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# STANDARDIZATION OF BLUE SHARK *PRIONACE GLAUCA* CATCH RATES OF THE JAPANESE-FLAGGED COMPONENT OF THE SOUTH AFRICAN LARGE PELAGIC LONGLINE FLEET BASED ON OBSERVER RECORDS.

Charlene da Silva[1], Denham Parker[1], Sven Kerwath[1]

## SUMMARY

The blue shark *Prionace glauca* is caught as bycatch in the large pelagic longline fishery in South Africa. The fleet includes a domestic component with varying but increasing degree of observer coverage, and a foreign-flagged component of Japanese vessels that operate under joint venture agreements with South African Right Holders. Japanese flagged vessels have been operating under a mandatory 100% observer coverage since 2007. The catch and effort data include consistent records of bycatch species in numbers caught per set. We investigated blue shark abundance by standardising the Catch per Unit Effort (CPUE) in numbers from Observer data for the time series 2007 to 2019. To do this, we applied a Generalised Additive Mixed Model (GAMM) with a Poisson error distribution. Explanatory variables of the final model included *year*, *month*, *grid* (lat, long) with the number of blue shark caught in a set offset by the number of hooks set, so as to maintain a count distribution. Vessel was included as a random effect. Despite a period of relatively low catch rates (2009-2012) followed by a period of relatively high catch rates (2015-2017), the results indicate that blue shark CPUE in the south-western IOTC area has been stable overall. Our dataset is unique in that the joint-venture Japanese flagged vessels have required 100% observer coverage since 2007. Given the increasing stricter catch regulation on shark species, our observer dataset may be the most appropriate dataset to accurately represent trends in abundance of blue sharks in the south-western IOTC region.

## KEYWORDS

*Blue sharks, standardized cpue, longline, GAMM, random effect, observer data*

## AFFILIATIONS

[1]Department of Forestry, Fisheries and the Environment (DFFE), South Africa

INTRODUCTION

Commercial fishing for large pelagic species in South Africa dates back to the 1960s (Welsh, 1968; Nepgen, 1970). This South African fishery ceased to exist after the mid 1960's, as a result of a poor market for low quality southern bluefin *Thunnus maccoyii* and albacore *Thunnus alalunga* (Welsh 1968). However, foreign vessels, mainly from Japan and Chinese-Taipei, continued to fish in South African waters from the 1970s until 2002 under a series of bilateral agreements. Interest in pelagic longline fishing 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. Thirty experimental longline permits were subsequently issued in 1997 to target tuna (Penney and Griffiths 1999). Shark-directed longline fishing only started 30 years later with the introduction of the shark directed fishery composed of vessels targeting both demersal and pelagic sharks. The large pelagic longline fishery was formalised in 2005, when 18 long-term rights were issued for the swordfish-directed fishery and 26 for the tuna-directed fishery (Parker and Kerwath, 2020). The pelagic shark directed component was amalgamated with the tuna and swordfish longline fishery with incentives provided for increasing their landed-catches of swordfish. All vessels operating in the large pelagic longline fishery were restricted to a shark landed-catch of <10% of the total landed-catch of the sector (MCM 2008). In 2011, the rights holders fishing under an exemption were fully integrated into the tuna directed fishery (da Silva et al. 2015).

Shark landings in the tuna and swordfish fishery are capped according to a precautionary upper catch limit (PUCL) of 2 000 t dressed weight per annum (DAFF 2014b) and permit conditions have become progressively more stringent over the years to discourage retention of sharks. Landings of Thresher sharks belonging to the genus *Alopias*, hammerhead sharks belonging to genus *Sphyrna*, oceanic whitetip sharks *Carcharhinus longimanus*, porbeagle sharks *Lamna nasus*, dusky sharks *C. obscurus* and silky sharks *C. falciformis* are prohibited. Live release of sharks is strongly encouraged. Fins have to remain attached to the sharks' bodies and the use of wire traces is prohibited. In addition, shark catch cannot exceed 50% of the total landed mass of the annual catch of the vessel.

