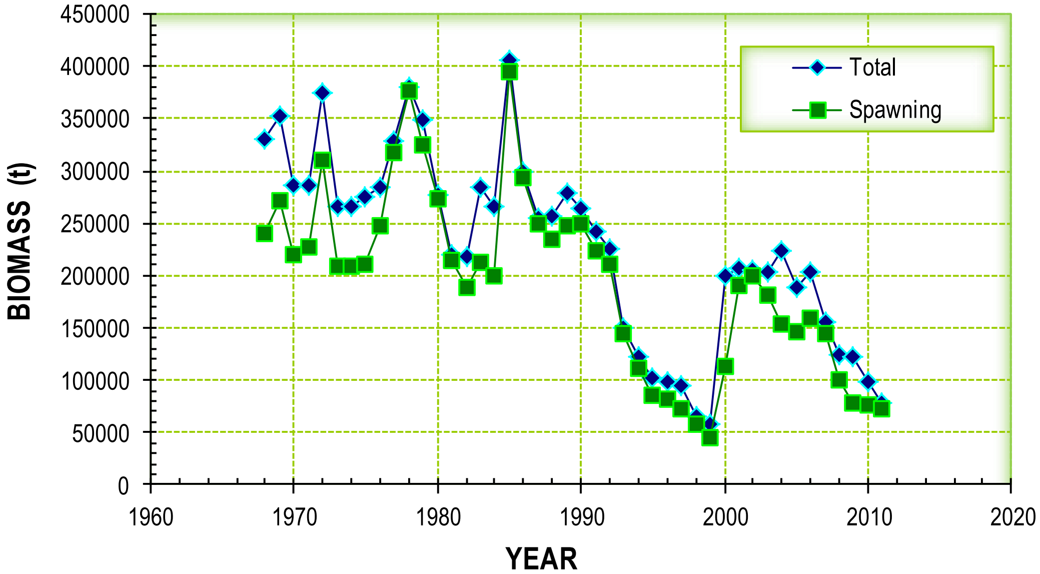

Figure 6. Total and spawning Atlantic mackerel biomasses (t) in NAFO subareas 3 and 4 for the 1968-2011period (DFO 2012).

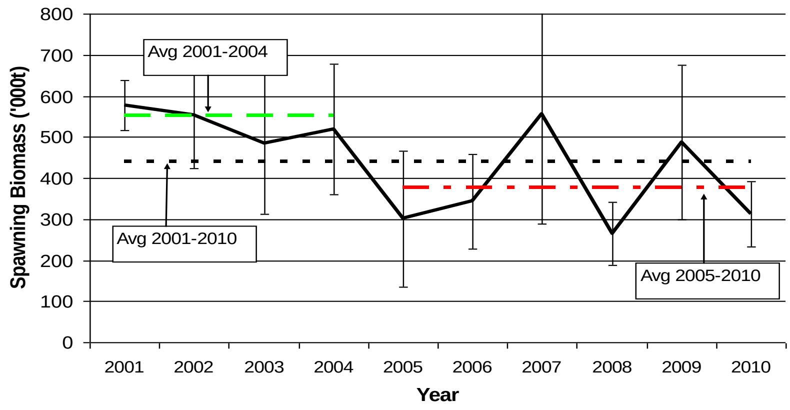

Figure 7. Spawning Stock Biomass (SSB) index from acoustic surveys for the overall southwestern Scotia/Bay of Fundy spawning component of herring (DFO **2011**).

