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SPATIAL AND TEMPORAL PATTERNS IN BLUE SHARK (*PRIONACE GLAUCA*) CATCH IN SOUTH AFRICAN LONGLINE FISHERIES

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Abstract

The blue shark is targeted in the pelagic shark-directed longline fishery and is a common bycatch in the tuna and swordfish directed fishery in South Africa. Of the total pelagic shark landings in South Africa, the blue shark comprised 35% of landed mass from 1998 to 2008. Spatio-temporal analyses on nominal, and standardised CPUE revealed seasonality, with greatest blue shark abundance during summer and autumn off the west coast of South Africa. Standardised CPUE for both fisheries revealed that blue shark abundance has remained relatively stable from 1998 to 2008. This is contradictory to findings reported from observer data from the tuna directed longline fishery, which found a significant reduction in CPUE from 2001 to 2005.

Keywords: standardised CPUE, abundance estimates, tuna and swordfish directed fisheries

Introduction

Fishery-dependant data can be used for stock assessments (Kilduff *et al.* 2009), and are typically used to calculate catch per unit effort (CPUE), which serves as an indicator of abundance (Hillborn & Walters 1992, Pikitch *et al.* 2008b). Analysis of CPUE data can reveal spatial and temporal trends in the abundance of a species. This information is useful in understanding the population structure and movement patterns of a species (Bonfil 1994, Latour 2005, Pikitch *et al.* 2008b).

Understanding the spatio-temporal trends in the abundance of a species can facilitate in mitigating the problems of bycatch, by identifying areas where there is a spatial overlap between target and non target species (Crowder & Myers 2001). Management plans can take into account these trends in abundance, and reduce bycatch by limiting fishing in areas or during particular seasons where the target species is abundant, and where non- target species are less frequently encountered (Crowder & Myers 2001, Hyrenbach *et al.* 2000).

Spatial information can also be used for conservation planning and the selection of closed areas or closed seasons (Pikitch *et al.* 2008b). In general, there is a lack of spatial information on pelagic shark abundance, as they are widespread and undergo vast migrations, often crossing international boundaries (Camhi *et al.* 2008). Although pelagic sharks are known to be among the most heavily impacted species by fishing, the lack of reliable fishery and biological data has resulted in very little effective management for open ocean sharks (Pikitch *et al.* 2008b).

The blue shark is the most commonly caught large, pelagic shark and forms a major bycatch species in the pelagic longline fishery targeting tuna and swordfish (Petersen 2009, Mandelmann *et al.* 2008). It is additionally a target species in a pelagic shark-directed longline fishery (Camhi 2008, Petersen 2009, Stevens *et al.* 2000). Bonfil (1994) estimated that over 6 million blue sharks are caught annually as bycatch in the longline fishery worldwide. However, this is likely to be an underestimate as shark catches are often under-reported by skippers and discards and landings are not adequately monitored (Camhi *et al.* 1998).

In South Africa a shark-directed fishery was initiated in 1991, subsequently effort in this fishery has declined rapidly. The decline in effort is associated with the Department of Agriculture, Forestry and Fisheries (DAFF) intention to terminate the pelagic shark-directed fishery (DEAT 2007). As the pelagic shark-directed fishery's gear operates in the same way as the tuna/swordfish-directed fishery, DAFF considered it more appropriate to manage these two fisheries under one sector, namely the large pelagics.

DAFF aimed to terminate the targeting of pelagic sharks by merging the shark-directed vessels into the tuna/swordfish-directed fishery. The introduction of the shark-directed vessels to the tuna-directed fishery has increased the number of right-holders. DAFF proposed increasing the total allowable effort from 30 vessels prior to 2005 to 50 vessels, of which 20 have been issued permits for swordfish and 30 for tuna-directed vessels (DEAT 2009). Pelagic shark catches are to be managed as a bycatch species, where catch is limited by an upper precautionary limit (UPCL) set to 2000 t dressed weight of sharks. Once the UPCL is reached the fishery is to close. The termination of the shark-directed fishery has been a prospect since 2005. However, seven vessels still have rights under exemption permits (DEAT 2009).

In the tuna-directed fishery an onboard observer programme has been established since 1998 (Smith 2007). Observers record all species caught, as well as the length frequencies of all tuna, billfishes and sharks. DAFF aims for 20% observer coverage of domestic vessels and 100% coverage of foreign vessels (Smith 2007). Observer data from the South African tuna-directed fishery was analysed by Petersen (2009). Petersen (2009) reported a decline in standardised CPUE for blue sharks from 2001 to 2005, as well as a decrease in average length of blue shark caught by this fishery.

The catches from these fisheries are monitored at all major landing sites (Cape Town, East London, Hout Bay, Port Elizabeth, Richards Bay and Saldanha Bay) (DEAT 2004).

The aim of this paper is to identify the spatial and temporal distribution of the blue shark in the South Atlantic and Indian oceans by analysing CPUE of this species within the shark-directed and tuna-directed fisheries. Additionally findings from this paper will be compared to those based on observer data analysed by Petersen (2009). This information can advise management authorities that address catch restrictions, and effort allocation as well as contributing information in the prioritisation of closed seasons/areas.

Methods

Landings data from the South African shark-directed and tuna-directed fisheries were obtained from the Department of Agriculture, Forestry and Fisheries (DAFF). Although data were available from 1992 for both fisheries, due to poor quality of earlier records, data from only 1998 until 2008 were analysed. These data comprised of details for each vessel within the fisheries, information included the date, time, start and end co-ordinates for the line, total number of hooks, and the total mass of species landed for each set.

Annual fishing effort for both fisheries was calculated in terms of the total number of vessels operating in each year and the total number of hooks set per year. Additionally the average number of hooks set per month was calculated for each fishery. The catch composition for each fishery was calculated as the average annual landed mass of a species, relative to the average annual landings for all species.

Spatial analysis

Catch per unit effort (CPUE) was calculated as the total mass (kilograms) of a species landed divided by the number of hooks per set. Sets with an unspecified number of hooks were excluded from the analyses.

Spatial and temporal trends in blue shark catch were plotted using GIS programme ArcMap 9.2. Annual and seasonal trends in nominal CPUE were spatially analysed by averaging data over 1^o latitude by 1^o longitude grid blocks. Blue shark bycatch ratios were calculated for the tuna-directed fishery by dividing the mass of blue shark landed by the total mass of tuna and swordfish landed per set. These values were averaged over each season and grid block.

CPUE values were used as an index of abundance, assuming that CPUE is proportional to population size.

$$CPUE = qN \tag{1}$$

where q is defined as the catchability coefficient, and N as the population size (Hillborn & Walters 1992).

However, the catchability coefficient may differ as a result of changes in vessel efficiency, as well as among areas and over time (Maunder & Punt 2004). The effects of these factors were removed to obtain CPUE that reflected true changes in population abundance, a process that is referred to as "catch-effort standardisation" (Maunder & Punt 2004).

Standardising CPUE records

A general linear model (GLM) was used to identify factors that may explain variations in CPUE, and to provide a standardised CPUE series (Maunder & Punt 2004).

The data were filtered to remove records that had missing information such as co-ordinate values, dates or vessel names. Vessels that had not fished for more than 5 years were also removed. Reducing the data to these vessels allowed for continuity of individual vessel performance records over at least half the period. Fishing areas were grouped into 5^{o} latitude by 5^{o} longitude grid blocks (Fig.1). Grid blocks with fewer than 100 records were removed from the analysis.

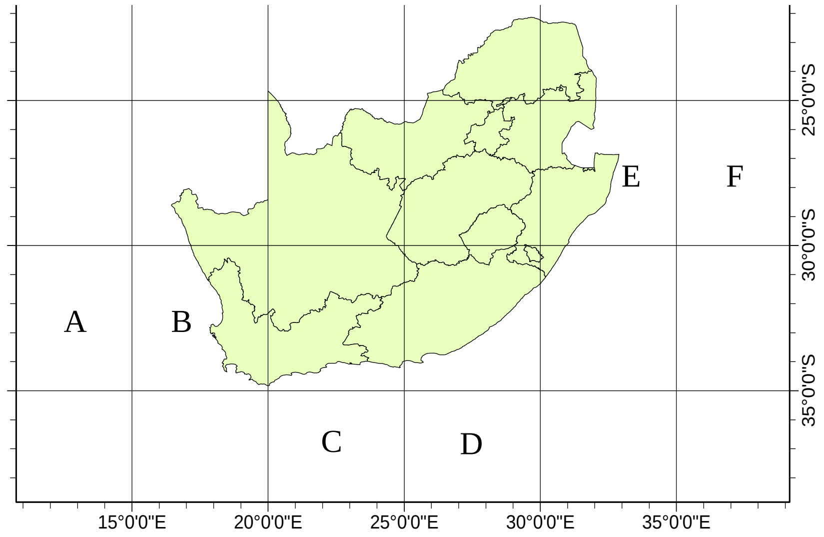


Figure 1. Location of areas used in GLM analysis. Areas B, C and D were used for the shark-directed data set, while areas A to F were used for the tuna-directed analysis.

