STANDARDIZED CPUE OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY TUNA LONGLINERS OPERATING OFF SOUTHERN BRAZIL (1998-2006)

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SUMMARY

In the present paper the CPUE of swordfish caught by longliners based in São Paulo State, southern Brazil, from 1998 to 2006, was standardized, using GLM, assuming a quasi-Poisson error distribution. The explanatory variables tested were "year", "month", "target" and "area". The best fit model included all variables, plus the interactions "year: month" and "year: area". The target species and month were the main factors explaining the observed variability of the catch rate (52% and 18.2%, respectively). The overall deviance explained by the model was 45.9%, indicating a reasonably good fitting. The standardized swordfish CPUE increased from 1998 to 2002, when it peaked, declining, then, in the following 2 years. After experiencing a slight recovery in 2005, it dropped again, markedly, in 2006. The variation of the nominal and standardized CPUE did not differ much during the whole period, except for the last year, in 2006, when the standardized value was noticeably lower.

RÉSUMÉ

Ce document présente la standardisation de la CPUE de l'espadon capturé par les palangriers basés dans l'état de São Paulo, au sud du Brésil, de 1998 à 2006, à l'aide d'un GLM, en postulant une distribution d'erreur quasi-Poisson. Les variables explicatives testées étaient "année"," mois"," cible" et " zone". Le meilleur ajustement du modèle incluait toutes les variables ainsi que les interactions "année: mois" et "année: zone". L'espèce cible et le mois étaient les principaux facteurs expliquant la variabilité observée dans les taux de capture (52% et 18,2%, respectivement). La déviance globale expliquée par le modèle était de 45,9%, indiquant un ajustement raisonnablement satisfaisant. La CPUE standardisée de l'espadon s'est accrue de 1998 à 2002, atteignant son maximum, suivie d'un déclin les deux années suivantes. Après une légère augmentation en 2005, elle a de nouveau chuté, de façon marquée, en 2006. La variation de la CPUE nominale et standardisée n'était pas très différente pendant toute la période, sauf pour la dernière année, 2006, où la valeur standardisée était bien plus faible.

RESUMEN

En este documento se estandarizó la CPUE del pez espada capturado por los palangreros con base en el Estado de Sao Paulo, al sur de Brasil, entre 1998 y 2006, utilizando un GLM que asumía una distribución de error quasi-Poisson. Las variables explicativas probadas fueron "año", "mes", "objetivo" y "área". El mejor ajuste del modelo incluía todas las variables, además de las interacciones "año:mes" y "año:área". La especie objetivo y el mes fueron los principales factores que explicaban la variabilidad observada de la tasa de captura (52% y 18,2%, respectivamente). La desvianza global explicada por el modelo fue del 45,9%, lo que indica un ajuste razonablemente bueno. La CPUE estandarizada del pez espada aumentó desde 1998 hasta 2002, cuando alcanzó un pico, y luego descendió en los dos años siguientes. Tras experimentar una ligera recuperación en 2005, volvió a caer de forma marcada en 2006. La variación de la CPUE nominal y estandarizada no fue muy diferente durante todo el periodo excepto por el último año, 2006, en el que el valor estandarizado fue sensiblemente inferior.

KEYWORDS

Catch, effort, swordfish, catchability, longline, tuna fisheries

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1. Introduction

The Brazilian tuna longline fleet, operating in the southwestern Atlantic Ocean, often catches important amounts of swordfish, both as a target as well as a by-catch of tuna-targeting vessels. Part of this fleet is based in Santos and Guarujá, located in the coast of São Paulo State. The tuna longline fishery based in São Paulo firstly operated with Japanese chartered boats, from 1958 until 1961 (Moraes, 1962; Lima and Wise, 1963). In 1965/ 1966, two Brazilian boats began to fish in the area (Arfelli and Amorim, 1988), with the number of vessels subsequently increasing, up to 20 boats, in 1998, when it peaked. The fleet size was then reduced, reaching 14 vessels, in 2000 (Amorim *et al*., 2002). In the beginning (1958-79), the Santos fleet targeted mainly tunas, which represented more than 50% of total yield, a percentage, however, that gradually decreased in the following years due to changes in the targeting strategy. From 1981 to 1994, for instance, São Paulo based tuna longliners directed their fishing effort to sharks, which accounted for almost 60% of their yield, in 1993 (Arfelli *et al.*, 1997a). Catches of swordfish, however, ranked first or second in weight among all the other catches in most years**.** From 1994 on, in order to specifically catch swordfish, the fishing boats gradually changed from the Japanese longline type to surface monofilament longline, using light-sticks to attract fish (Arfelli, 1996).