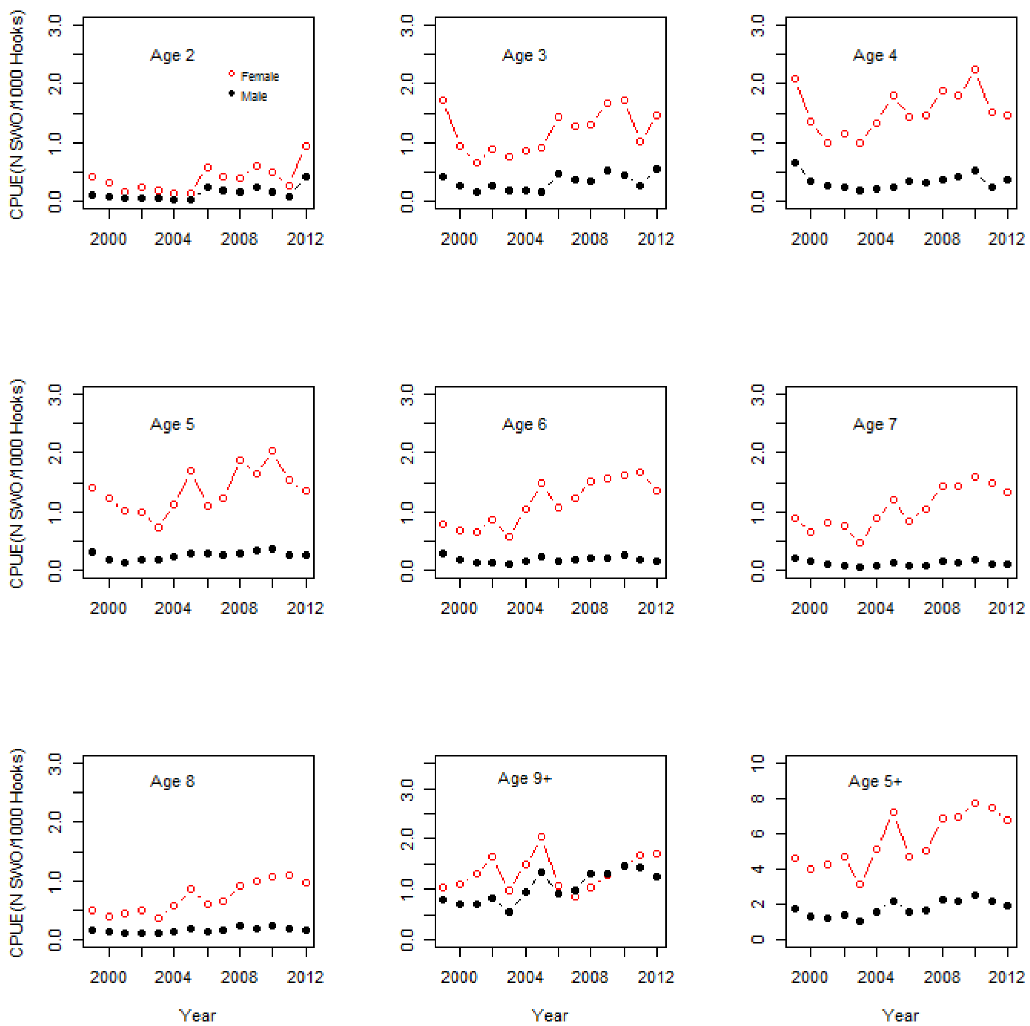

Figure 8. Sex- and age-specific nominal CPUE for swordfish (number of fish per 1000 hooks) for ages 2 – 9+ and 5+ from the Canadian pelagic longline fishery, 1999 – 2012. Red, hollow circles represent females, while black, filled circles represent males for each age group.

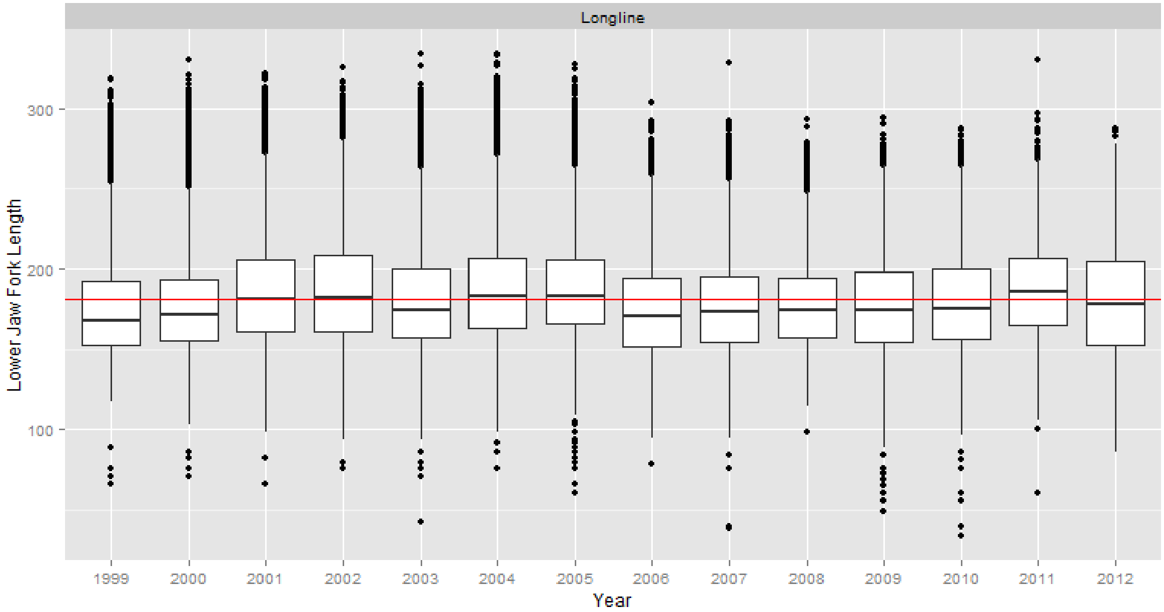

Figure 9. Annual boxplot of Lower Jaw Fork Length (cm) of swordfish caught by longline in Canadian waters between 1999 and 2012. Red line indicates mean LJFL (181 cm).

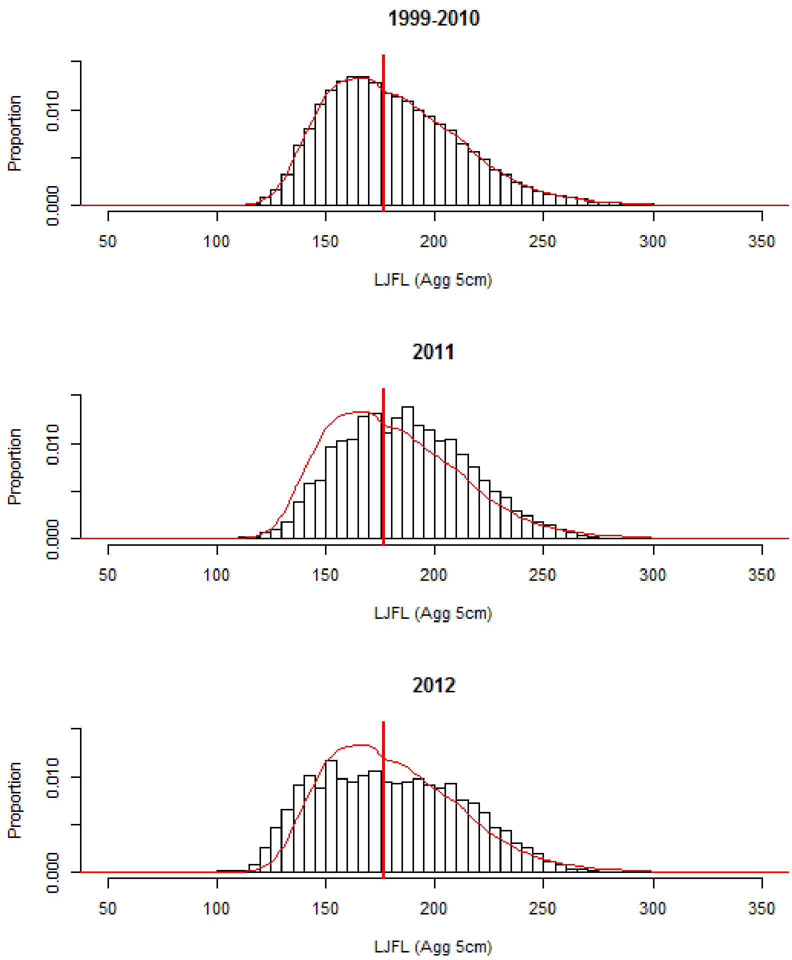

Figure 10. Catch at size distribution of swordfish caught by the pelagic longline fleet in Canadian waters between 1999 and 2012. Red curve shows the smoothed combined distribution of the catch from 1999 to 2012 and vertical red line indicates series mean, for reference.