Despite these measure the fishery still catches significant numbers of juvenile shortfin mako *Isurus oxyrinchus* and blue shark *Prionace glauca*, as these species are prevalent in the tuna grounds along the southern African shelf in both the Atlantic and the Indian Oceans. In the tuna-directed fishery an onboard observer programme has been ongoing since 1998 (Smith 2007). Observers record all species caught, the length frequencies of all tuna, billfishes and sharks, as well as information on discards.

The previous attempt at standardizing blue shark CPUE was completed using mainly the shark directed domestic component of pelagic longline fishery on data between 1998 and 2008, prior to many of the permit conditions that would have affected behaviour of rights holders (Jolly et al. 2011). This showed that blue shark CPUE has remained relatively stable from 1998 to 2008 in the shark directed fishery.

A recent analysis of fishing behaviour and fishing mortalities (landings plus discard mortalities) in the South African-flagged pelagic longline fishery suggests diverse targeting and discard behaviour (Jordaan et al 2020). High rates of blue shark discards (53%) has been suggested during the study period of 2013-2015. Therefore, consistent catch data that includes discards and retentions, as is available for the Japanese-flagged component of the South African fleet through the observer programme, provides the only viable option to use commercial CPUE as an index of abundance. Here we present the first standardised catch-per-unit-effort (CPUE) indices for blue sharks obtained from data collected on the onboard observer programme from the Japanese vessels operating in South African waters between 2007 and 2019. This analysis used methodology from previous assessments on other large pelagic longline species (Parker and Kerwath, 2020; da Silva et al. 2017; Parker et al. 2017; Winker et al. 2017):

## MATERIALS AND METHODS

### *Catch and effort data preparation*

Retained and discarded blue shark catch (in numbers) collected from the national observer programme dataset for the period between 2007 and 2019 (Sets = 14 513; hooks= 36 305 114; blue shark = 124 959). Each record included the following information: (1) date, (2) unique vessel name, (3) catch position at a 1x1 degree latitude and longitude resolution and (4) number of retained or discarded blue sharks and (5) hooks per set. For this analysis, observer data were extracted from the Japanese flagged vessels operating under joint venture were spatially confined to the IOTC area of competence (Longitude >20) and sets with less than 500 hooks were omitted as they were deemed "unsuccessful" deployments. The final dataset comprised of: (Sets = 9 553; hooks= 26 242 591; blue shark = 45 769).

***Model framework***

Number of blue sharks observed during the period was standardized using a Generalized Additive Mixed Model (GAMM) with a Poisson distribution, which included the covariates *year*, *month* (spline) and offset by *hook number*. A Poisson distribution was considered appropriate as the response variable was the number of blue shark observed, the data were not zero-inflated and although the data indicated a level of over-dispersion this did not seem to affect the fits.

The full GAMM evaluated for blue sharks was:

$$Nr\ blue\ sharks_i = exp(\beta_0 + Year + s_1(Month) + s_2(Long, Lat) + \alpha_V)$$

where $s_1()$ denotes cyclic cubic smoothing function for *Month*, $s_2()$ a thin plate smoothing function for the two-dimensional covariate of Lat and Long called *grid*. The inclusion of individual Vessels as random effects term provides an efficient way to combine catch in numbers of blue sharks recorded from various vessels ($n$ = 24) into a single, continuous time-series, despite discontinuity of individual vessels over the time series (Helser *et al.*, 2004). The main reason for treating vessel as a random effect was because of concerns that multiple catch records produced by the same vessel may violate the assumption of independence caused by variations in fishing power and skipper skills and behaviour, which can result in overestimated precision and significance levels of the predicted catch trends if not accounted for (Thorson and Minto, 2015). Hook number was included in the model as an offset. The significance of the random-effects structure of the GAMM was supported by both Akaike's Information Criterion (AIC) and the more conservative Bayesian Information Criterion (BIC). Sequential $F$-tests were used to determine the covariates that contributed significantly ($p < 0.001$) to the deviance explained.