Most models used in the assessment of stock status of pelagic fishes are largely based on Catch per Unit of Effort (CPUE) series. Nevertheless, since many factors affect CPUE, such as season, area, gear configuration, and, surely, the targeting strategy, among others, nominal CPUEs are of little value as they do not express the actual abundance of the exploited stock. A common way to compensate for such influences is to use Generalized Linear Models (GLM) to standardize CPUE series. Arfelli *et al.* (1997b), for instance, standardized the swordfish CPUE of 1986-95 data from São Paulo longliners, with GLM, and concluded that the positive answer of the swordfish stock to a directed fishing effort could indicate that the level of exploitation of that species was below MSY, and that the high increase of the CPUE in 1994-95 was mainly due to a change in the fishing gear, from the traditional Japanese-style longline to the monofilament-surface longline.

In the present paper the CPUE of swordfish caught by São Paulo longliners, from 1998 to 2006, was standardized, using GLM, in an attempt to generate a reliable time series of relative abundance for the species, off Southern Brazil, in more recent years.

2. Material and methods

The catch and effort data analyzed in the present paper were obtained from the logbooks of tuna longliners based in São Paulo, made available by the Laboratório de Referência em Controle Estatístico da Produção Pesqueira Marinha do Instituto de Pesca/ SAA/ SP, through ProPesq® system (Ávila-da-Silva *et al*., 1999). The logbook data included a total of 6,486 sets, from 1998 through 2006, containing vessel identification, fishing location, starting and retrieval time of the longline sets, number of hooks deployed and number of fish caught by species. Swordfish was caught in 6,101 sets (94.2%).

The yearly relative abundance of swordfish was estimated by generalized linear model (GLM), assuming a quasi-Poisson error distribution and *log* as link function. The response variable was the CPUE defined as the number of fish caught per thousand hooks. The following factors were tested in the analyses: year (9), month (12), area (5) and target (3). The levels of the "area" factor were based on spatial distribution of fishing sets of São Paulo longliners, while the levels of the "target" factor were defined by cluster analysis (Mourato *et al*., unpublished), as follows: Area: 1: > 20°S; 2: 20°- 30°S / < 40°W; 3: > 30°S/ < 40°W; 4: 20°- 30°S/ > 40°W; and 5: > 30°S/ < 40°W (**Figure 1**); and Target: 1: other fishes; 2: blue shark; and 3: swordfish. A stepwise approach was initially used to identify the variables and interactions with a significant influence in the CPUE. Since all variables were considered significant, only those representing more than 2% of the deviance were included in the final model. The diagnostic plots described by Ortiz and Arocha (2004) were run to evaluate the fitness of the models.

3. Results and iscussion

The deviance analysis (**Table 1**) indicated that target species and month were the main factors explaining the observed variability of the catch rate (52% and 18.2% respectively). The strong influence of the "target" factor, inferred by the cluster analysis (Mourato *et al*., unpublished), found in the present study, was also observed in other studies also based on data from the Brazilian tuna longline fleet (Hazin *et al*., 2007; Mourato, 2007). The other factors included in the model were year, area, and the interactions year*month and year*area, all of them

significant at $p < 0.001$ level (**Table 1**). The overall deviance explained by the model was 45.9%, indicating a reasonably good fitting, which is not so common, when using set by set data, with no aggregation, such as in the present case (*eg*. Punt *et al*., 2000). The distribution of residuals (**Figures 2 and 3**) showed a reasonably good fit, while the 95% confidence intervals for the standardized CPUE series were also relatively narrow (**Figure 4**).

The standardized swordfish CPUE increased from 1998 to 2002, when it peaked, declining, then, in the following 2 years. After experiencing a slight recovery in 2005, it dropped again, markedly, in 2006 (**Figure 4**). The variation of the nominal and standardized CPUEs did not differ much during the whole period, except for the last year, in 2006, when the standardized value was noticeably lower (**Figure 5**). The reason for such a discrepancy, however, was not clear.