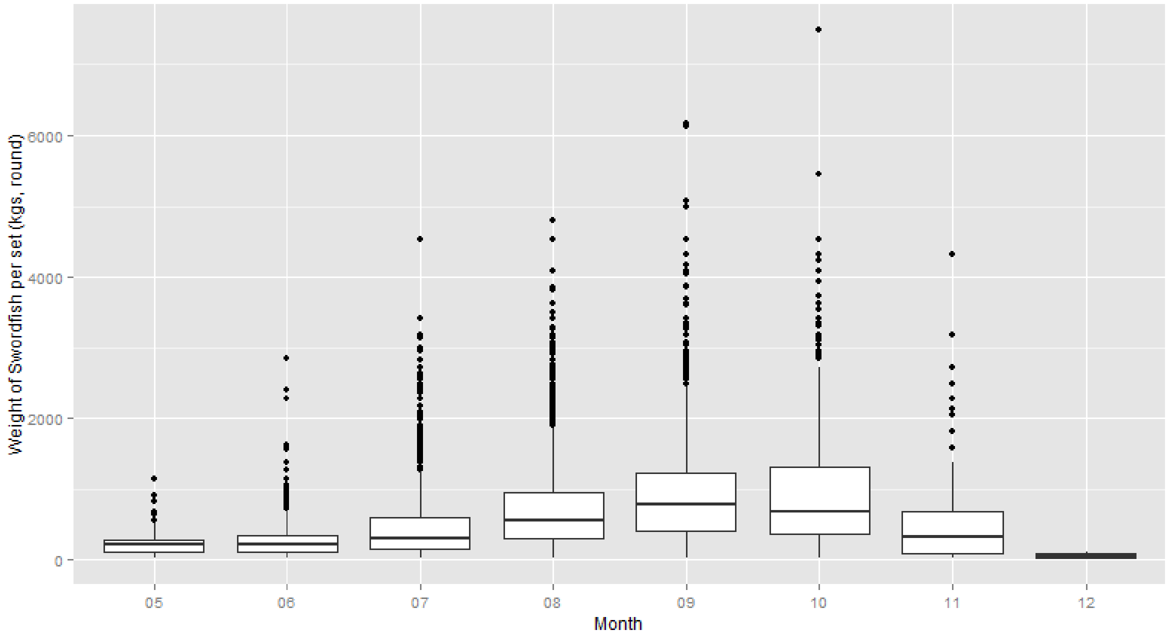

Figure 11. Weight of swordfish (kg) caught per set by the Canadian pelagic longline fleet from 2002 until 2012, by month.

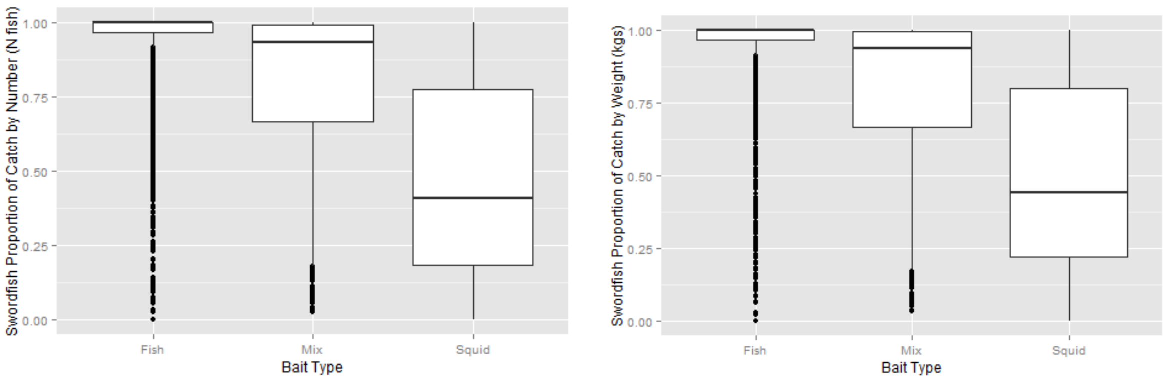

Figure 12. Use of bait type and proportion of swordfish caught by number (left) and weight (right) for the Canadian pelagic longline fishery.