Annual CPUE was standardised by fixing all covariates other than *year and lat,long* to a vector of standardized values $X_0$. The choices made were that *month* was fixed to July (*month* = 7), which represented the month with the most sets deployed as there was no definitive seasonal trend. Number of hooks were set to 2640 which is the mode number of hooks per set during the period. The expected yearly mean $CPUE_y$ and standard-error of the expected $log(CPUE_y)$ for the vector of standardized covariates $X_0$ were then calculated as average across all *lat-,long* combinations $a$, such that:

$$E[CPUE_y(X_0^T \hat{\beta})] = \frac{1}{A}\sum_{a}^{A} exp(\hat{\mu}_{y,a})$$

and

$$\hat{\sigma}_y(X_0^T \hat{\beta}) = \sqrt{\frac{1}{A}\sum_{a}^{A} \hat{\sigma}_{y,a}^2}$$

where $\hat{\mu}_{y,a}$ is the standardized, model-predicted $log(CPUE_{y,a})$ for *year y* and *lat* and *long* for grid cell $a$, $\hat{\sigma}_{y,a}$ is the estimated model standard error associated with $log(CPUE_{y,a})$, $A$ is the total number of *lat,long* combinations (or *grids*) and $T$ denotes the matrix in which $X$ is transposed.

## RESULTS AND DISCUSSION

The analysis of deviance for the step-wise regression procedure showed that all of the covariates considered were highly significant ($p < 0.001$) and the inclusion of all considered fixed effects were supported by both the AIC and BIC (Table 1). The inclusion of the *lat* and *long* for grid cells contributed to the greatest improvement in the deviance explained in the model (81.3%), followed by *month* (14.6%) and *year* (4.1%). Overall, the model was able to explain 18.1% of the variation in the data.

Previous attempts to classify 'catchability' of vessels within the fleet include using *vessel type* as a categorical variable, using a subset of vessels from each class as indicator vessels or using cluster analysis to group 'catchability' of vessels based on targeting tactic (Kerwath et al., 2012; Parker and Kerwath, 2020; da Silva et al. 2017; Winker et al. 2013;2014). This information was challenging to obtain, and neither of these attempts significantly improved the model's explanatory power. As such, including *vessel* as a random effect was deemed the most appropriate solution (Parker and Kerwath, 2020). Given the notable variation among vessels (Fig.2), it is unsurprising that the inclusion of the random vessel effect produced the most parsimonious error model.

The spatial distribution of blue shark catches by Japanese joint-venture vessels operating in the IOTC region is shown in Fig.1. In general, these vessels operate in the same large areas, with a notable exception in 2019 where blue shark catches extended further offshore than in other years. There is little evidence of seasonality in catches of blue shark by this fleet, however an observed peak in March (Fig. 3) is an artefact of relatively few sets occurring during this month. The majority of Japanese flagged vessels only fish in South African waters for the period April-October.

Nominal and standardized CPUE (together with CVs, 95% C.I.) for southern Indian Ocean blue sharks caught by Japanese flagged vessels operating under a joint venture are presented in Table 2. Standardised CPUE rates of approximately ranged from 3.7 – 6.9 sharks per set, with the standard set comprising of 2 640 hooks. There was negligible difference between the nominal CPUE and model outputs from the standardized CPUE that accounted for temporal variation (month and year). However, the inclusion of location (lat, long) and vessel as a random effect produced estimates that deviated considerably from the nominal CPUE, particularly at the beginning and end of the time-series (Fig. 4). The lowest CUE was recorded in 2010 (normalised CPUE = 0.75) and the highest in 2019 (normalised CPUE = 1.37). Despite a period of relatively low catch rates (2009-2012) followed by a period of relatively high catch rates (2015-2017), the results indicate that blue shark CPUE in the south-western IOTC area have exhibited long term stability for the period 2007 – 2019.

The analysis of relative abundance based on logbook information is becoming increasingly difficult due to the continual implementation of stricter regulations with respect to landings sharks. Accounting for these changes adds complexity. As such, long-term Observer datasets with adequate fleet coverage have become essential to this process, as all sharks caught, including discards, should be noted. Our dataset is unique in that the joint-venture Japanese flagged vessels have required 100% observer coverage when operating in South African waters, and data is available since 2007. Given these attributes, this may be the most appropriate dataset to accurately represent trends in abundance of blue sharks in the south-western IOTC region.