Explanatory variables included in the GLM were year, month, grid block and vessel name, all of which were included as categorical factors. The full model is given below,

$$ln(CPUE_i + c) = \beta_0 + \beta_t + \beta_m + \beta_v + \beta_a + \in_i \tag{2}$$

where c is the constant, β_0 the intercept, β the set of coefficients for each effect, t the year effect, m the month effect, v the vessel effect, a the area effect (grid blocks: B – D) and $\in$ the error term.

The GLM fitted to the shark-directed CPUE data used a log-normal residual structure. A constant was added to allow for the transformation of zero values. Studies have suggested adding constant values such as 1, 10% of the overall CPUE mean (Campbell *et al.* 1996) or 10 times the largest CPUE value (Maunder & Punt 2004, Porch & Scott 1994). Berry (1987) proposed a solution to this problem, developing an algorithm which calculates a constant that reduces the kurtosis and skewness of the data, resulting in normally distributed residuals. Using Berry's algorithm a constant of 0.1186 was added to each CPUE value.

The percent explained deviance was calculated for each successive factor added to the model using the equation,

$$\%\ explained\ deviance = \frac{null\ deviance - residual\ \ deviance}{null\ deviance} \times 100 \quad (3)$$

The model with the lowest Akaike Information Criterion (AIC) (Akaike 1974) was chosen as the best supported model.

Standardised CPUE time series was calculated for a reference set of the factors by applying the fitted model. The median of the month and area, and the vessel with the most records were chosen as reference values (year - 2008, month - December, vessel - A, grid block - D (Fig. 1).

A standardised CPUE series was calculated for each factor. For example, a standardised CPUE series for the year factor was calculated as,

$$CPUE_t = exp(\beta_0 + \beta_t + \beta_A + \beta_{Dec} + \beta_D) \quad (4)$$

where β_0 is the intercept, β_t the estimate of the year factor for year *t*, β_A the estimate for vessel A, β_{Dec} the estimate for the month December, and β_D the estimate for area D.

The variance for year *t* was calculated by summing the variance of year *t*, the variance of the intercept and the variance for each reference factor. The variance of the base year (1998) was calculated as the average variance for the years 1999 to 2008.

Standardising the catch values for the tuna-directed fishery data set was more complicated, as 57% of the CPUE values were zero. To overcome this, a hurdle a model consisting of two parts was used to overcome the high number of zero values (Zuur *et al.* 2009). The first part modelled the probability of obtaining a positive value using a binomial distribution, while the second part modelled only the positive values, using a normal distribution. This process is referred to as the delta-lognormal-approach (Lo *et al*. 1992).

Categorical factors included in the model were year, month, area (5^o by 5^o grid block) and vessel name. The equation for the lognormal model is given below,

$$ln(CPUE_i) = \beta_0 + \beta_t + \beta_m + \beta_v + \beta_a + \in_i \qquad (5)$$

where β_0 is the intercept, t the year effect, m the month effect, v the vessel effect, a the area effect (grid blocks: A - F) and $\in$ the error term.

The percent explained deviance was calculated for each successive factor added to the model using equation 4.3. The model with the lowest Akaike Information Criterion (AIC) was chosen as the best fit.

A standardised CPUE series for the tuna-directed data was calculated from a reference set (year - 2002, month - December, vessel - A, grid block - G). For example, the year effect was calculated as the probability of obtaining a positive CPUE value for year t, multiplied by the predicted catch rate for year t. The probability of a catch was calculated using the following equation,

$$P_t = \frac{exp(\beta_0 + \beta_t + \beta_{Dec} + \beta_A + \beta_G)}{1 + exp(\beta_0 + \beta_t + \beta_{Dec} + \beta_A + \beta_G)} \qquad (6)$$

where P_t is the probability of a positive catch during year t, β_0 is the intercept, β_t the year estimate year t, β_{Dec} the estimate for the month December, β_A the estimate for vessel A, β_G the estimate for area G.

To calculate variance estimates required the re-running of the GLM using a bootstrap or jacknife procedure. This was computationally too intensive and as a result no variances were calculated for the hurdle model (Maunder & Punt 2004).

GLM's were executed in the R 2.10 programming environment (R Development Core Team 2008).

Results

Annual and seasonal fishing effort

The total number of vessels active in the shark-directed fishery ranged from 20 in 2000 to only 4 in 2008 (Fig. 2). The greatest number of hooks (0.4 million) were set in 2007, and a minimum of 0.09 million hooks in 2001. Although the number of shark-directed vessels fluctuated considerably, the number of hooks set per year has remained relatively consistent.

The total number of vessels in the tuna fishery ranged from 15 in 1999/2006 to 29 in 2007, with the number of hooks ranging between 0.5 to 4.5 million. Effort in the tuna-directed fishery was considerably greater with more vessels and a greater number of hooks set compared to the shark fishery.

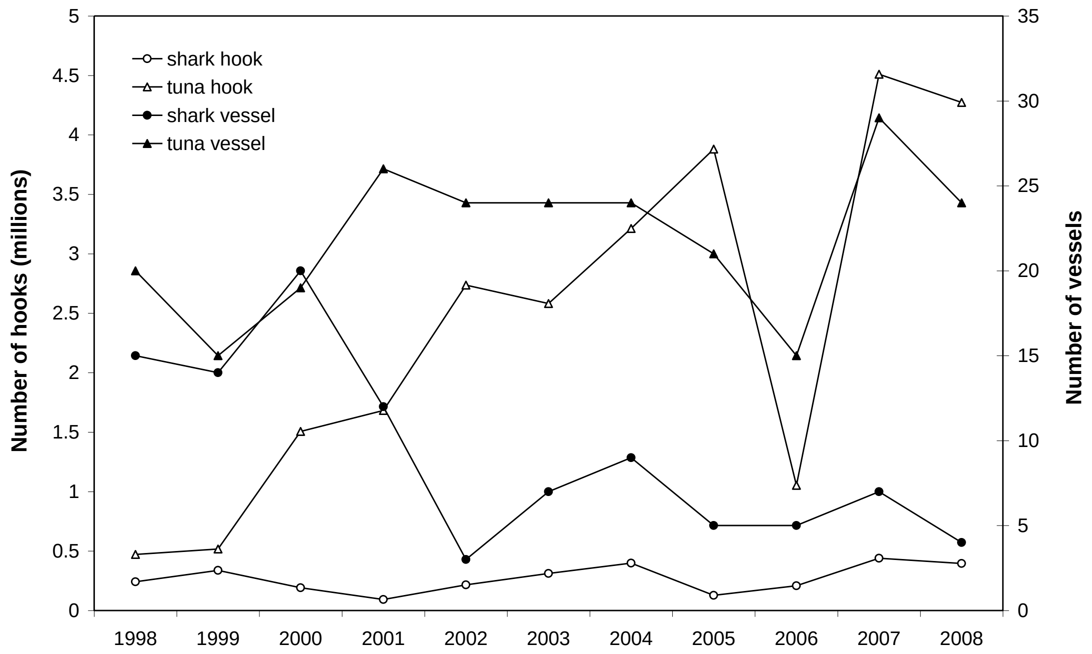


Figure 2. Number of hooks and number of vessels per year for the South African shark-directed and tuna-directed fisheries (1998-2008).

The average number of hooks deployed per month for the shark-directed fishery ranged from 877 and 1310 in July and June respectively (Fig. 3). There was no seasonal trend in effort, as the average number of hooks set in summer and winter did not differ considerably (1020 and 1028 respectively).

In the tuna-directed fishery the greatest number of hooks were set in September (1979), and the least set in March (1471). The tuna-directed fishery had a stronger seasonal trend in effort, with significantly more hooks set during the winter months (July – September) (df = 3, F = 260.91, $p < 0.001$).