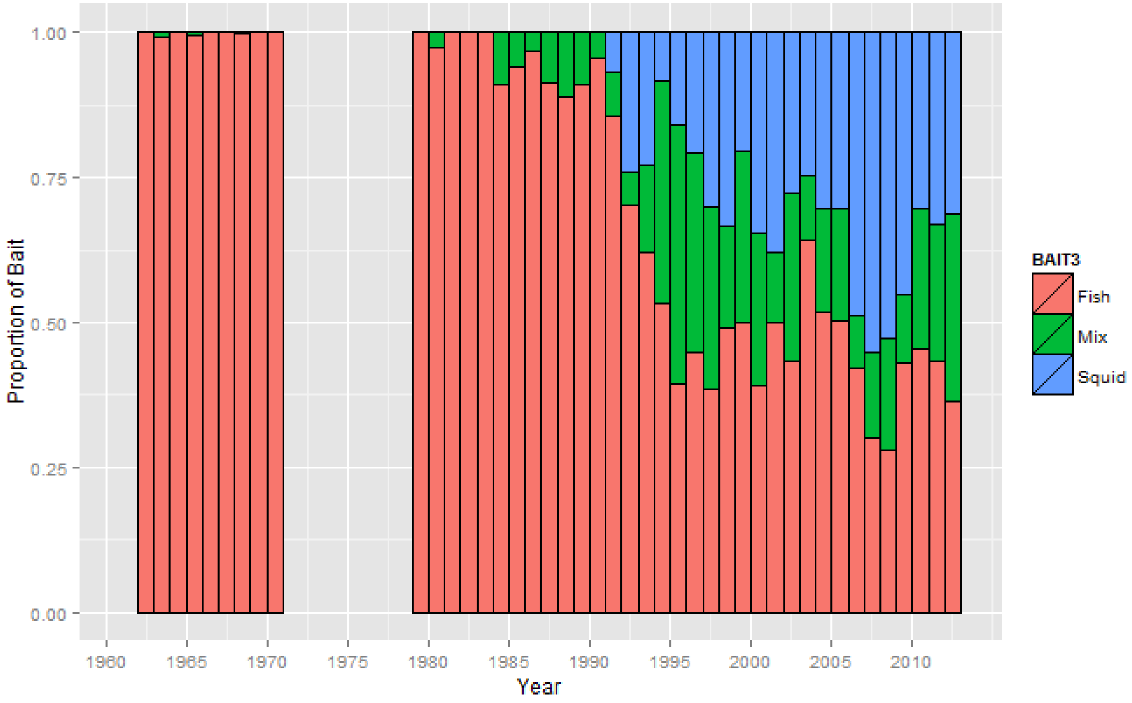

Figure 13. Trip-level bait use in the Canadian pelagic longline fishery. Bait type was grouped into one of three categories, depending on proportion of pelagic fish (P_{pel}) for the trip. P_{pel} of [0,0.333) was considered '*Squid*', P_{pel} of [0.333, 0.667) was considered '*Mix*' and P_{pel} of [0.667, 1] was considered '*Fish*'.

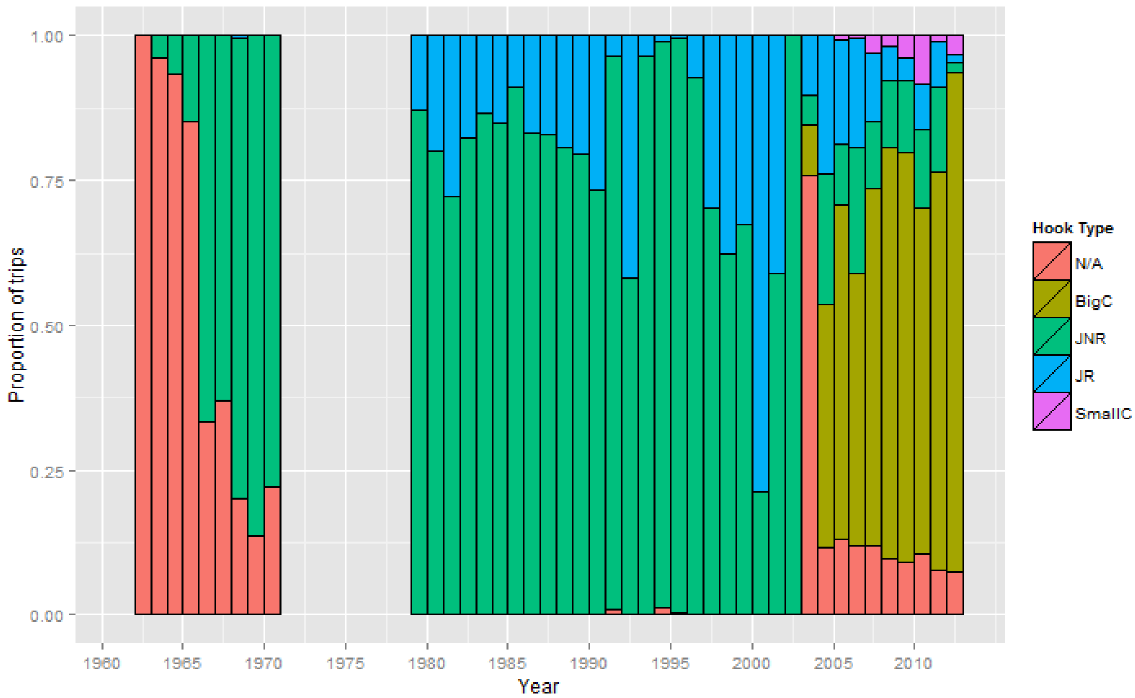

Figure 14. Hook type use on trips in the Canadian pelagic longline fishery. Hook types are: '*N/A'* – information not available; '*BigC'* – big circle hook; '*JnR'* – J hook non-ringed; '*JR'* – J hook ringed and '*SmallC'* – small circle hook.