Comparison between the standardized CPUE series generated by the present analysis, based on set-by-set data obtained from logbooks, with another one reported last year (Mourato *et al*., 2007), on the same fishery, using monthly aggregated data from commercial sheets of fishing companies, also shows somewhat discrepant trends, particularly from 2000 to 2003 (**Figure 6**), although both tend to show a drop in recent years. Such behavior is in contrast with the standardized CPUE series based on set by set data from logbooks, of the entire Brazilian longline fleet (Hazin *et al*., 2007) (**Figure 6**), including São Paulo longliners, which shows a consistent increasing trend, from 2000 onward. Such a difference could either be related to the different geographical range of both data bases, as well as to a particular behavior of São Paulo fleet, including possible changes in targeting strategy not accounted for by the cluster analysis. In order to overcome such a difficulty, other factors that might reflect the targeting strategy, such as number of hooks per basket, should be included in future analyses.

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Table 1. Deviance analysis of the fitted model for the standardization of swordfish CPUE caught by the São Paulo longliners fleet during 1998-2006.

	Df	*Deviance*	*Resid. Df*	*Resid. Dev.*	*Pr(Chi)*	*Explained Deviance*	*Explained by the Model*
NULL			6463	48980.64			
month	11	4081.16	6452	44899.48	0.0000	18.2%	8.3%
Year	8	2561.4	6444	42338.08	0.0000	11.4%	13.6%
Area	4	1564.13	6440	40773.95	0.0000	7.0%	16.8%
target	2	11681.91	6438	29092.04	0.0000	52.0%	40.6%
*year*month*	87	2130	6351	26962.04	0.0000	9.5%	45.0%
*year*area*	31	448.88	6320	26513.16	0.0000	2.0%	45.9%

Table 2. Standardized CPUE and respective standard error, nominal CPUE and scaled values of the fitted model for the standardization of swordfish CPUE caught by the São Paulo longliners fleet during 1998-2006.

Year	*Stand. CPUE*	*SE*	*Nominal CPUE*	*Scaled Stand. CPUE*	*Scaled Nominal CPUE*
1998	5.74	0.55	10.26	0.95	1.00
1999	6.63	0.41	12.18	1.10	1.19
2000	6.16	0.48	9.90	1.02	0.96
2001	7.07	0.65	10.17	1.17	0.99
2002	8.39	0.70	8.71	1.39	0.85
2003	5.74	0.65	7.04	0.95	0.69
2004	5.39	0.45	7.75	0.89	0.75
2005	6.24	0.60	6.39	1.03	0.62
2006	3.02	0.78	20.04	0.50	1.95