## TABLES

**Table 1.** Model statistics for the fixed variables of the GAMM applied to blue shark (*Prionace glauca*) indicating the deviance explained by parameters selected for the final model.

| | DF | AIC | BIC | Deviance | Deviance Explained | % Deviance Explained | P-Value |
|---|---|---|---|---|---|---|---|
| NULL | 1 | 69398.61 | 69405.77 | 40071.55 | 0 | 0 | |
| Year | 13 | 69161.82 | 69254.96 | 39810.76 | -260.788 | 4.05 | **< 0.001** |
| Month | 19 | 68231.49 | 68367.49 | 38868.46 | -942.301 | 14.63 | **< 0.001** |
| s(Lat,Long) | 28 | 63012.21 | 63211.11 | 33631.62 | -5236.83 | 81.32 | **< 0.001** |

**Table 2.** Nominal and standardised CPUE values, including standard error (SE) and confidence intervals (LCI, UCI) for blue shark (*Prionace glauca*) for the period 2007 - 2019.

| Year | Nominal | CPUE | Normalised CPUE | CPUE SE | LCI | UCI |
|---|---|---|---|---|---|---|
| 2007 | 5.03 | 5.22 | 1.06 | 0.07 | 4.59 | 5.93 |
| 2008 | 6.32 | 4.75 | 0.96 | 0.06 | 4.18 | 5.39 |
| 2009 | 4.08 | 4.10 | 0.83 | 0.07 | 3.60 | 4.67 |
| 2010 | 3.81 | 3.72 | 0.75 | 0.07 | 3.27 | 4.24 |
| 2011 | 4.25 | 3.98 | 0.80 | 0.06 | 3.50 | 4.51 |
| 2012 | 4.55 | 4.36 | 0.88 | 0.07 | 3.83 | 4.96 |
| 2013 | 4.75 | 5.50 | 1.11 | 0.07 | 4.83 | 6.26 |
| 2014 | 4.41 | 4.30 | 0.87 | 0.07 | 3.77 | 4.91 |
| 2015 | 6.07 | 5.95 | 1.20 | 0.07 | 5.21 | 6.79 |
| 2016 | 5.20 | 6.79 | 1.37 | 0.07 | 5.94 | 7.75 |
| 2017 | 4.56 | 5.21 | 1.05 | 0.07 | 4.55 | 5.96 |
| 2018 | 4.47 | 5.16 | 1.04 | 0.07 | 4.49 | 5.92 |
| 2019 | 5.48 | 5.22 | 1.06 | 0.07 | 4.54 | 6.01 |