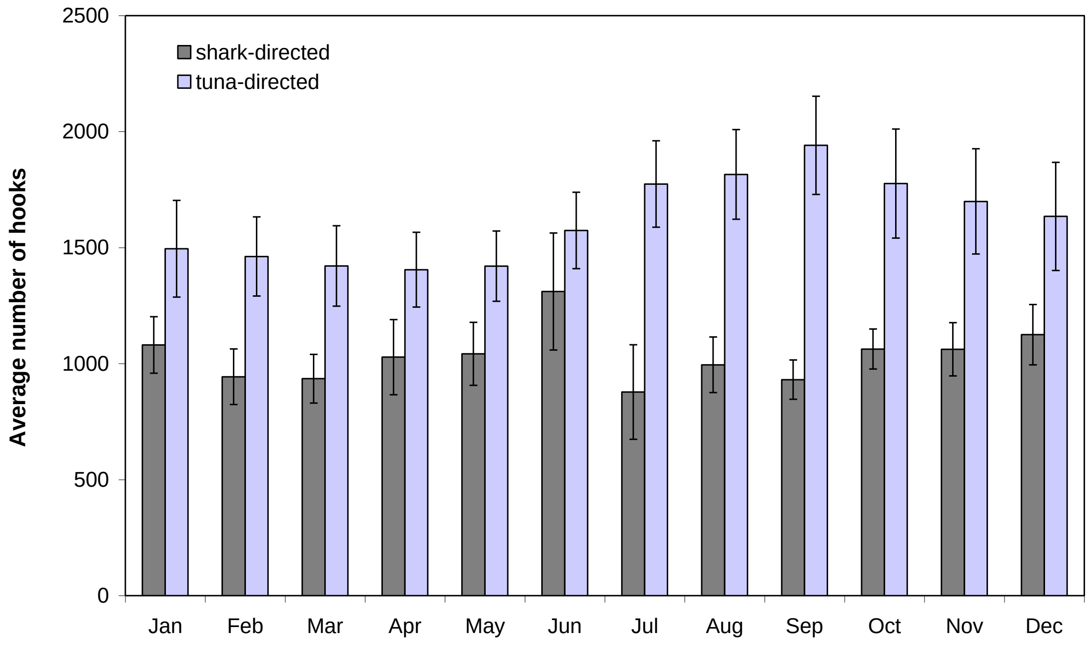


Figure 3. Average number of hooks sets per month and associated standard error for the shark-directed and tuna-directed fisheries in South Africa (1998-2008).

The average number of hooks set per grid block ranged from 400 to 2886 for the shark-directed fishery (Fig. 4). The majority of the grid blocks for the shark-directed fishery had on average 800 to 1600 hooks set, with most of the effort concentrated in the South Atlantic Ocean (west of 20^{o} east).

The average number of hooks set per grid block ranged from 460 to 3776 for the tuna-directed fishery. Although effort in the tuna fishery occurred over a greater spatial range compared to the shark-directed fishery, effort was concentrated in the Indian Ocean. Many of the grid blocks in the Indian Ocean had over 2400 hooks set within them, with effort concentrated along and around the Agulhas Bank, as well as over areas associated with seamounts.

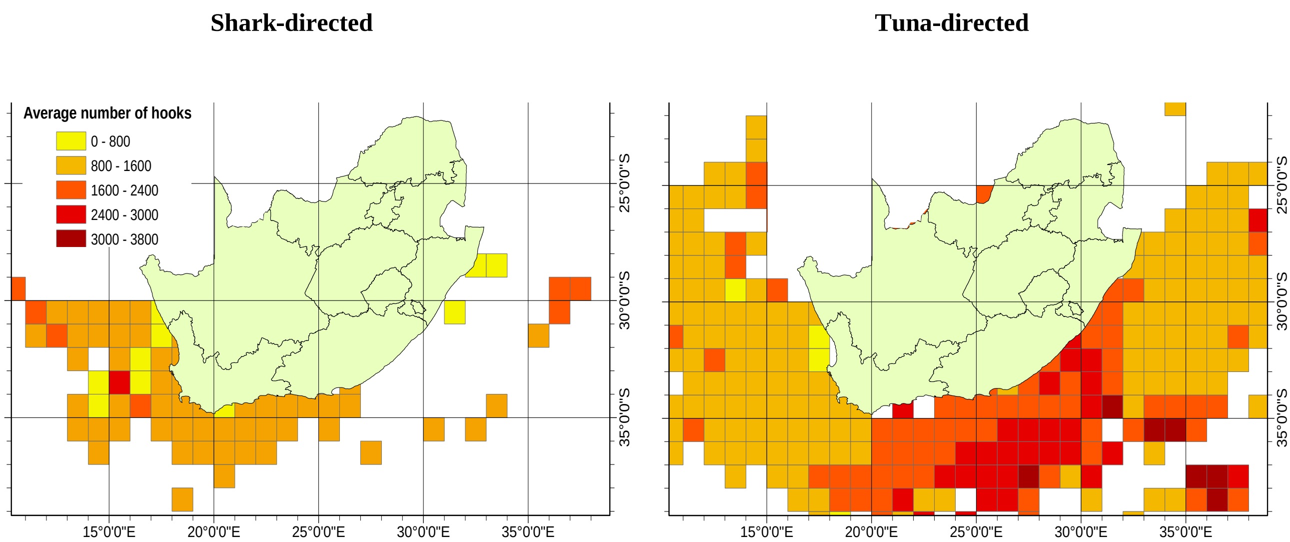


Figure 4. Average number of hooks set per grid block for the shark-directed and tuna-directed fisheries in South Africa (1998-2008).

Catch composition

Four species of shark were caught in the shark and tuna-directed fisheries, with the blue (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) shark dominating the shark catch in both fisheries (Table 1.).

The blue shark and the shortfin mako shark comprised 23.79% and 69.92% of the total average landed mass in the shark-directed fishery. In the tuna directed fishery the bulk of the catch was comprised of target species; yellowfin (*Thunnus albacores*), longfin (*T. alalunga*), bigeye tuna (*T. obesus*) (a combined total of 57.04%) and swordfish (*Xiphias gladius*) (33.62%).

The blue and shortfin mako shark comprised 6.02 % and 2.77 % of the average annual landed mass of catch in the tuna-directed fishery. Thresher sharks comprised less than 1% of the total shark catch for both fisheries. Both fisheries landed comparable amounts of blue shark, with the shark and tuna fishery landing an average annual mass of 80898 ± 123.17 and 70875 ± 41.06 kilograms of blue shark respectively, despite the effort in the tuna-directed fishery being greater.

Table 1. The average annual landed mass of species caught in the South African shark and tuna-directed fishery (1998-2008).

Species	**Average Annual Landed Mass**		**% Composition**	
	Shark Directed	**Tuna Directed**	**Shark Directed**	**Tuna Directed**
Blue shark (*Prionace glauca*)	80898	70875	23.79	6.03
Mako shark (*Isurus oxyrinchus*)	237762	32554	69.92	2.77
Thresher shark (*Alopias superciliosus*)	2241	976	0.66	0.08
Carcharhinus spp	7002	13	2.06	0
Unidentified shark		5382		0.46
Tuna (*Thunnus spp*.)	12146	670184	3.57	57.04
Swordfish (*Xiphias gladius*)	2716	395011	0.8	33.62

The highest percent of blue shark catch for both fisheries was found in area B (between 30 ^{o} – 35 ^{o} S and 15 ^{o} – 20 ^{o} E) (Fig. 5). In this area, blue shark catches contributed over 80% of the landed mass for the shark-directed fishery and over 20% for the tuna-directed fishery. For both fisheries the blue shark comprised more of the catch in terms of mass in the South Atlantic Ocean (preceding 20^{o} E), than in the Indian Ocean. The amount of blue shark landed per area was considerably less in the tuna fishery compared to the shark fishery.

Shark-directed **Tuna-directed**

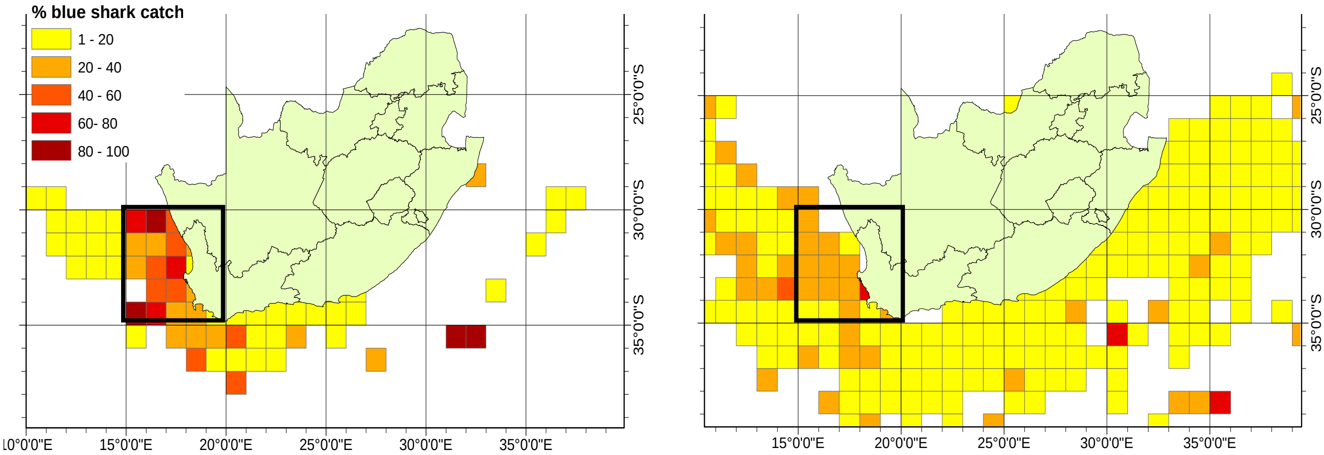


Figure 5. The annual average landed mass of blue shark in the shark and tuna-directed fisheries (1998-2008) (Area B outlined in bold).