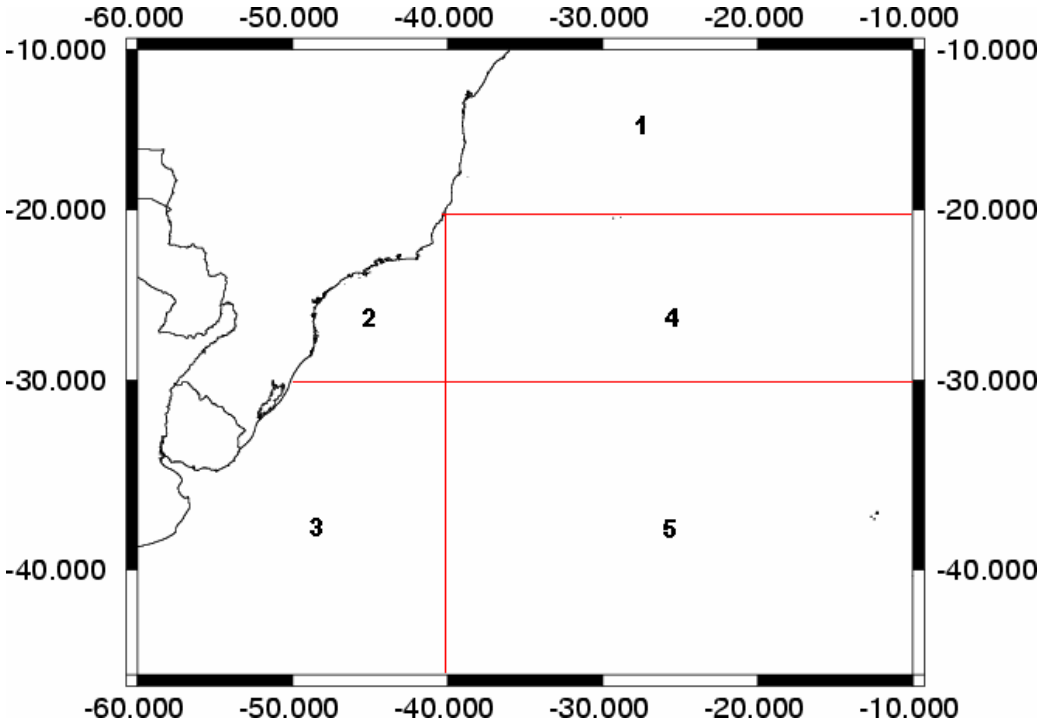

Figure 1. Division of fishing ground of São Paulo longliners fleet in to 5 sub-areas, following Mourato *et al*. (unpublished). Division of sub-areas: **1**: > 20°S; **2**: 20°- 30°S / <40°W; **3**: >30°S / <40°W; **4**: 20°- 30°S / >40°W; **5**: >30°S / <40°.

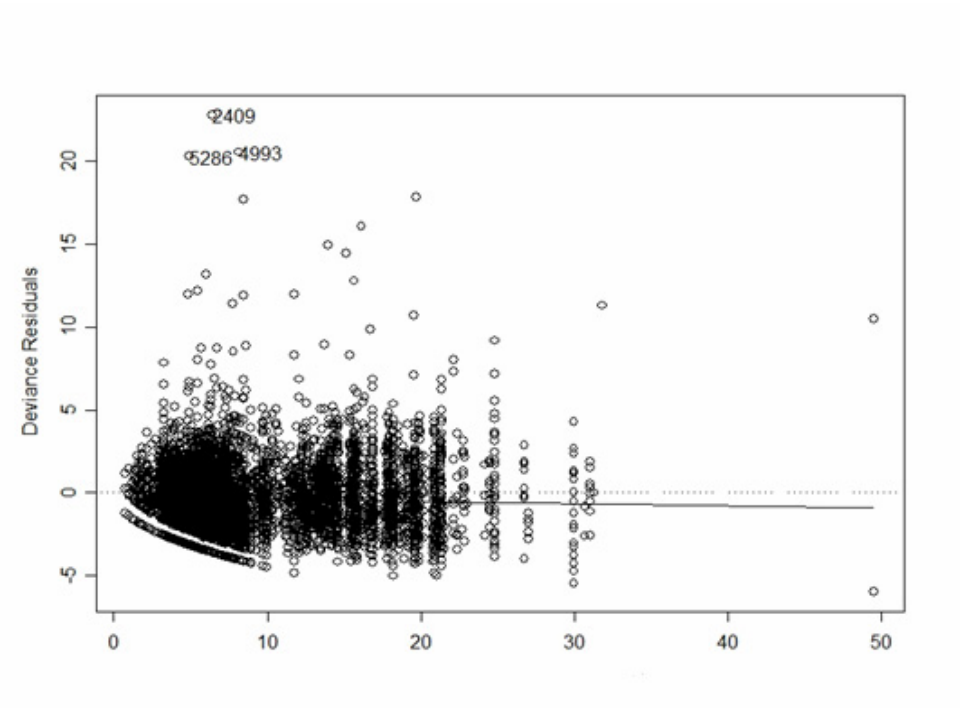

Figure 2. Distribution of residual vs fitted values of the model for the standardization of swordfish CPUE caught by the São Paulo longliners fleet during 1998-2006.

