SCRS/2013/159 Collect. Vol. Sci. Pap. ICCAT, 70(4): 1970-1980 (2014)

STANDARDISATION OF THE CATCH-PER-UNIT-EFFORT FOR SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY THE SOUTH AFRICAN PELAGIC LONGLINE FLEET (1998 – 2012)

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SUMMARY

A pelagic longline sector targeting swordfish is a relatively new venture for South Africa. The CPUE series for swordfish, expressed in number of fish per 1000 hooks, was standardised using a negative binomial GLM for swordfish caught from 1998 to 2012 by local and foreign vessels in the ICCAT region (<20°E) of South Africa. The explanatory variables included year (15), month (12), total number of hooks per set, catch location (6), flag (4), target (3), vessel name (28) and vessel size (LOA). Total deviance explained by the model was 40.73%, 22.20% and 20.64% of which was explained by total number of hooks per set and by flag. Vessel size and target had the least explanatory power. A standardised CPUE was generated and the trend indicated a decline in abundance from 1998 to 2000, where it has stabilised with small declines since. Improvements in the model includes adjusting the boundary between the Atlantic and Indian Oceans that better reflects the transition between the Atlantic and Indian Ocean swordfish stocks. Targeting based on cluster analysis of species would be a further improvement on the method.

RÉSUMÉ

Le secteur palangrier pélagique ciblant l'espadon est une initiative relativement nouvelle pour l'Afrique du Sud. La série de CPUE pour l'espadon, exprimée en nombre de poissons pour 1.000 hameçons, a été standardisée à l'aide d'un GLM binomial négatif pour l'espadon capturé de 1998 à 2012 par des navires locaux et étrangers dans la zone de l'Afrique du Sud relevant de l'ICCAT (<20°E). Les variables explicatives incluaient année (15), mois (12), nombre total d'hameçons par opération, lieu de la capture (6), pavillon (4), cible (3), nom du navire (28) et taille du navire (LOA). La déviance totale expliquée par le modèle s'élevait à 40,73%, dont 22,20% et 20,64% ont été expliqués par le nombre total d'hameçons par opération et par pavillon. La taille du navire et la cible avaient le moins de puissance explicative. Une CPUE standardisée a été créée et la tendance a indiqué une chute de l'abondance de 1998 à 2000, puis une stabilisation de celle-ci avec de légères baisse depuis lors. Au nombre des améliorations apportées au modèle, on peut citer l'ajustement de la délimitation entre les océans Atlantique et Indien qui reflète mieux la transition entre les stocks d'espadon de l'océan Atlantique et de l'océan Indien. Un autre moyen d'améliorer la méthode consisterait à réaliser un ciblage basé sur l'analyse par grappes des espèces.

RESUMEN

El sector de palangre pelágico que se dirige al pez espada es una iniciativa relativamente nueva para Sudáfrica. La serie de CPUE para el pez espada, expresada en número de ejemplares por 1.000 anzuelos, se estandarizó utilizando un GLM binomial negativo para el pez espada capturado desde 1998 a 2012 por buques locales y extranjeros en la región de ICCAT(<20°E) de Sudáfrica. Las variables explicativas fueron año (15), mes (12), número total de anzuelos por lance, localización de la captura (6), pabellón (4, objetivo (3), nombre del buque (28) y tamaño del buque (LOA). La desviación total explicada por el modelo fue de 40,73%. De esta el 22,20% y 20,64% se explicaba por el número total de anzuelos por lance y por pabellón. El tamaño del buque y la especie objetivo tenían la potencia explicativa más baja. Se generó una CPUE estandarizada y la tendencia indicaba un descenso en la abundancia desde 1998 a 2000, año en el que se estabilizó y, a partir de entonces, tuvo pequeños descensos. Las mejoras en el modelo consistieron en ajustar la delimitación entre los

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océanos Atlántico e Índico que refleja mejor la transición entre los stocks de pez espada del Atlántico y del Índico. La estrategia de pesca basada en un análisis de conglomeración sería una mejora adicional al método.