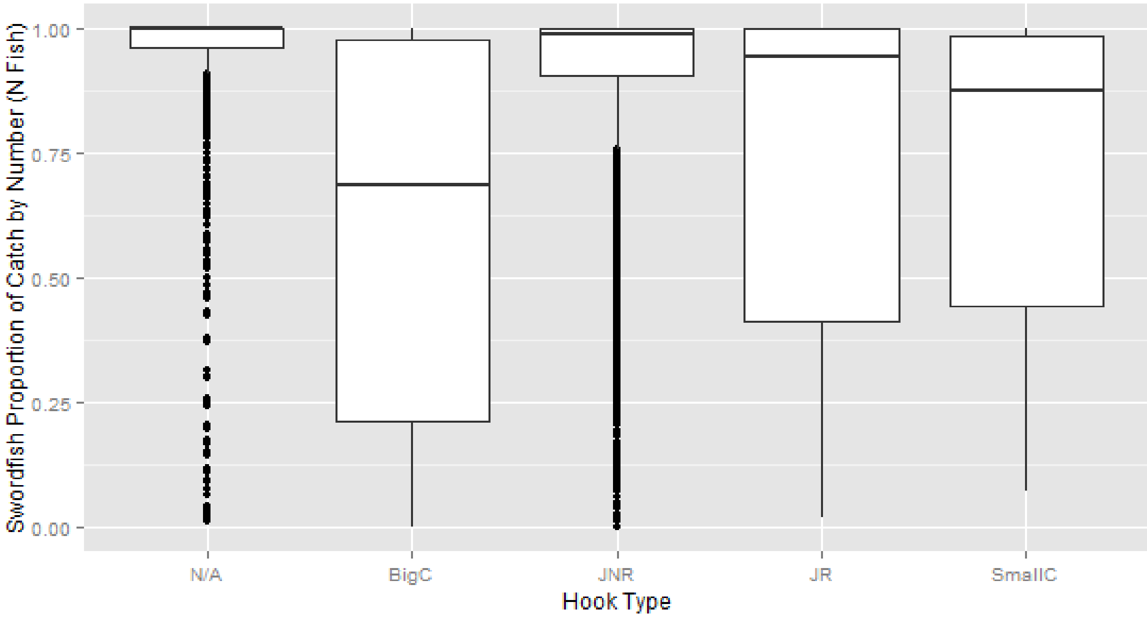

Figure 15. Use of hook type and proportion of swordfish caught by number for the Canadian pelagic longline fishery. Hook types are: '*N/A'* – information not available; '*BigC'* – big circle hook; '*JnR'* – J hook non-ringed; '*JR'* – J hook ringed and '*SmallC'* – small circle hook.

Figure 16. Nominal CPUEs based on longline trips using *circle*, *J* and *unknown* hook types. Note that J hooks were illegal in 2012 and were not used.

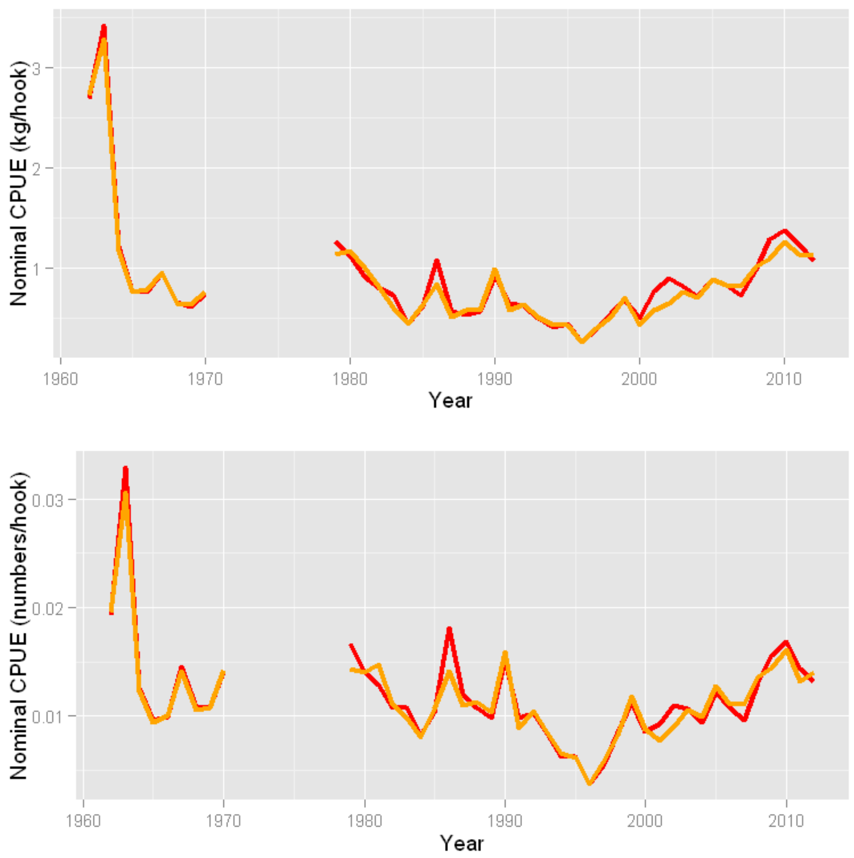

Figure 17. Nominal age-aggregated weight (upper plot) and numbers based (lower plot) CPUEs for the Canadian pelagic longline fishery. The orange line represents the total annual catch/total annual effort and the red line represents the average of the trip level catch/effort. There was no fishing for 1971 to 1978.

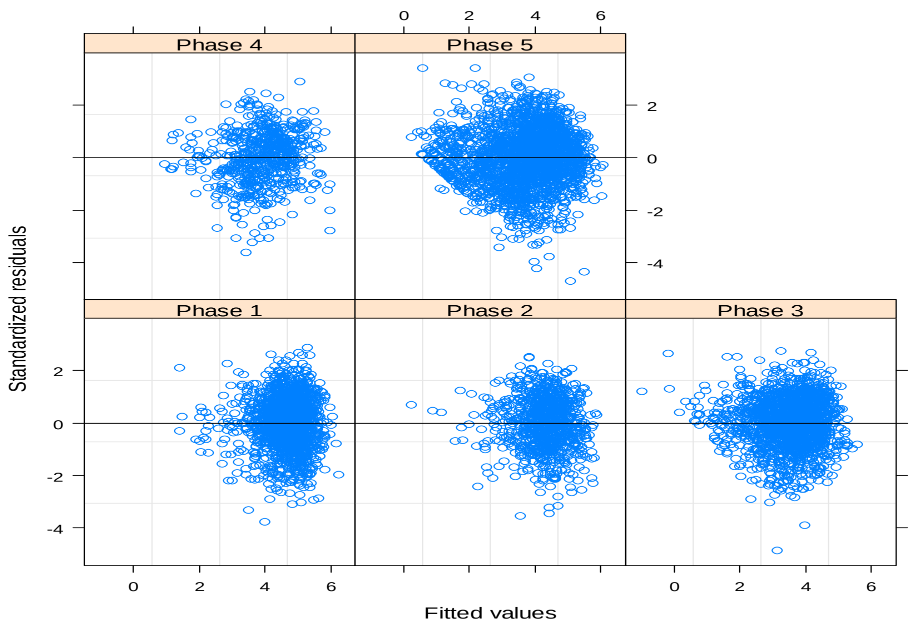

Figure 18. Scatter plots of Pearson residuals versus fitted values for the final numbers-based model conditioned on management phases (**Figure 5**). Phase 1, 1962:1970 (unrestricted fishing); Phase 2, 1979:1993 (post export restrictions on mercury contaminated fish, introduction of quotas); Phase 3, 1994:1998 (mandatory logbook submissions); Phase 4, 1999:2001 (trip and area restrictions) and Phase 5, 2002:2012 (switch from fleet quota to individual transferable quotas).