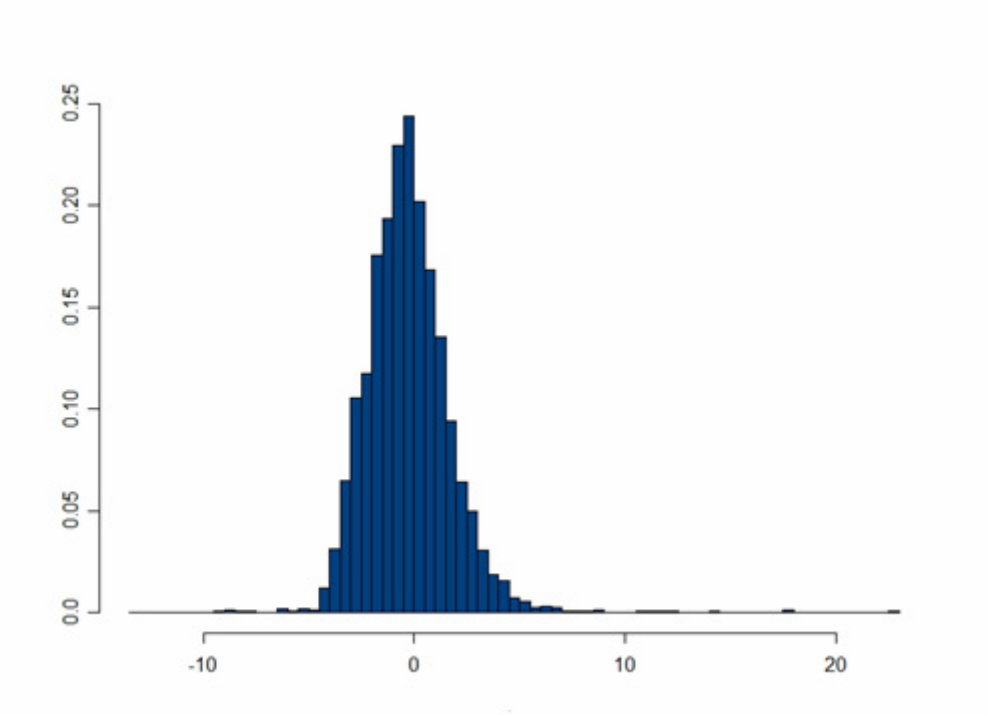

Figure 3. Histogram of residuals of the fitted model for the standardization of swordfish CPUE caught by the São Paulo longliners fleet during 1998-2006.

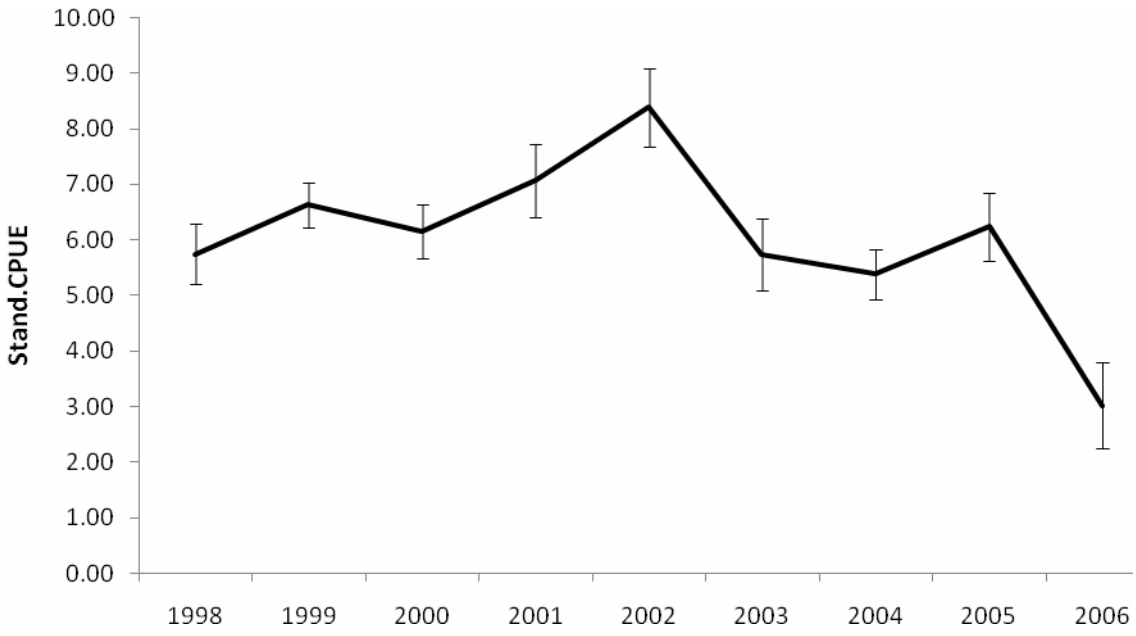

Figure 4. Standardized CPUE (number of fish/1000 hooks) of swordfish caught by São Paulo longliners between 1998 and 2006.