KEYWORDS

Swordfish, Xiphias gladius*, Standardised CPUE, Pelagic longline, GLM, Negative binomial*

1. Introduction

Commercial longlining for tuna in South Africa has been documented since the 1960's with catches reaching ~2000 MT. Southern bluefin tuna and albacore comprised the bulk of the catch. The fishery ceased to exist after the mid 1960's, as a result of a poor market for low quality bluefin and albacore tuna landed by South African fishers. Interest to target tuna with longline gear re-emerged in 1995 when a joint venture with a Japanese vessel confirmed that tuna and swordfish could be profitably exploited within South Africa's waters. 30 experimental longline permits were issued in 1997 to target tuna. The main purpose of this fishery was to develop a catch performance for South Africa such that South Africa could receive quotas from the Regional Fisheries Management Organisations (RFMOs). Longlining for swordfish has led to sharp declines in swordfish abundance in South Africa's EEZ. Swordfish is generally (though not exclusively) targeted by the smaller (20 – 30m) South African vessels whilst the foreign vessels target tunas (bigeye and yellowfin).

A total of 50 long-term (10 year) rights were made available at the end of 2005; 17 rights were issued to the swordfish-directed fishery and 26 to the tuna-directed fishery (1 right = 1 vessel). Fewer swordfish-directed rights were made available to reduce the fishing pressure on swordfish. Large pelagic catches improved to > 3 500 t in 2005 with the assistance of foreign flag charters. However, none of the foreign flagged vessels (e.g. Japan, Korea, Seychelles and St. Vincent) reflagged to South African and as a result no further provision was made for the use of foreign flag charters in 2006. Consequently large pelagic catches declined to < 500 t. In 2007 foreign flagged vessels were allowed to fish in South Africa yet again to, a) improve the South Africa's catch performance, b) to transfer skills to South African crew and c) to eventually reflag South African. To date, there are on average 10 – 15 foreign-flagged vessels taking out permits to fish in South Africa each year.

Within the pelagic longline fishery blue sharks *Prionace glauca* and mako sharks *Isurus oxyrinchus* are considered valuable bycatch species. When long-term rights were issued in 2005 the intention was to terminate the targeting of pelagic sharks by amalgamating the directed shark fishers into the tuna and swordfish longline fishery with incentives toward increasing catches of swordfish. However, due to an administrative oversight the pelagic shark directed fishery were granted exemptions to permit conditions allowing them to target shark. Even though the rights holders fishing under the exemption were amalgamated into the tuna and swordfish fishery in April 2011 they continue to target pelagic sharks.

Initially, fishing effort was concentrated along the western edge of the Agulhas Bank and slowly spread to include the west coast of South Africa and the Mid-Atlantic Ridge by 2001. In addition, fishing effort expanded to the east coast of South Africa towards the end of 2001 with the development of fish and ice processing facilities at Richard's Bay. Swordfish is generally targeted in the South West Indian Ocean region (20° – 30°S, 30° – 40°E) and along the west coast of South Africa at the continental edge (30° – 35°S, 15° – 18°E). For the purposes of this study for ICCAT, only data west of 20° east longitude was used in the standardisation (**Figure 1**).

This is the first time a standardised catch-per-unit-effort will be conducted for swordfish caught in the South African pelagic longline fishery. The South African vessels are heavily reliant on swordfish for the industry to survive. A standardised CPUE for South Africa and its contribution towards the stock assessment will aid towards better management and conservation of the resource.

1.1 Catch limitations

From the start of the fishery a size limitation of 125 cm LJFL and 25kg (whole weight) was enforced, until 2005 when that was reduced to 119cm LJFL and 18kg (dressed weight) to minimise dumping at sea. All undersize swordfish are confiscated by the Fishery Control Officers/Monitors who are required to monitor all discharges of longline vessels fishing on a South African permit.