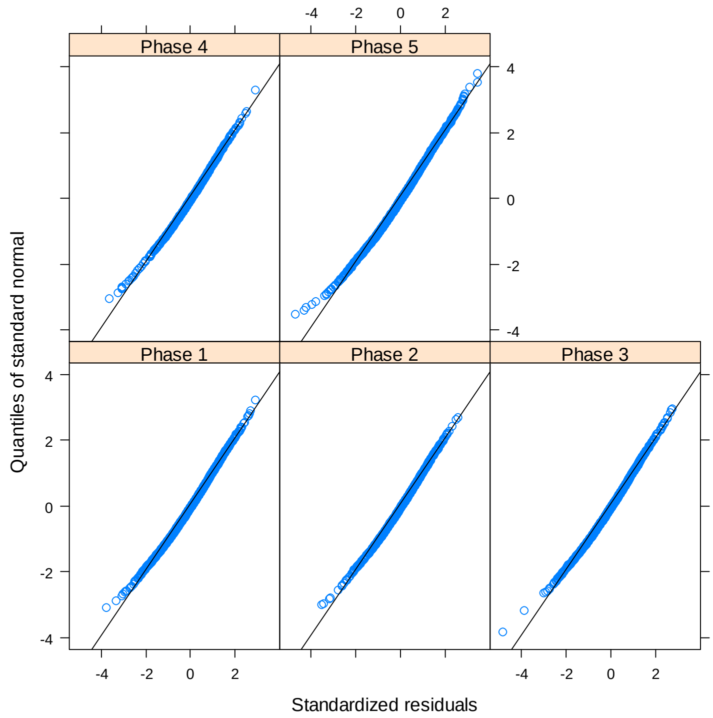

Figure 19. Normal plots of Pearson residuals from the final numbers-based model conditioned on management phases (**Figure 1 Figure 5**). Phase 1, 1962:1970 (unrestricted fishing); Phase 2, 1979:1993 (post export restrictions on mercury contaminated fish, introduction of quotas); Phase 3, 1994:1998 (mandatory logbook submissions); Phase 4, 1999:2001 (trip and area restrictions) and Phase 5, 2002:2012 (switch from fleet quota to individual transferable quotas).

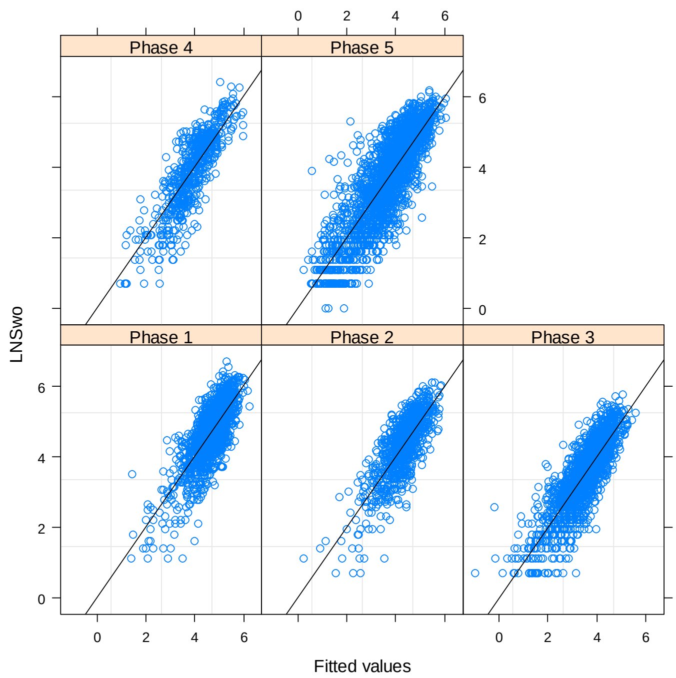

Figure 20. Observed versus the values predicted by the final numbers-based model conditioned on management phases (**Figure 5**). Phase 1, 1962:1970 (unrestricted fishing); Phase 2, 1979:1993 (post export restrictions on mercury contaminated fish, introduction of quotas); Phase 3, 1994:1998 (mandatory logbook submissions); Phase 4, 1999:2001 (trip and area restrictions) and Phase 5, 2002:2012 (switch from fleet quota to individual transferable quotas).

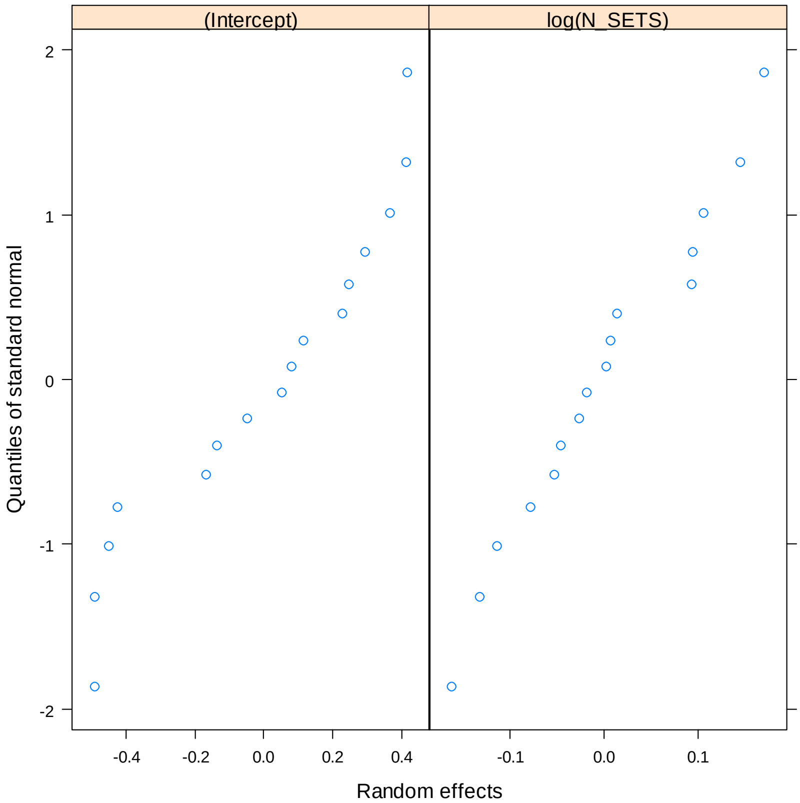

Figure 21. Marginal normality of the random intercept and slope effects for the final numbers-based model. Estimates represent the variation among areas and the interaction between the number of sets and areas, respectively.