Spatial and temporal trends in blue shark CPUE

Blue shark CPUE ranged from 0.01 to 1.43 kilograms per hook in the shark-directed fishery (Fig. 6). Grid blocks with the highest CPUE were found in area B, whereas lowest CPUE occurred in grid blocks of area A (Fig. 1). It is apparent that blue shark CPUE are considerably lower in the Indian Ocean for the shark-directed fishery, as there were few grid blocks with a CPUE over 0.3 kg/hook within this area.

Blue shark CPUE ranged from 0.001 to 0.65 kg/hook in the tuna-directed fishery. Grid blocks with the highest CPUE were found in area B (similarly to the shark-directed fishery). Although the average blue shark CPUE was much lower within all grid blocks compared to the shark-directed fishery, blue shark CPUE for the tuna-directed fishery occurred over a greater spatial range.

Shark-directed **Tuna-directed**

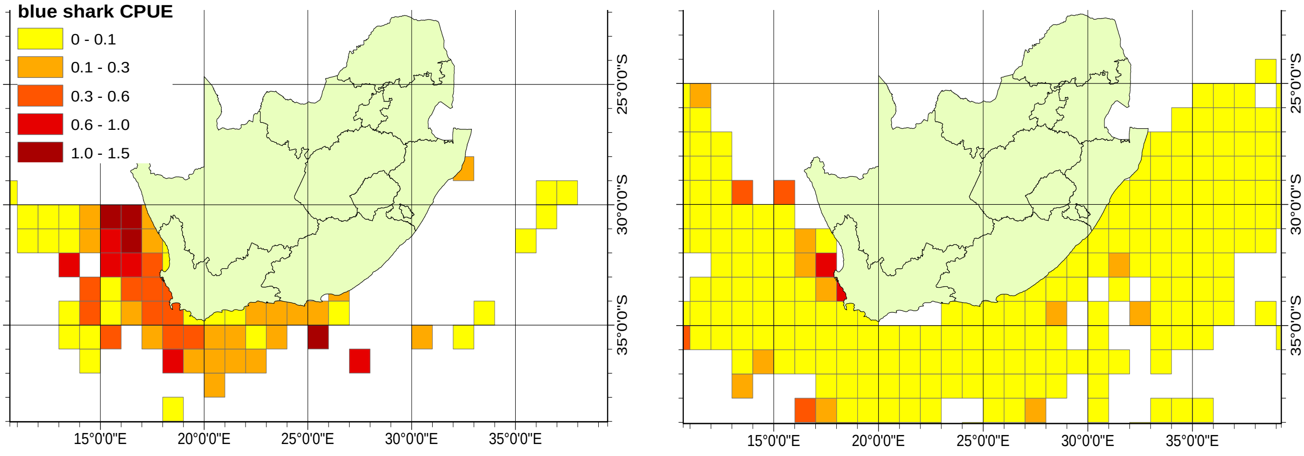


Figure 6. The average blue shark CPUE for the South African shark-directed and tuna-directed fisheries (1998-2008)

The average blue shark CPUE by season ranged from 0.0066 and 4.5 kg/hook in spring and winter for the shark-directed fishery (Fig. 7). Grid blocks with the highest CPUE occurred during autumn and summer along the west coast of South Africa (area B). During summer CPUE records were evident in grid blocks within the Indian Ocean, occurring as far as 38 ^{o} E. The lowest CPUE was in spring and winter, with many grid blocks with CPUE lower than 0.5 kg/hook. Additionally grid blocks for these 2 seasons occurred over a smaller spatial range, occurring no further than 23^{o} E.

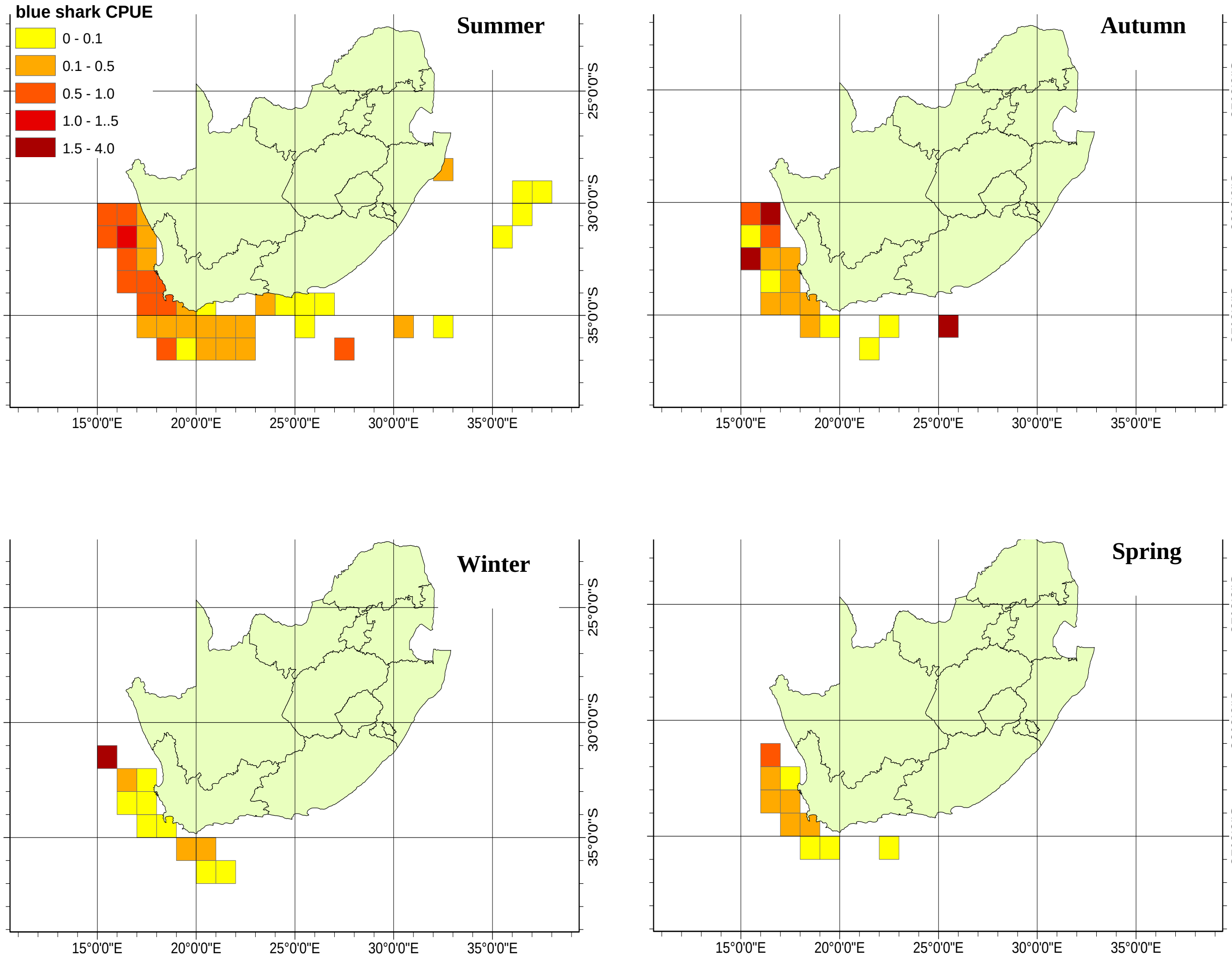
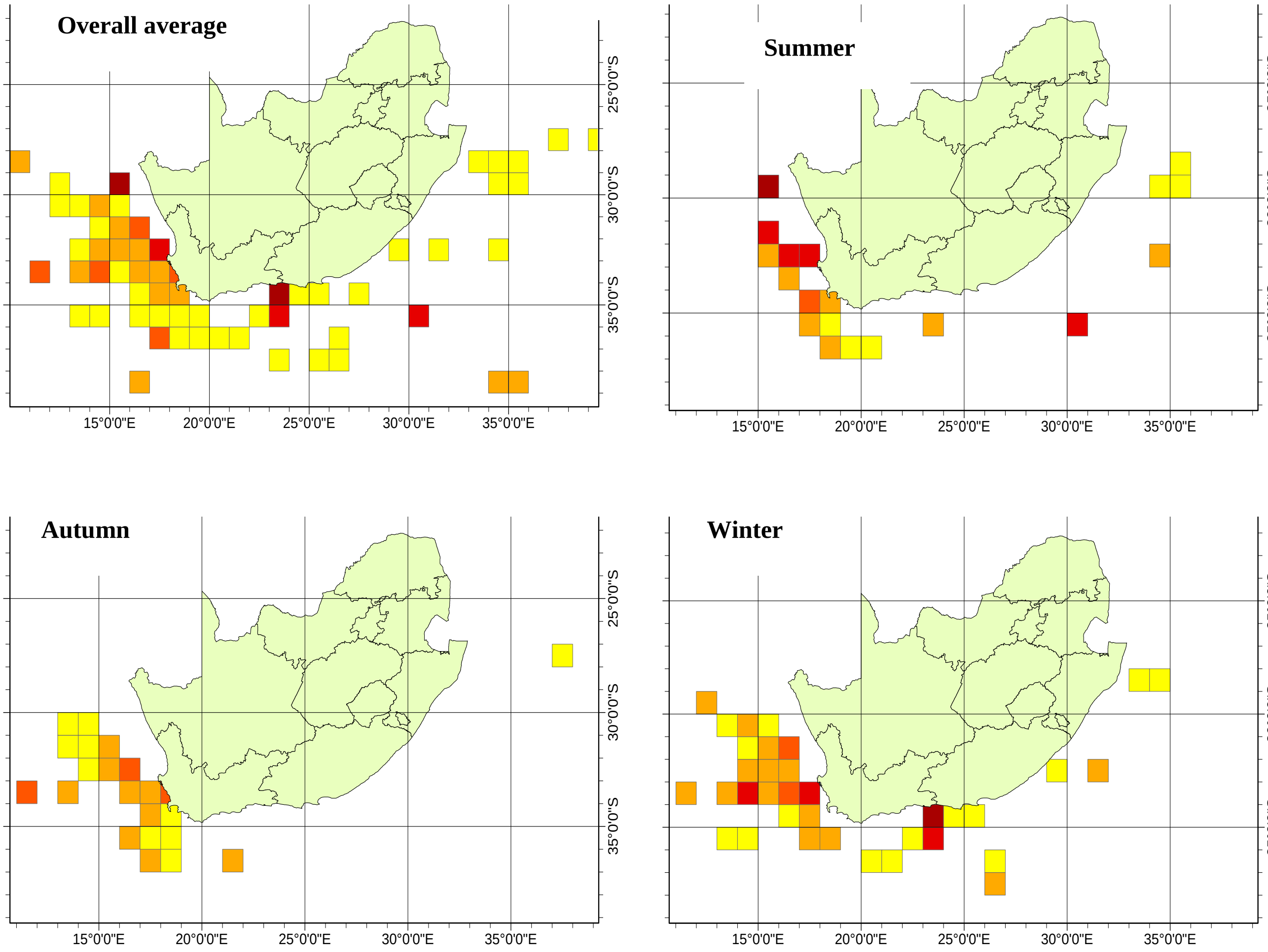
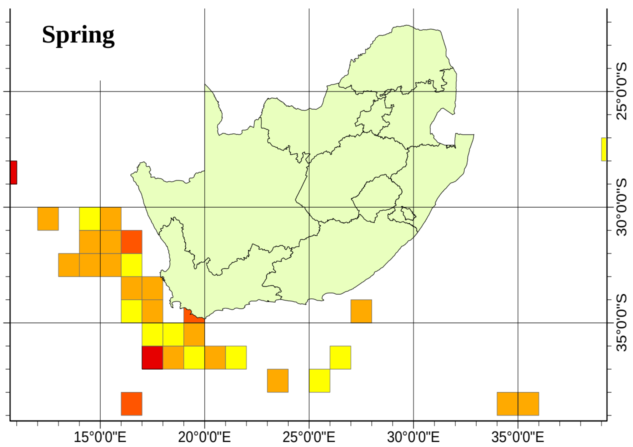