During the experimental phase of the fishery South Africa established a self-imposed quota limit of 1000 t until 2002. South Africa was excluded from the sharing arrangement for south Atlantic swordfish and had not been granted a swordfish allocation for the ICCAT convention area. A further restriction was that swordfish may not exceed 15% of the total catch per landing. The intention of these restrictions was to prevent the development of a swordfish fishery in the ICCAT convention area. Strict enforcement of this by-catch limit in the South African EEZ during 1998 and 1999 had forced many of the South African fishers to land their catches in ports of neighbouring countries. Furthermore, and very importantly, it was later discovered through import statistics from the United States that the 15% by-catch limit on swordfish had vessels declaring swordfish catch as tunas (bigeye and yellowfin). Without properly established monitoring and compliance at the start of the fishery this misreporting and underreporting went unnoticed.

South Africa was issued with quota limits for swordfish from 2003. The quota limits have ranged between 890t and 1200t and the current quota is 1001t for 2013. South Africa has not been limited by this quota and the annual catches in most recent years are around 200t, far from reaching the quota limits.

2. **Methods**

2.1 Data collection

Since the inception of the experimental fishery in 1997, the collection of catch statistics data has been a mandatory requirement for pelagic longline vessels of all nationalities fishing with a South African permit. The vessels are required to fill in logbooks onboard and submit the data monthly. All pelagic longline data have been stored and managed in a dedicated database. Since this is a relatively new fishery refining the type of data collected is an ongoing process. Over the years additional fields of data have been included to facilitate analyses.

2.2 Data filtering and variables

The management boundary between ICCAT and the Indian Ocean Tuna Commission (IOTC) falls along the 20°East. As such, all data ≤ 20°East were excluded from the analysis. The data was cleaned of erroneous data explained by obvious data entry errors.

Vessels that had been fishing for fewer than 4 years were excluded from the analysis. A majority (76%) of the swordfish was caught by the vessels that had been fishing for 4 or more years. By excluding these vessels, the variation from intermittent fishing over short periods has been minimised.

Month (factor)

Month was included as opposed to quarter, which was a collinear variable. The degree of seasonality of the fishery, especially from the arrival and departure of foreign vessels during winter (April to October), is to be tested.

Flag (covariate)

The four nationalities included in the analysis were South Africa, Japan, Seychelles and St. Vincent. Korea had minimal fishing activity (81 sets) in the ICCAT region over the analysis period and was removed from the analysis.

Target (covariate)

The vessels have one of three targets- swordfish, tuna or pelagic shark (blue and mako sharks) - as is stipulated in the permit for which they apply for every year. The target for each vessel remains the same throughout the time period. The vessels do not tend to change their target once they have obtained the skill set.

Vessel name (covariate)

The individual vessel identity through the vessel name was included as a measure of skill and skipper experience. Even though this is a relatively new fishery for South Africa, the skill level among local and foreign vessels can vary. Within the local fleet the ability to capture swordfish varies. It can be argued that the explanatory power of individual vessels is captured in the variables Flag and Vessel size. In a future analysis, vessel name could be included as a random effect.

Vessel size (covariate)

The vessel size was included as length overall (LOA) (m) as opposed to gross tonnage. The number of crew was not chosen to represent vessel capacity as these are unreliable data.

Catch location (covariate)

The latitude and longitude at the start of each the set was used to denote the catch location. Catch location was used as categorical variable with 6 levels. Three latitudinal zones: north west (<33°S, ≤5°E), north middle (<33°S, 6-13°E) and north east (<33°S, ≥14°E). Three longitudinal zones: south west (≥33°S, ≤5°E), south middle (≥33°S, 6-13E) and south east (≥33°S, ≥14°E).

Hook number (covariate)

The total number of hooks for each set was included as an indication of the length of the longline. Data on the number of hooks per basket have not been collected.