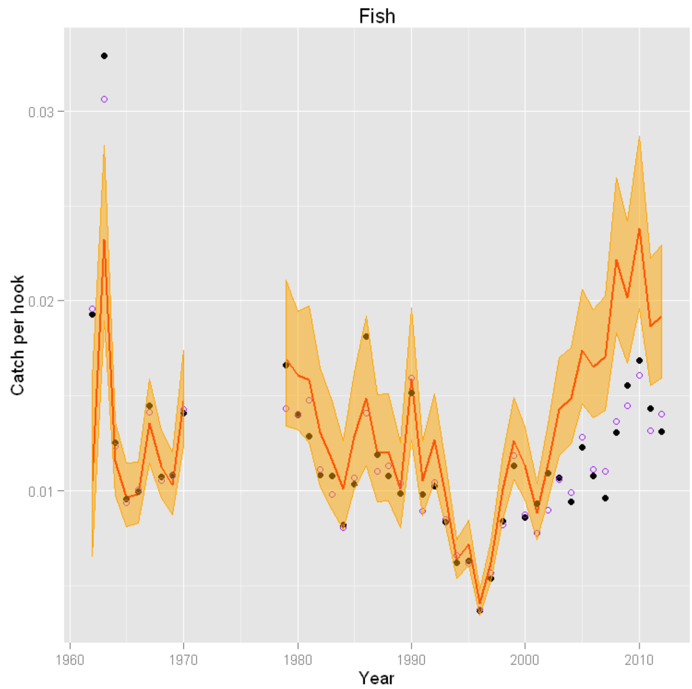

Figure 22. Standardized catch in numbers expressed on a per hook basis (red line) and nominal catch rates (purple circles: total annual catch/total annual hooks and black points: average of trip catch per hook) for north Atlantic swordfish caught by the Canadian pelagic longline fishery. The 95% CI for the predicted catch is given in orange. See text for details. Note that there is no data between 1970 and 1979.

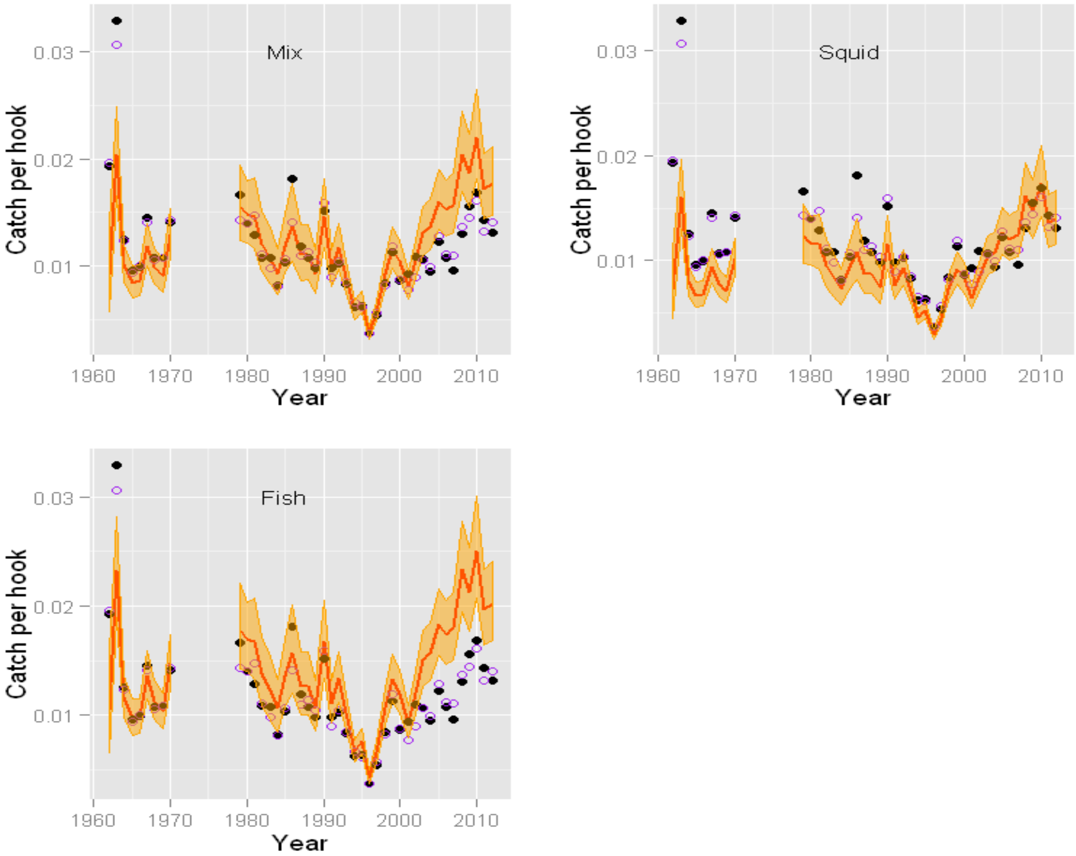

Figure 23. Standardized catch in numbers conditioned on bait type for north Atlantic swordfish caught by the Canadian pelagic longline fishery. The standardized catch is expressed on a per hook basis (red line). Points represent the nominal catch rates (purple circles: total annual catch/total annual hooks and black points: average of trip catch per hook). The 95% CI for the predicted catch is given in orange. See text for details. Note that there is no data between 1970 and 1979.