## FIGURES

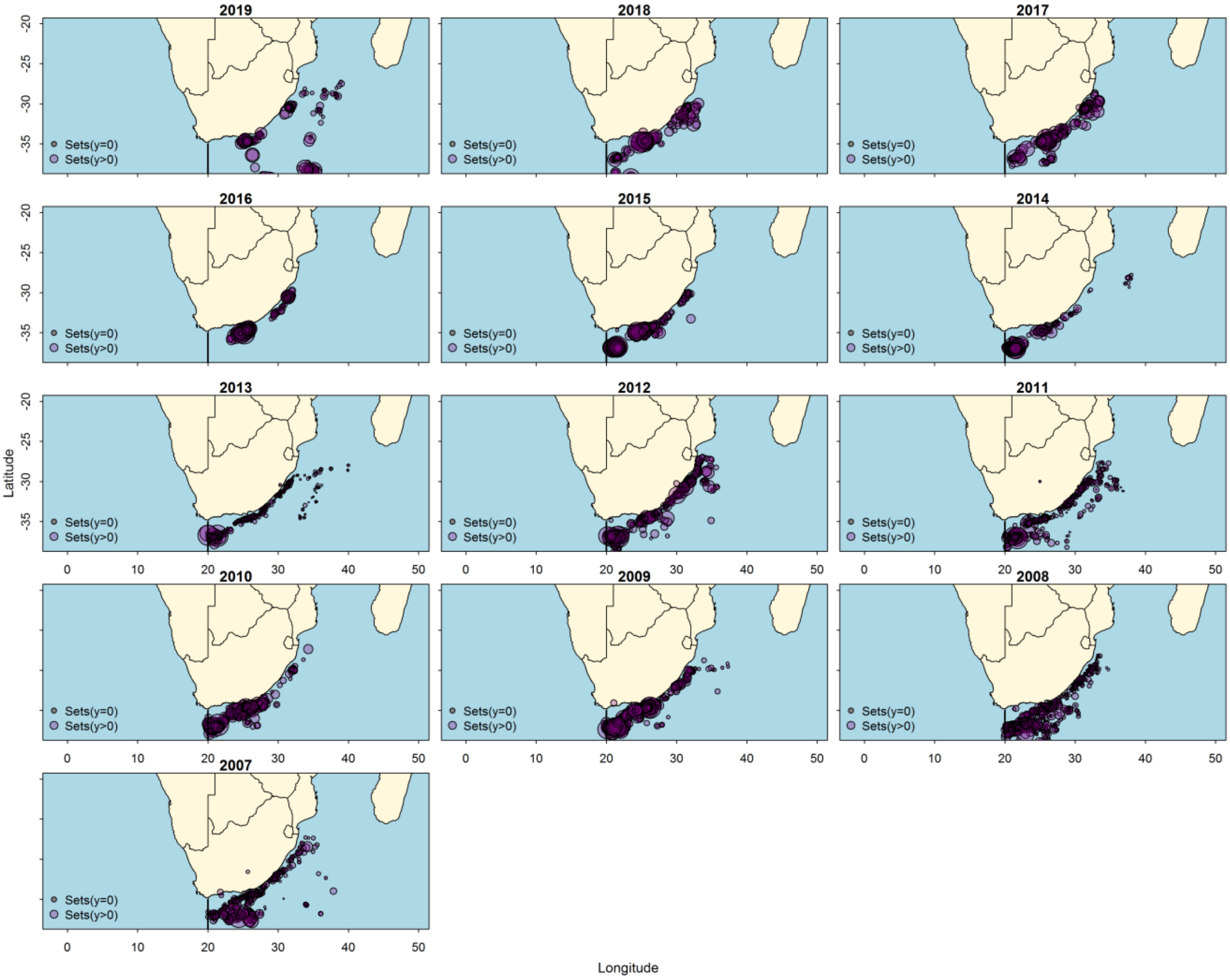


**Figure 1.** Annual effort for available for the Japanese-flagged component of the South African longline fleet. Longline sets that did not encounter a blue shark are the smallest circles, and the circle diameter increases proportional to the weight of blue sharks caught per set. The black line indicates the ICCAT/IOTC boundary.