The percentage of missing data removed for each variable was <1% for latitude, longitude and number of hooks, respectively, and 1.3% for Korean data. The final dataset included a total of 6990 sets from June 1998 to December 2012.

Variables that could not be included because of a lack of data were buoy line length, hook line/branch line length, the percentage of hooks with light sticks, the use of a line setter, type of bait, sea surface temperature (SST) and soak time (time from start of set to time of hauling start). Either these data were only captured from 2004 onwards or the data were not collected by the vessels on their catch statistics forms. The capture of other species was not included as additional variable as this information is thought to be included in the co-variate 'target'. The other large pelagic species caught by pelagic longline are similar to swordfish and including these species may take away from the year effect (Maunder and Punt, 2004).

No interaction terms were included in this analysis though it may be useful to test the interaction of, i) flag and target and ii) flag and vessel size in future analyses.

2.3 Model

The swordfish catch (number of fish per 1000 hooks) was modelled with a negative binomial distribution to account for the over-dispersed catch data (variance, 56.9, was much greater than the mean, 5.1).

The variables and the most parsimonious model were selected through a stepwise selection using the Bayesian Information Criterion (BIC) (Schwarz, 1978) to assess whether the inclusion of additional variables improved the model. The final model:

$$Y = year + month + hooknr + catchlocation + \mathrm{flag} + target + vesselname + vesselsize$$

where the response variable (*Y*) is the catch (number) of swordfish per 1000 hooks. The explanatory variables are year (*year*), month (*month*), total number of hooks per set (*hooknr*), the catch location zone (*catchlocation*), the vessel nationality (*flag*), the target (*target*), the vessel name (*vesselname*) and the LOA of the vessel (*vesselsize*).

The model was run using the *glm.nb()* function with the package *pscl* (Jackman, 2012) in version 2.15.1 of R software (R Core Team, 2013).

3. Results

Table 1 summarises the number of observed vessels, nationalities, sets and hooks for the time series. **Table 2** indicates that St. Vincent fished off South Africa at the start of the fishery until 2009. Seychelles was present from 2001 to 2009 and Japan has increased their presence in the ICCAT region (as opposed to their preferred IOTC side of South Africa to target yellowfin and bigeye) since 2007.

The deviance analysis for the step-wise regression procedure showed that all of the variables considered were significant and the total deviance explained by the model was 40.73% (**Table 3**). The factors *hooknr* and *flag* explained the largest proportion of the total deviance explained by the model, whereas vessel *length* and *target* had the least effect.

The normalised nominal CPUE does not differ much from the normalised standardised CPUE (**Table 4** and **Figure 2**). The standardised CPUE (**Figure 3**) indicates high abundance in 1998 and 1999 at the start of the fishery. Catches decline from 1998 to 2000 but stabilise on a low level thereafter.

Table 5 shows the predictor dataset for the standardised CPUE.

4. Discussion

At the start of the fishery from 1997 until 1999, monitoring of catches during offloading in port and the placement of observers on local and foreign longline vessels was not yet well established. Underreporting of catches would lead to an even steeper decline in standardised CPUE during these years; hence the validity of the analysis from 1998 to 2000 has to be carefully scrutinised. Additionally, the reporting of catch statistics from multiple vessels for entire trips was far below 100% coverage, providing us with fewer data to analyse. Overall, we do believe that the trend witnessed in the standardised CPUE reflects the change in abundance quite accurately.

The CPUE has not reached the same level as 1998 and from 2000 the abundance trend has been declining slowly. Swordfish are oceanic species but are known to occur in coastal waters (Collette, 1995). Swordfish are known for having localised sub-populations that will remain in particular locations driven by environmental conditions (Muths *et al.* 2013, in the south west Indian Ocean) based around food availability (e.g. seamounts) (Campbell and Hobday, 2003). The older mature individuals will migrate seasonally to the spawning grounds and will head back to these areas thereafter (Poisson, 2009). Swordfish in these sub-populations are vulnerable to overfishing due to this type of residency. And if swordfish have a replenishment rate that is slower than the rate they are being removed, then the sub-populations will decline. The higher abundance and subsequent decline witnessed in 1998 and 1999 for South Africa has also been witnessed at the 'Brisbane grounds' in Australia's dedicated swordfish fishery from 1997 onwards (Campbell and Hobday, 2003).