Figure 7. Seasonal trends in the average blue shark CPUE in the South African shark-directed fishery (1998-2008).

Blue shark to tuna catch ratios in the tuna-directed fishery ranged from 0.005 to 24.00 in spring and summer respectively (Fig. 8). For all seasons the greatest bycatch ratio occurred within area B. There was a high proportion of blue shark bycatch in both summer and winter, as several grid blocks had bycatch ratios greater than 1. Blue shark bycatch was lowest during autumn with 40 % of the grid blocks with a ratio less than 0.5. The combined plot of blue shark to tuna catch ratio for years 1998 to 2008, reveal that area B, as well as a few localities throughout the Indian Ocean had a bycatch ratio greater than 0.5.





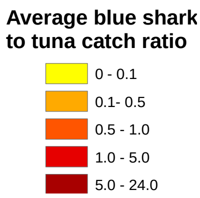


Figure 4.8. Average seasonal blue shark bycatch to tuna catch ratios in the South African tuna-directed fishery (1998 -2008).

Standardised CPUE

Standardised CPUE for the blue shark were calculated for the shark-directed landings data from 1998 to 2008 using the results from the GLM. All the effects within the analysis were significant. The model explained 49% of the observed variability, with the vessel effect contributing the greatest proportion of the explained variance (17%) (Table 2.).

Table 2: Results of analysis of deviance of explanatory factors in the GLM for the shark-directed data (1998-2008). Factors were sequentially added to the model.

Model no.	Model structure	DF	AIC	Explained deviance	F value	p value
1	Year	10	5371	14	48.41	< 0.001
2	Month	11	5213	22	25.33	< 0.001
3	Area	2	4991	32	156.38	< 0.001
4	Vessel	8	4528	49	50.23	< 0.001

The residuals were normally distributed and a quantile-quantile plot illustrated that they did not differ greatly from those of a normal distribution (Fig. 9), thereby satisfying model assumptions

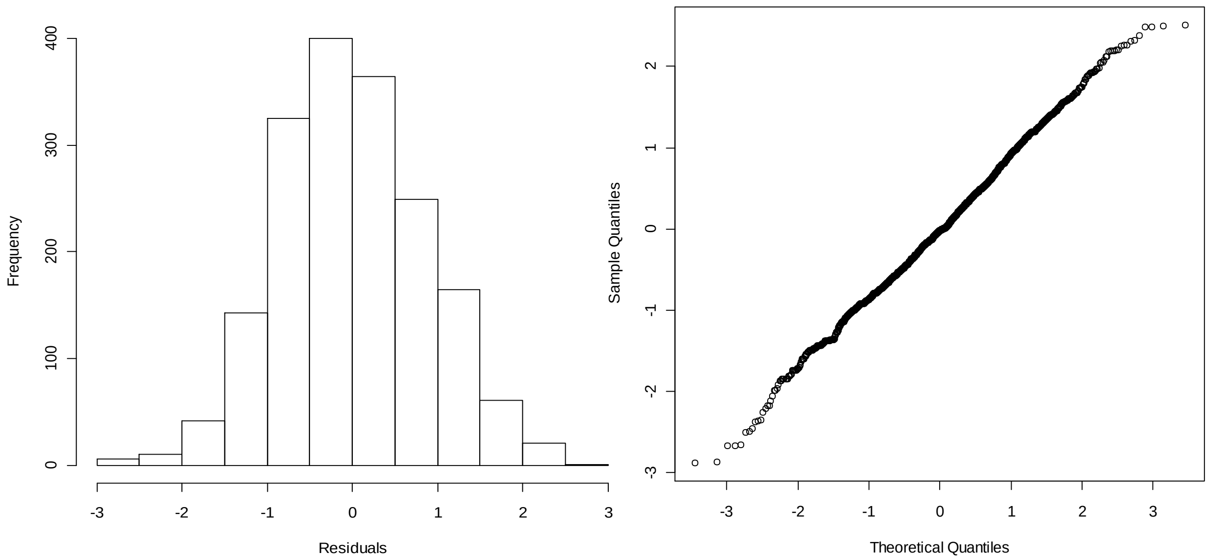


Figure 9. Histogram and quantile-quantile plot of the residuals for the final model selected as the best fit to the South African shark-directed CPUE data (1998-2008).

Annual standardised CPUE ranged from 0.07 to 0.18 kilograms of blue shark per hook in 1999 and 2003 respectively (Fig.10). The year factor accounted for 14% of the observed variability (Table 2.).

While there is no apparent trend in annual blue shark CPUE, there is a strong seasonal effect in blue shark CPUE (Fig. 11). CPUE were at the highest during the summer months of January (0.18 kg/hook), February (0.19 kg/hook) and March (0.17 kg/hook), with CPUE steadily decreasing from May to the lowest value in August (0.06 kg/hook). From September onwards CPUE remained relatively constant until December.