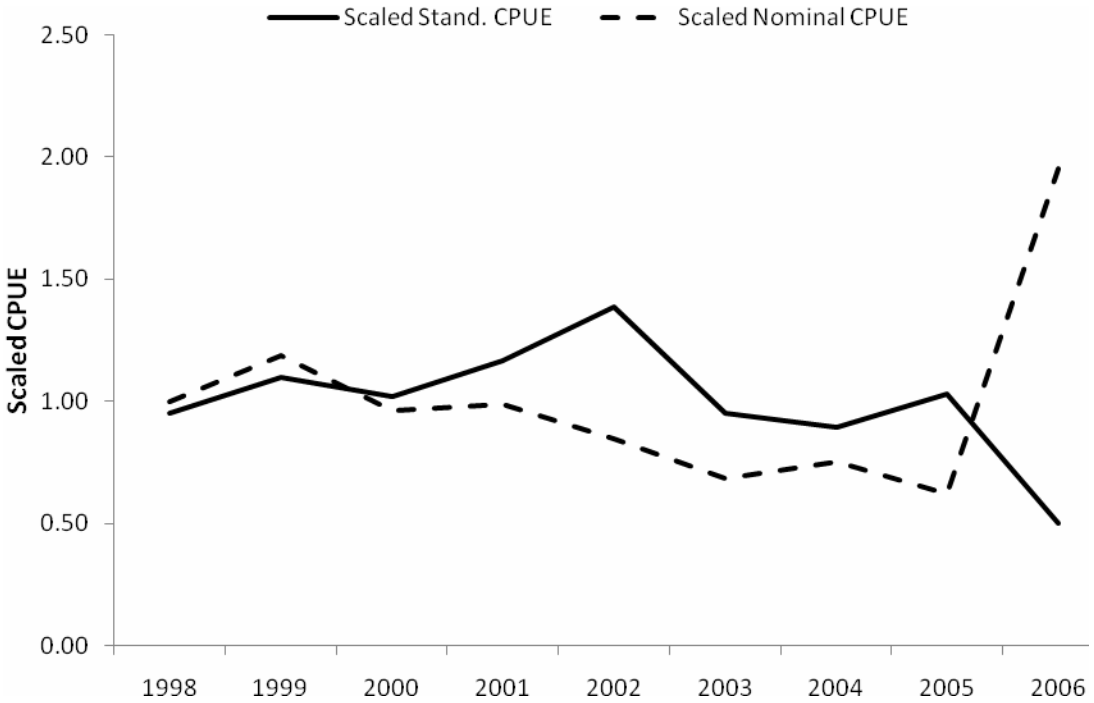

Figure 5. Scaled CPUE (number of fish/1000 hooks) of swordfish caught by São Paulo longliners between 1998 and 2006.

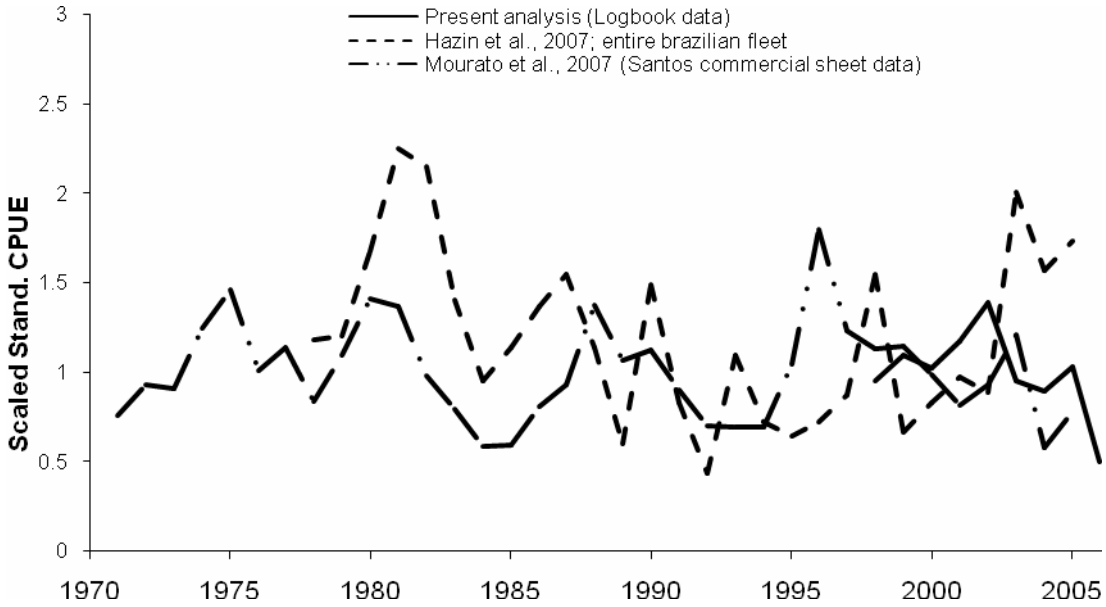

Figure 6. Comparison between of the standardized CPUE of swordfish caught by São Paulo longliners and the entire Brazilian tuna longline fleet.