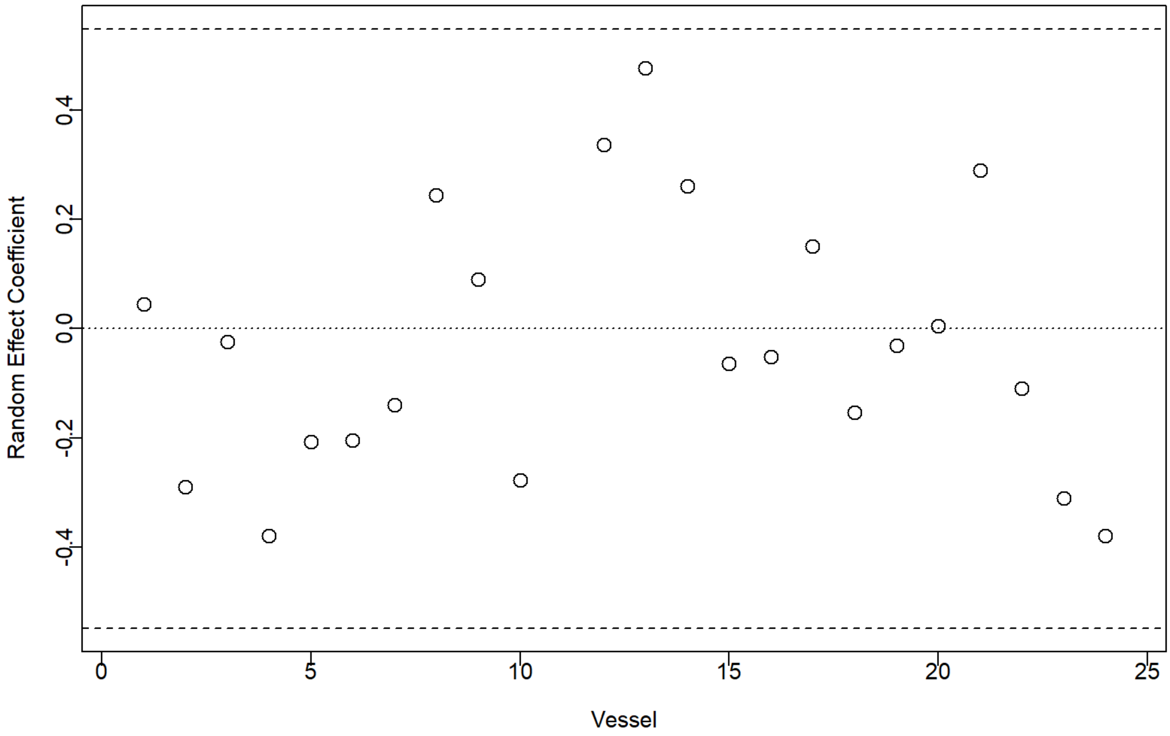


**Figure 2**. Random effects coeffients (dots) illustrating the deviation from the mean of zero across the 24 vessels retained for the analysis. Dashed lines denote the 95% confidence interval of the mean.

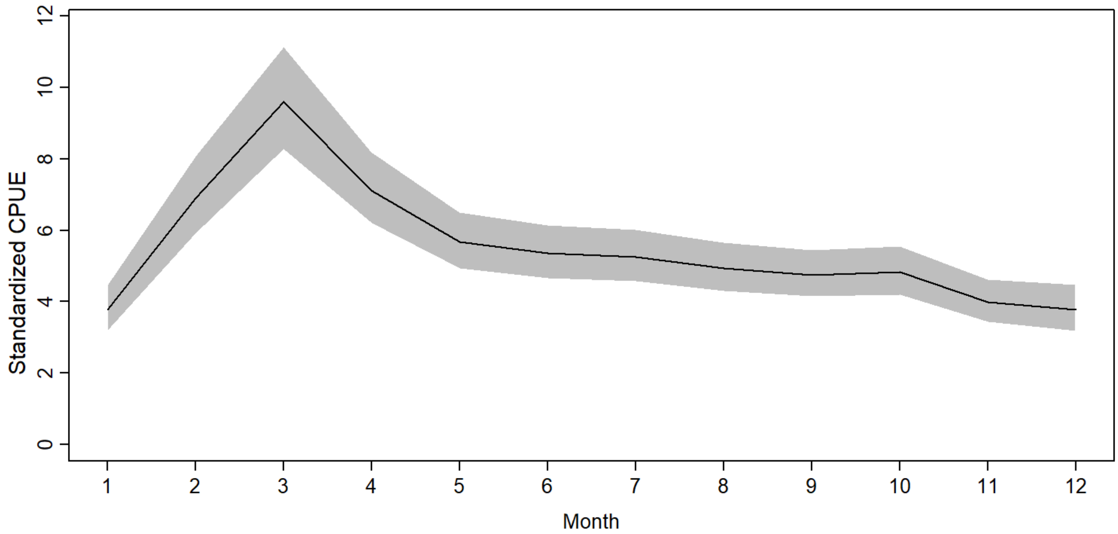


**Figure 3.** The influence of the fixed effects *Month* on the CPUE of blue sharks when modelled using the GAMM applied to the South African observer dataset on Japanese flagged vessel fishing under joint venture