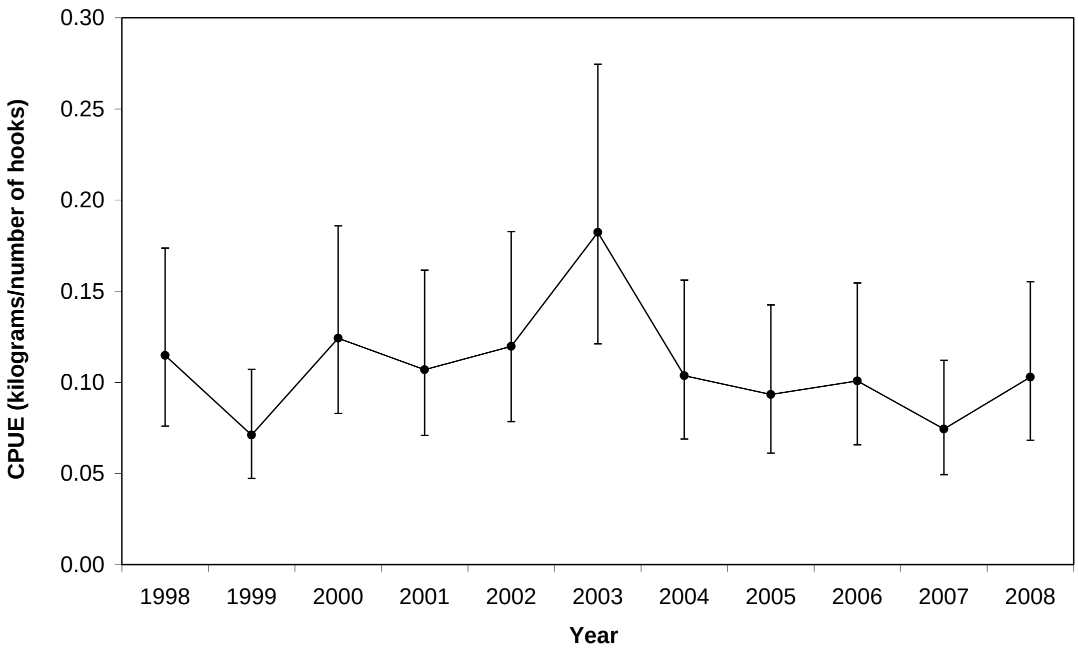


Figure 10. Annual standardised catch per unit effort (CPUE) and associated 95% confidence intervals for the blue shark from the South African shark-directed data (1998-2008) (Reference set: month - December, vessel - A, area - D).

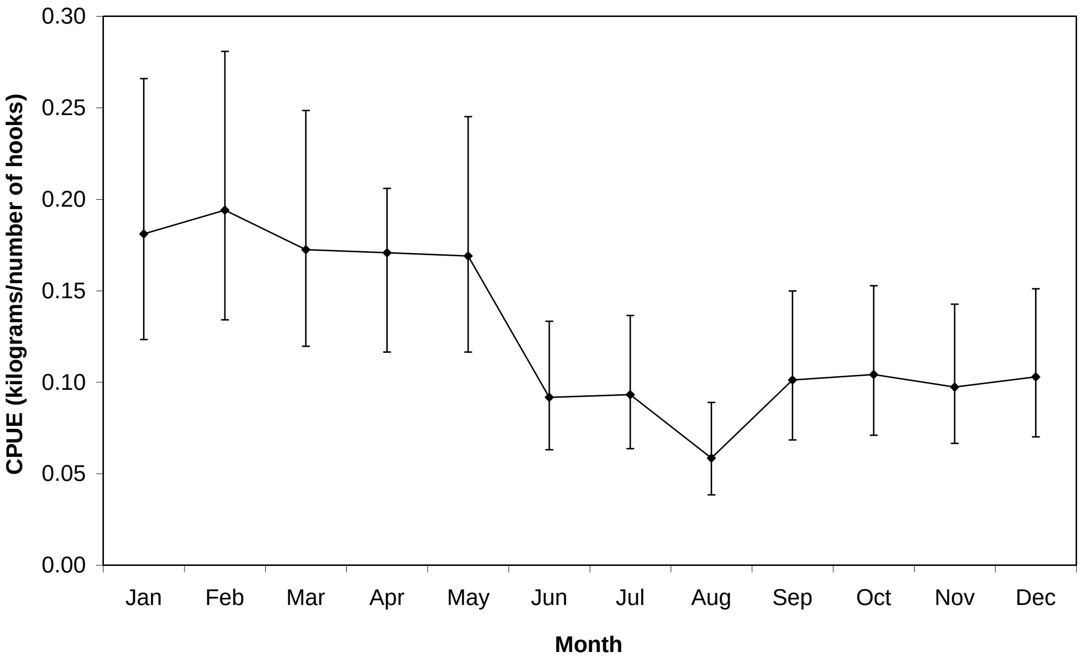


Figure 11. Monthly standardised catch per unit effort (CPUE) and associated 95% confidence intervals for the blue shark from the South African shark-directed data (1998-2008) (Reference set: year - 2008, vessel - A, area - D).

Standardised blue shark CPUE for the shark-directed fishery by area revealed that there was a slight difference in the mass of blue shark landed per hook within each fishing area (Fig. 12) The highest CPUE of 0.10 kg/hook occurred in area B, followed by area D (0.09 kg/hook) and area C with the lowest value of 0.05 kg/hook.

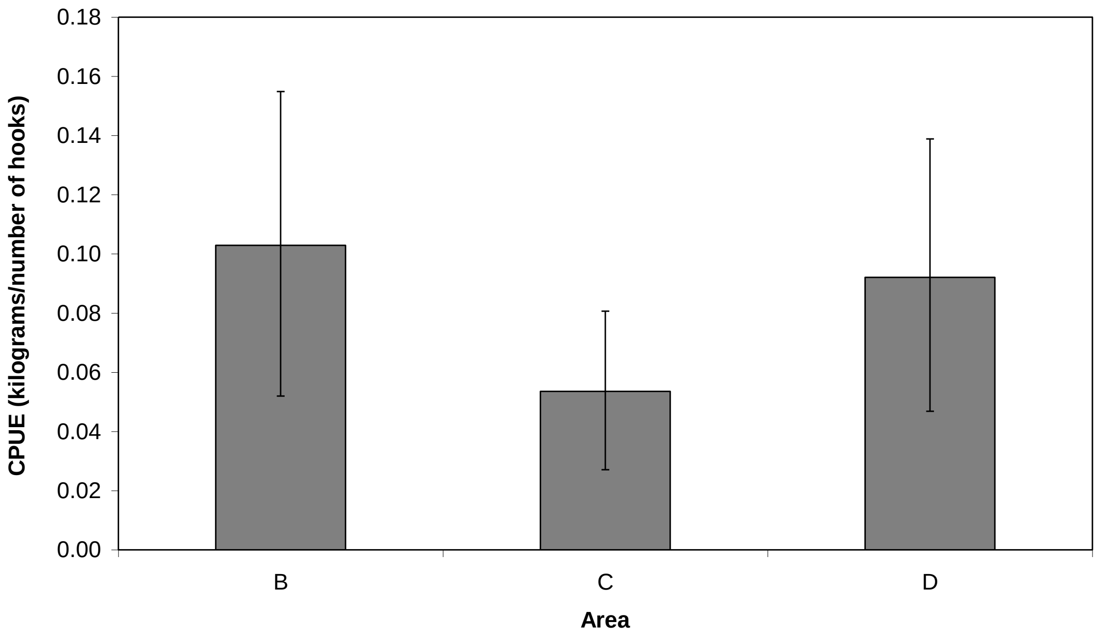


Figure 12. Standardised CPUE by area for the South African shark-directed fishery and associated 95% confidence intervals (1998-2008) (Reference set: year - 2008, month - December, vessel - A).

All factors included in the GLM fitted to the tuna-directed data were significant (p values < 0.001) (Table.3). The final model explained 44% of the observed variation. The area factor contributed the greatest proportion to the explained deviance (21%), followed by the year (12%) and vessel (8%) factor.

Table 3: Results of analysis of deviance of the explanatory factors in the GLM for the tuna-directed data (1998-2008). Factors were sequentially added to the model.

Model no.	Model structure	DF	AIC	Explained deviance	F value	p value
1	Year	10	4511	12	20.98	< 0.001
2	Month	11	4484	15	12.59	< 0.001
3	Area	5	4060	36	32.43	< 0.001
4	Vessel	13	3891	44	29.58	< 0.001

A histogram of the residuals reveal that were normally distributed and a quantile-quantile plot indicated that the distribution of the model's residuals were not skewed from a normal distribution (Fig. 13), therefore satisfying model assumptions.