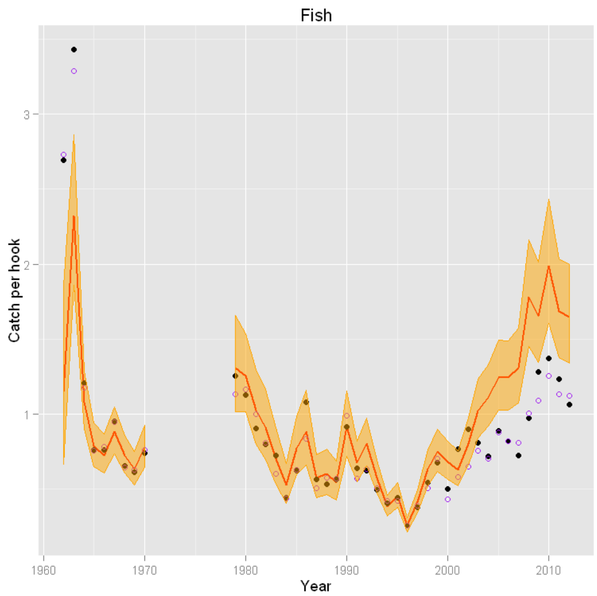

Figure 24. Standardized catch in weight expressed on a per hook basis (red line) and nominal catch rates (purple circles: total annual catch/total annual hooks and black points: average of trip catch per hook) for north Atlantic swordfish caught by the Canadian pelagic longline fishery. The 95% CI for the predicted catch is given in orange. See text for details. Note that there is no data between 1970 and 1979.

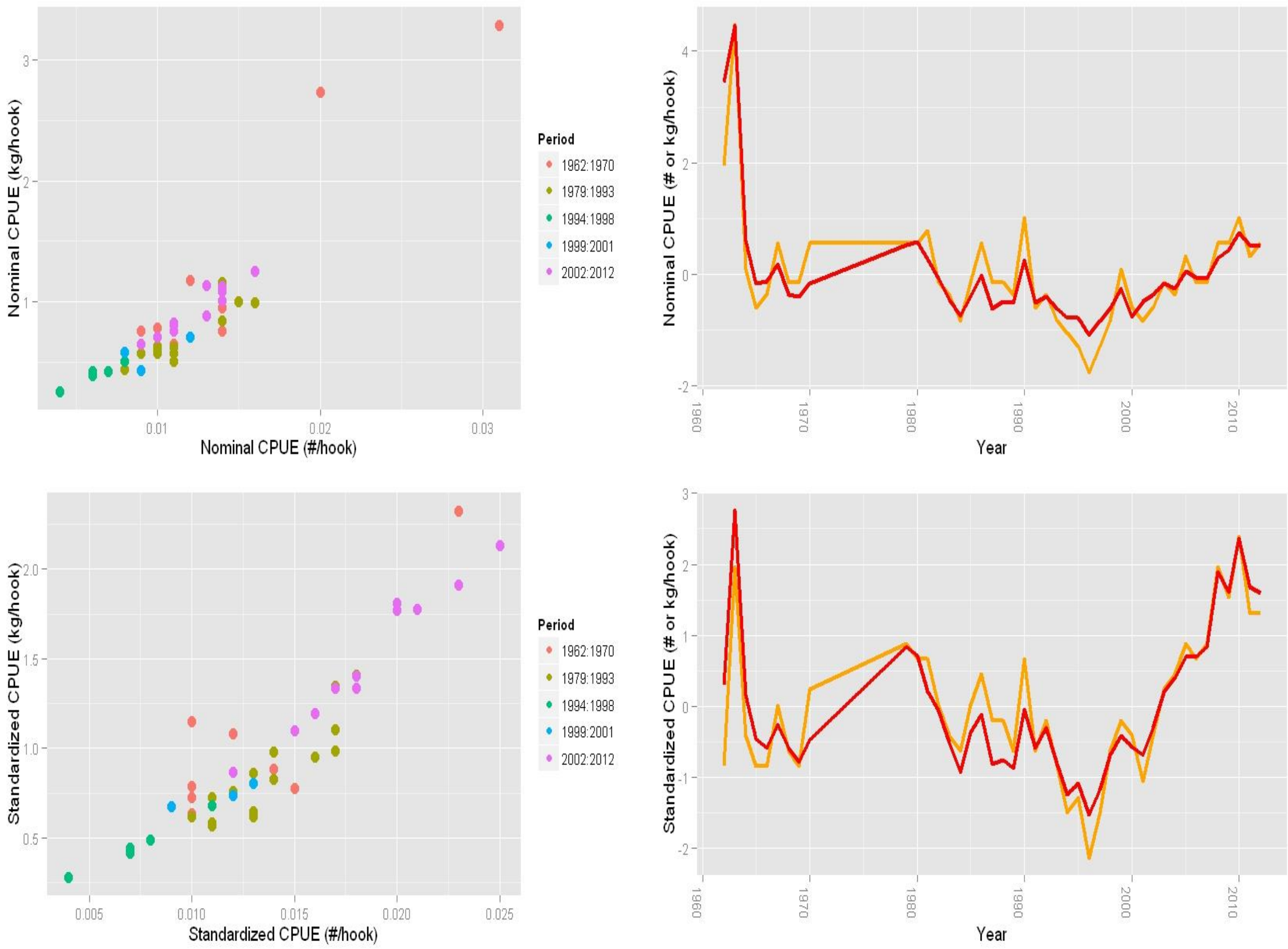

Figure 25. Comparative plots of nominal catch in weight versus catch in number (top left and right) and standardized catch in weight versus catch in number (bottom left and right) for north Atlantic swordfish caught by the Canadian pelagic longline fishery. For the right hand plots, catch in weight is in red and catch in number is orange. Nominal catch rates are the total annual catch/total annual hooks. Note that there is no data between 1970 and 1979.