Fleets that are restricted to coastal communities and target swordfish are sensitive to and vulnerable to changes in abundance. The stock assessment could indicate an under exploited or optimally exploited stock for the entire region overall yet the coastal communities display a different story. This should be kept in mind when running stock assessment models.

The big old fat fecund female fish (BOFFFF) hypothesis proposed by Berkley *et al.* (2004) implies that older females produce more and better quality offspring as they age. Removing older larger females that congregate in the sub-populations and that produce more offspring than younger females has an impact on the region and overall productivity in the stock.

In addition to the above hypothesis, South Africa is in the southern range limit for coastal swordfish (Itano, 2011) bringing forth a further challenge for the waters around South Africa to repopulate. The South African vessels have remained in the coastal regions without extending their effort to the high seas because their vessels are not large enough (20 – 30m LOA) or well equipped enough to venture further.

The other major fleets (e.g. Japan, Brazil, Spain, Uruguay) catching swordfish in the south Atlantic are targeting tunas with swordfish as by-catch. Their abundance curves are erratic as these vessels fish in the high seas, as opposed to South Africa's protracted coastal region, in targeting tunas (ICCAT, 2012).

The possibility that a change in regional environmental and/or oceanographic conditions cannot be ruled out as an explanation for the decrease in abundance (e.g. Podesta *et al.*, 1993; Bigelow *et al.*, 1999, Damalas *et al.*, 2007).

The variable *hooknr* indicates that fewer hooks increase the CPUE. The idea that there is a finite number of swordfish available in the area and, regardless of the number of hooks placed in the water, more than what is present cannot be caught. The same applies for soak time where beyond a certain point, the soak time does not matter. The hook numbers had a bimodal distribution of either around 1500 hooks or around 3000 hooks set. The greater number of hooks did not improve the chances of catching more swordfish.

For the variable *flag,* 'South Africa' had the greatest positive influence on the CPUE. This is significant since South Africa is new to this fishery. This result indicates that even though foreign vessels also had a positive influence on the swordfish CPUE, the local knowledge and consistent presence of South African vessels in the area had a greater impact on the CPUE and deviance explained than the level of experience of foreign vessels.

The 20°E boundary, where all data east of 20° meridian was excluded from the analysis, was applied to the data since that is the management boundary between ICCAT and IOTC. However, for a standardised CPUE where we want to model the abundance, the model should incorporate a boundary that better indicates the separation between east and west. There is evidence to suggest that the swordfish caught in the ICCAT have movements between the Indian Ocean based upon a transition zone between 17° and 23° east (Muths *et al.*, 2013) and this is currently being explored further. Until we have evidence such as genetics or boundary movement data to indicate the type of transition zone between the ICCAT and IOTC stocks, we could utilise a visual boundary in future analyses based on the distribution of fishing effort and CPUE.

The zero-inflated negative binomial model would be better suited for future analyses to accommodate the large number of zeroes in the catch data. Interaction terms including month, year and area would be worth testing in future analyses since a characteristic of pelagic longline vessels is to follow these open ocean migrants. A further improvement would be the incorporation of targeting based on a cluster analysis of catch data of all reported species (Hazin *et al.*, 2007).

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Table 1. A summary of the total number of sets, number of vessels, number of nationalities and number of hooks set per year from 1998 – 2012.