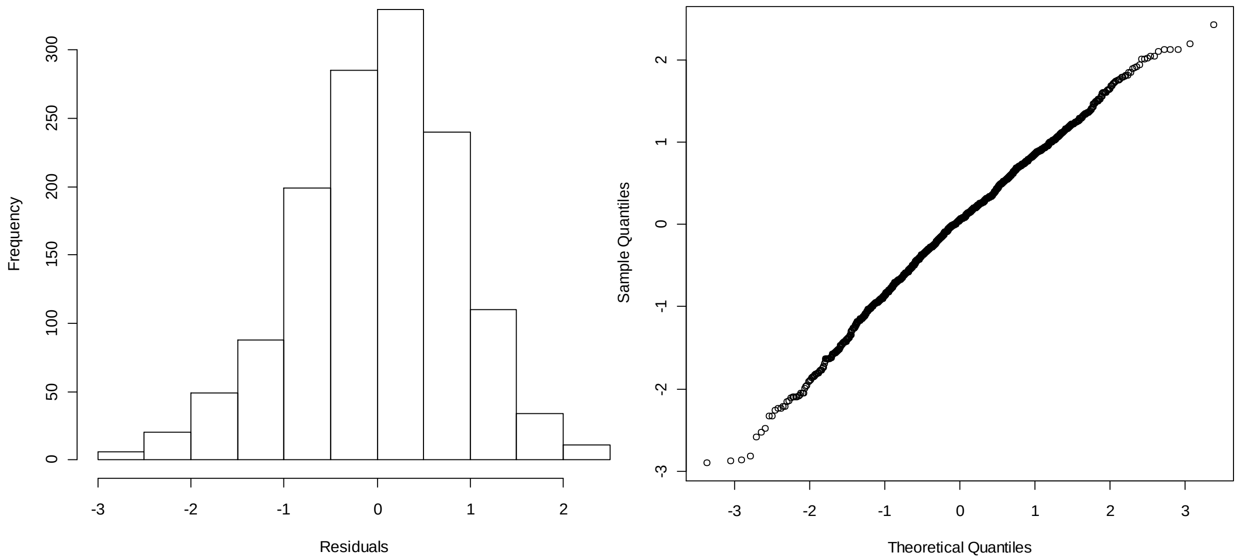


Figure 13. Histogram and quantile-quantile plot of the residuals for the final model selected as the best fit to the South African tuna-directed CPUE data (1998-2008).

Blue shark CPUE in the tuna-directed fishery ranged from 0.0017 to 0.0178 kg/hook in 1999 and 2004 respectively (Fig. 14). Annual blue shark CPUE remained steady from 1998 until 2001. From 2002 there was sharp increase in CPUE, with a peak in 2004. From 2004 onwards blue shark CPUE decreased rapidly to levels comparable to CPUE in 2002. The tuna-directed fishery had considerably smaller CPUE compared to the shark-directed fishery.

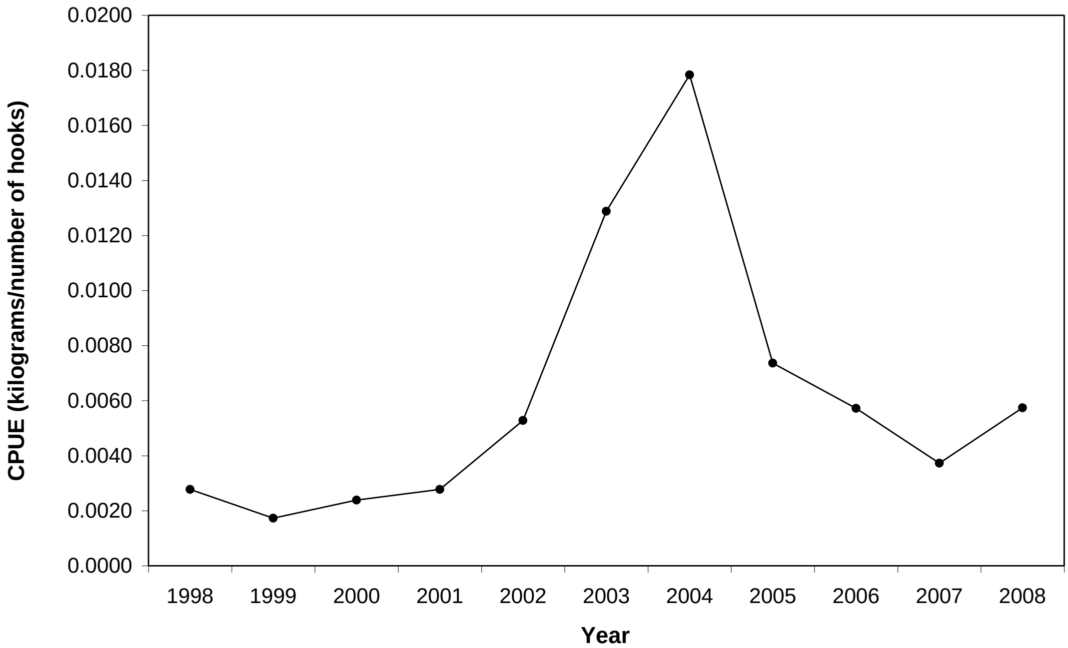


Figure 14. Yearly standardised catch per unit effort (CPUE) for the South African tuna directed fishery (1998-2008) (Reference set: month - December, vessel - A, area - G).

Standardised monthly blue shark CPUE for the tuna-directed fishery ranged from 0.0046 kg/hook in March and 0.013 kg/hook in July (Fig. 15). The highest CPUE occurred during July and August. These results are contradictory to the results of the shark-directed fishery which had the lowest CPUE during these two months.
There was no clear seasonal trend in blue shark CPUE in the tuna-directed fishery, as CPUE fluctuated greatly from January until June.

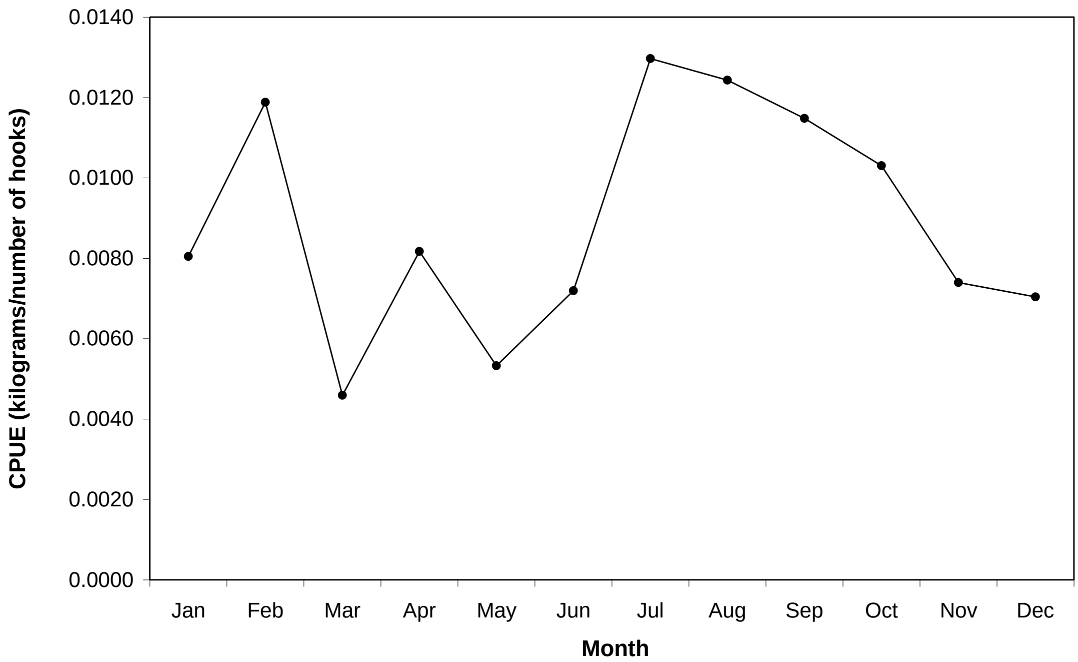


Figure 15. Monthly standardised catch per unit effort (CPUE) for the tuna directed fishery (1998-2008) (Reference set – year 2002, vessel A, Area G).

Standardised CPUE series by area revealed that area B (0.000019 kg/hook) had the highest blue shark CPUE, followed by area A (0.000012 kg/hook), both areas are located in the South Atlantic Ocean (Fig. 16). All areas in the Indian Ocean had considerably lower CPUE (CPUE < 0.000001 kg/hook).