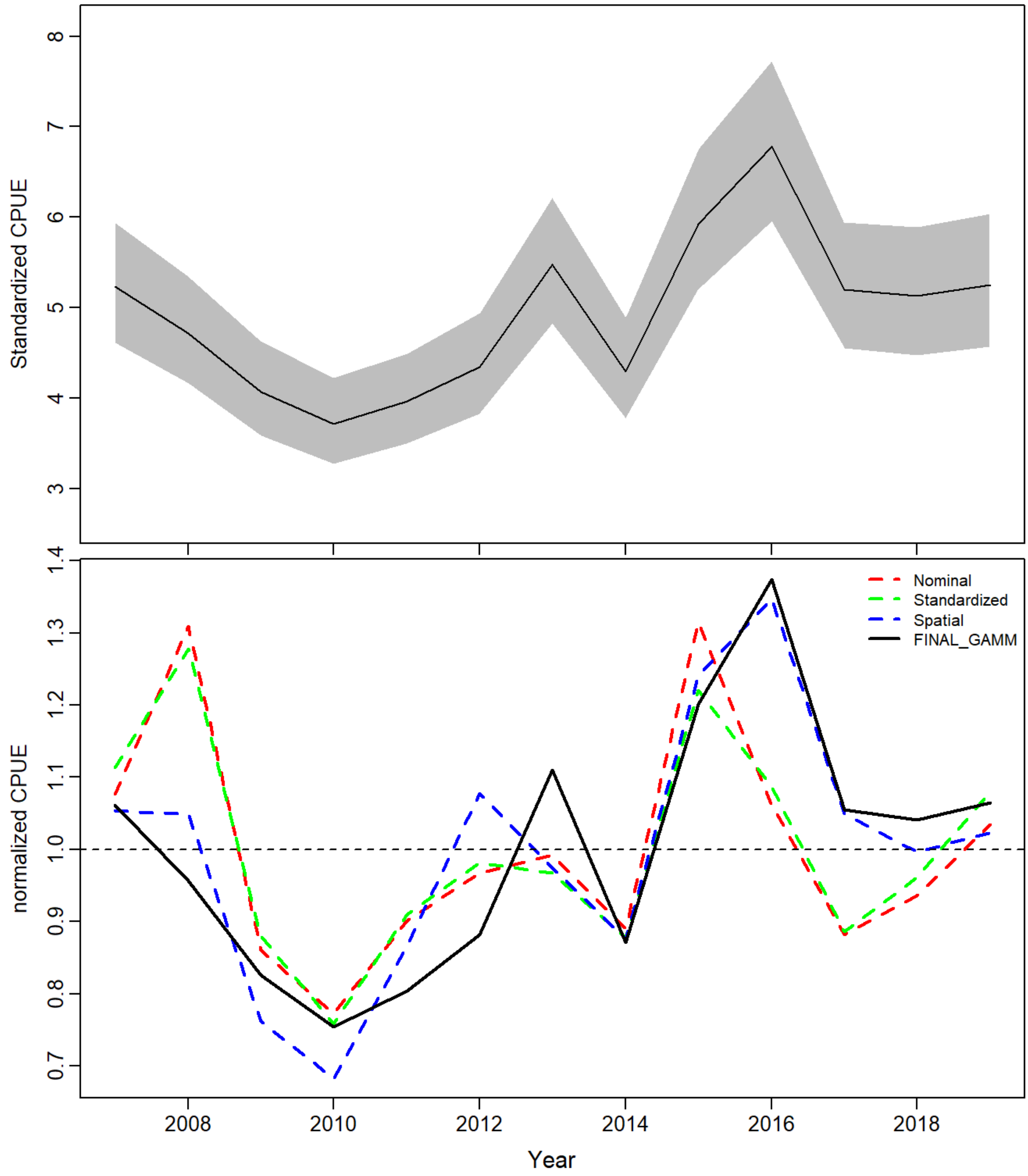


**Figure 4.** Standardized CPUE for blue sharks from the South African observer dataset on Japanese flagged vessels fishing under joint venture for the time period 2007 to 2019 (upper panel). The 95% confidence intervals for the nominal CPUE are denoted by grey shaded areas and comparison of nominal and the various standardized CPUE models (lower panel).

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