Year	*Total number of sets*	*Number of vessels*	*Number of nationalities*	*Total number of hooks*
1998	122	6	2	101735
1999	207	7	2	187718
2000	477	9	2	584585
2001	770	13	3	935630
2002	631	11	3	914392
2003	512	11	3	706346
2004	385	8	3	563542
2005	368	6	2	517988
2006	309	9	3	446230
2007	391	10	4	658524
2008	409	11	4	695805
2009	709	15	4	1099626
2010	637	18	2	1059903
2011	677	15	2	965153
2012	385	11	2	508757

Table 2. The number of longline sets made per year for South Africa, Japan, Seychelles and St. Vincent from 1998 – 2012 in the ICCAT region.

Year	*South Africa*	*Japan*	*Seychelles*	*St. Vincent*	*Total*
1998	80			42	122
1999	188			19	207
2000	234			243	477
2001	587		19	164	770
2002	357		101	173	631
2003	289		127	96	512
2004	175		132	78	385
2005	281			87	368
2006	239		18	52	309
2007	157	76	97	61	391
2008	151	72	125	61	409
2009	405	118	130	56	709
2010	479	158			637
2011	610	67			677
2012	367	18			385
Total					**6989**

Table 3. The statistics of the negative binomial model fit for swordfish caught by pelagic longline off South Africa (1998-2012). The terms were added sequentially, first to last. All factors contributed significantly to the total deviance explained.

Parameter	***Res. d.f.***	***d.f.***	***AIC***	***Δ AIC***	***Res.Dev.***	***Δ Dev***	***% explained***	***p***
NULL	6988		37612		13142.5			
LENGTH	6987	1	37607	-5	13128.9	-14	0.25	***
HOOKNR	6986	1	36917	-690	11940.7	-1188	22.20	***
TARGET	6984	2	36740	-177	11636.9	-304	5.68	***
FLAG	6981	3	35970	-770	10532.2	-1105	20.64	***
CATCHLOCATION	6947	5	35505.8	-464	9842.5	-690	12.89	***
VESSELNAME	6936	29	35171.1	-335	9332.8	-510	9.52	***
MONTHNAME	6922	11	34793.1	-378	8854.3	-479	8.94	***
YEAR	6676	14	33857.1	-936	7789.9	-1064	19.89	***
% deviance explained							**40.73**	

Table 4. Results of the standardised CPUE for swordfish caught by pelagic longline off South Africa (1998-2012).

	Standardised CPUE (n/1000 hooks)			
Year	**CPUE**	**95% Confidence Intervals**	**SE**	**nominal**
1998	71.7	164.4-31.3	0.4233	61.2
1999	25.2	57.6-10.9	0.4231	27.4
2000	13.2	29.8-5.8	0.4181	14.2
2001	10.6	23.9-4.7	0.4162	14.8
2002	15.2	34.3-6.7	0.4170	16.3
2003	9.1	20.5-4	0.4167	14.3
2004	8.9	20.1-3.9	0.4164	13.3
2005	10.3	23.2-4.5	0.4168	11.8
2006	8.4	19-3.7	0.4170	11.4
2007	10.4	23.4-4.6	0.4165	11.7
2008	5.5	12.3-2.4	0.4170	7.2
2009	5.2	11.8-2.3	0.4156	5.6
2010	7.2	16.3-3.2	0.4153	7.1
2011	4.4	9.8-1.9	0.4149	5.0
2012	4.0	9-1.8	0.4174	5.1

Table 5. The predictor dataset used to calculate standardised CPUE for swordfish caught by pelagic longline off South Africa (1998-2012).

YEAR	*VESSEL*	*MONTH*	*FLAG*	*TARGET*	*VESSEL LENGTH*	*CATCH LOCATION*	*SST (°C)*	*HOOK NUMBER*
1998	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
1999	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2000	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2001	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2002	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2003	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2004	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2005	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2006	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2007	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2008	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2009	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2010	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2011	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500
2012	ATALANTA	JUL	SA	SWO	21	NORTHEAST	18	1500

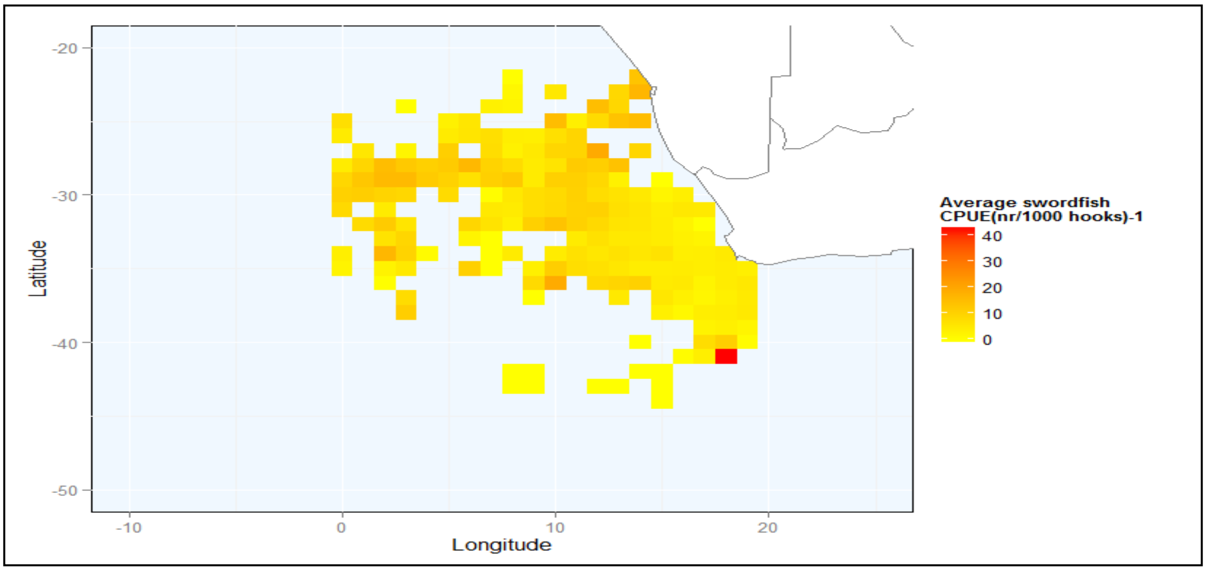

Figure 1. The average swordfish catch-per-unit effort (number of swordfish per 1000 hooks) in 1x1° grid blocks from 1998 to 2012 in the ICCAT region.

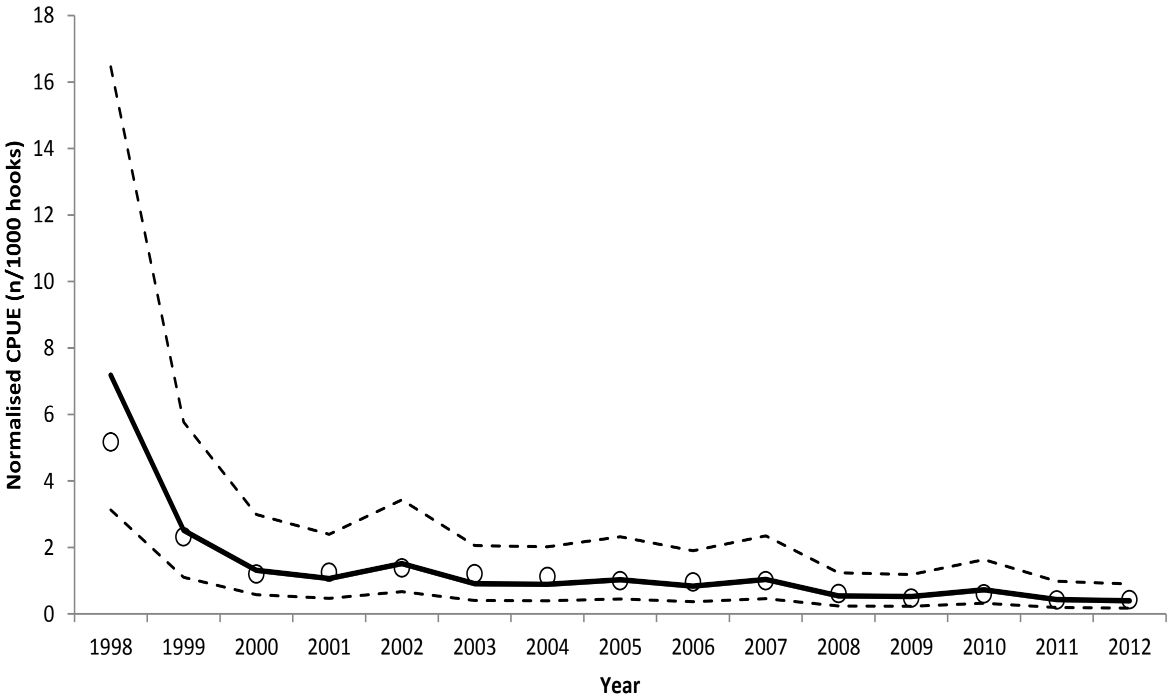

Figure 2. The normalised standardised CPUE (solid line) and the 95% confidence intervals (dashed lines) are plotted with the normalised nominal CPUE (open circles) for swordfish caught by pelagic longline off South Africa (1998-2012).

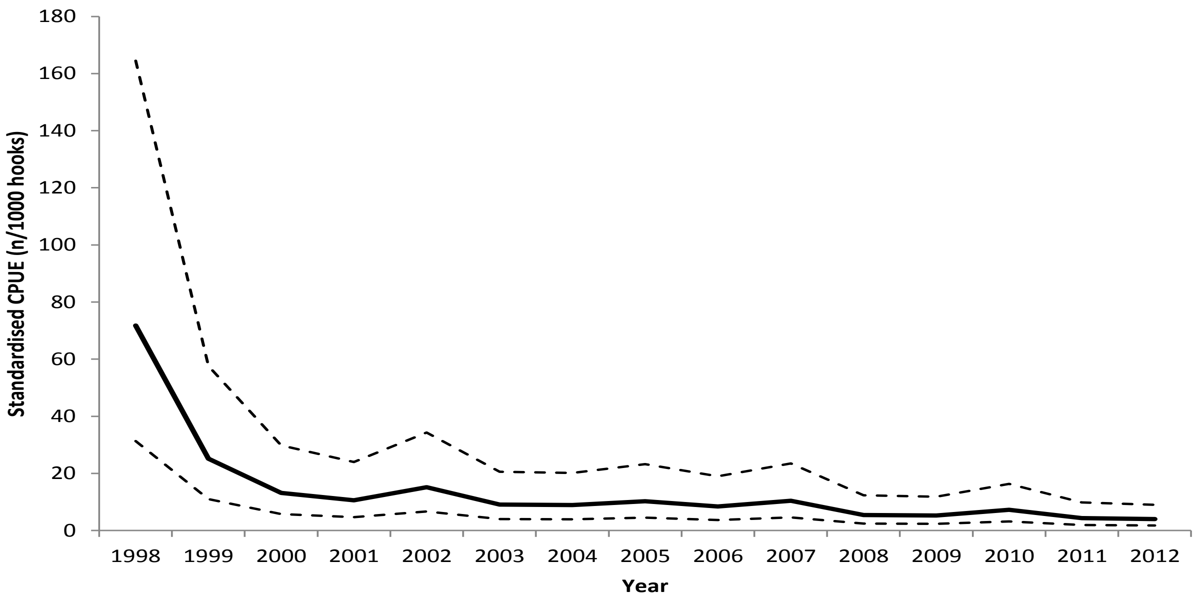

Figure 3. The standardised CPUE (solid line) and the 95% confidence intervals (dashed lines) for swordfish caught by pelagic longline off South Africa (1998-2012).