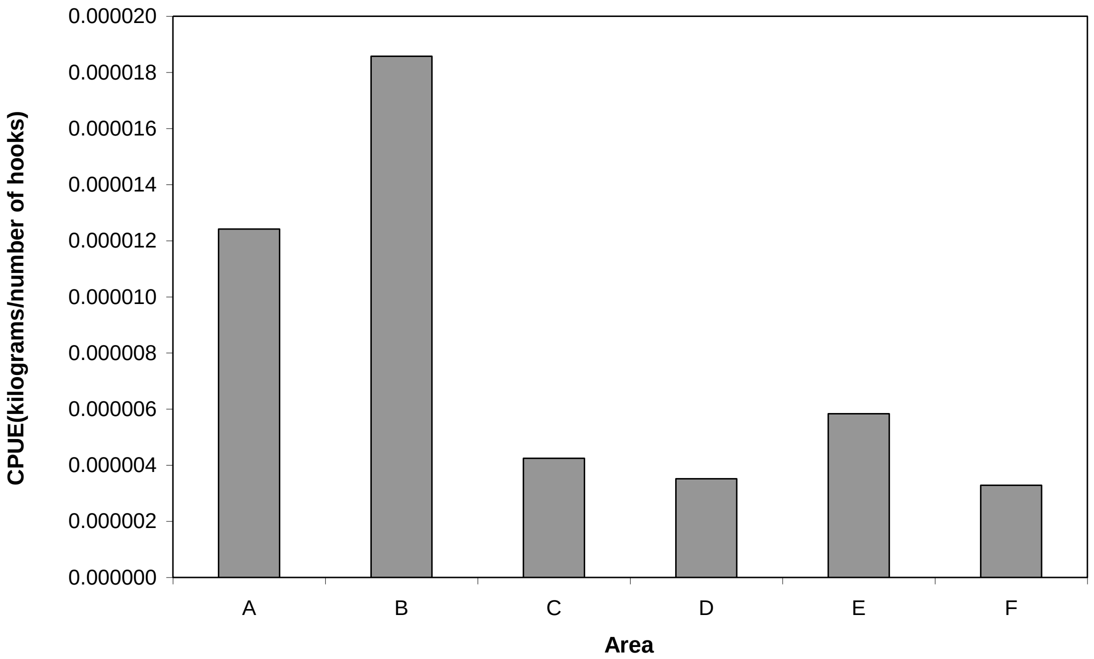


Figure 16. Standardised CPUE by area for the South African tuna-directed fishery (1998-2008) (Reference set: year - 2002, month - December, vessel - A).

Discussion

Annual and seasonal effort in the South African longline fisheries

The sharp decline in effort in 2006 in the tuna-directed fishery coincides with the termination of Asian-flagged vessels operating as charters, resulting in fewer vessels operating in this year (DEAT 2007). The policy for foreign flagged vessels operating in South Africa was again revised in 2007, where these vessels were allowed to operate under a one year trial period. During this period foreign vessels were obligated to transfer skills as well reflagging their vessel (DEAT 2007). This change in policy explains the rapid increase in the number of vessels operating within this year.

The shark-directed fishery revealed no seasonality in the number of hooks deployed. However, this fishery focussed most of their effort within the South Atlantic Ocean, while the tuna-directed fishery set most of their hooks during winter within the Indian Ocean. The seasonality and area in which effort is applied is likely to be related to the targeting of particular species. Penney & Griffiths (1998) reported that bluefin tuna comprises a greater proportion of the catch in winter, while yellowfin and albacore are in greater abundance in summer (Penney *et al.* 1992). The preferential setting of hooks in the Indian Ocean is possibly as a result of the targeting of yellowfin tuna and swordfish, as higher catches are associated with the warmer water of the Agulhas current (Sauer *et al.* 2003). Fishing effort within the Indian Ocean only increased from 2002, as ice and processing facilities were developed in Richards Bay. It has since become an important area for commercial fishing activities (Smith 2007).

Magnitude of shark catches

In 2002, approximately 39 500 t of pelagic sharks were landed worldwide, the blue shark comprised 59 % of this mass (Camhi *et al.* 2008). Pelagic shark landings from the South African shark and tuna-directed fisheries contribute approximately 1% of the worldwide landings of pelagic sharks.

Of the total pelagic shark landings in South Africa, the blue shark comprised 35% of the landed mass, revealing that this species is an important catch in both fisheries. Both fisheries land comparable mass of blue sharks, despite the tuna fishery applying greater fishing effort. This is as a result of shark bycatch restrictions set for the tuna-directed fishery, where by the shark bycatch cannot exceed 10% of the total mass of tuna landed (MCM 2008).

The shark-directed fishery landed three times the amount of shortfin mako relative to blue shark, suggesting that this species is the primary target in this sector. This is not surprising as the meat from the shortfin mako is of extremely high quality, and therefore in great demand (Vannuccini 1999).

The proposal of managing these two fisheries under one sector and the subsequent increase in effort, with the regulating of sharks as a bycatch species by the implementation of the UPCL of 2000 t, is concerning. In 2007, approximately 774 t of pelagic sharks were caught in both fisheries, with a combined effort of 35 vessels. The proposed UPCL is 2.5 times greater than the pelagic shark catch in 2007.

It is understandable to set a relatively high UPCL in the initial stages of the merge in order to allow new entrants the opportunity to improve their ability to target swordfish and tuna. However, such a high UPCL may undermine the ability to manage shark catches, as it may encourage vessels to land sharks rather than releasing them alive.

Distribution of blue shark catches

Spatial and temporal analyses on nominal CPUE, found the highest blue shark CPUE off the west coast of South Africa, as well as a several areas in the Indian Ocean. In general blue shark CPUE is higher in the South Atlantic Ocean. The high CPUE suggest that these particular areas have relatively high blue shark abundance. This spatial pattern in blue shark CPUE is additionally reflected in the standardised CPUE series by area, where blue shark CPUE was highest in area B which is situated in the South Atlantic, and declined rapidly from areas C to F which are located in the Indian Ocean (Fig. 1).

High CPUE off the west coast of South Africa may be expected as grid blocks with high values are associated with the Tripp seamount (20°37’ 00” S, 14°15’ 00” E). Oceanographic features such as sea mounts, or fronts have a relatively high productivity (Worm *et al.* 2003) and these areas attract predatory fishes such as sharks, tunas and billfish, and it is for this reason fishermen often exploit these areas (Morato *et al.* 2010, Sauer *et al.* 2003, Worm *et al.* 2003). The relatively high CPUE within areas of the Indian Ocean most likely correspond to such oceanographic features, such as the Mallory seamount (36°54' 00" S, 22°15' 00" E). Fréon & Dagorn (2000) state that seamounts, canyons and fronts are most likely used as mating, feeding, and nursery grounds for highly migratory pelagic species, additionally Litinov (2006) reported that blue sharks tend to aggregate over these features, therefore it is not unforeseen to have high blue shark CPUE within areas associated with seamounts and canyons.

Seasonality in blue shark CPUE

The shark-directed fishery has the highest nominal CPUE during autumn and summer. The high CPUE is located off the west coast of South Africa, suggesting that this area has a high abundance of blue sharks during the summer months. This result is emulated in the monthly standardised CPUE for the shark-directed fishery, where blue shark CPUE was greatest during the summer and autumn months. This temporal pattern in abundance may be related to blue shark migration, as this species is known to undertake seasonal migrations that are influenced by factors such as water temperature, prey abundance and reproductive status (Carey & Scharold 1990, Kohler *et al.* 2002).

Hazin *et al.* (1990) and Montealgre-Quijano & Vooren (2010) reported high blue shark CPUE off the coast of Brazil (southwestern Atlantic Ocean) during spring and summer. This suggests that blue sharks move out of South African waters at the end of autumn and migrate to waters off Brazil arriving in spring. Evidence of this migratory pattern has been reported by Da Silva *et al.* (2010) where an individual that had been tagged off Cape Point was recaptured off the coast of Uruguay.

Interestingly the monthly standardised CPUE for the tuna and shark-directed fishery reveal contrasting fluctuations in blue shark CPUE. The monthly standardised CPUE for the tuna-directed fishery revealed higher CPUE during winter, suggesting greater blue shark abundance during this time of the year. The discrepancy in CPUE may be as a result of fishing in different areas. The tuna-directed fishery applies greater effort in the Indian Ocean. It is probable that this fishery tracks changes in blue shark abundance within the Indian Ocean, while the shark fishery tracks changes in the abundance of South Atlantic blue sharks.

The structure of South Atlantic and Indian Ocean blue sharks is unknown. It is possible that the South Atlantic and Indian oceans are separate stocks but evidence reported by da Silva *et al.* (2010) suggests inter-mixing of blue sharks from the South Atlantic to the Indian Ocean, possibly signifying the existence of a single stock.

Annual trends in blue shark CPUE

Blue shark CPUE has remained relatively stable from 1998 to 2008 in the shark-directed fishery, suggesting that blue sharks within South African waters are not declining. Annual standardised CPUE for the tuna-directed fishery revealed a strange pattern with a sharp increase in CPUE in 2004, followed by a rapid decline to levels observed prior to this event (Fig. 14). It is difficult to explain why such an event occurred as monthly, spatial and vessel effects should have been accounted for during the standardisation process.

The sharp increase in annual CPUE co-incides with the chartering of Asian-flagged vessels operating under South African permits (Smith 2005). This may have affected fishing practices, resulting in the landing of more blue sharks and the subsequent inflation in the CPUE. Ignoring this anomaly and simply comparing CPUE from 1998 and 2008, it is apparent that blue shark CPUE has remained relatively stable and has even increased slightly. As with the shark-directed data, it is apparent that blue shark abundance has remained stable throughout this time period.

These finding are not in agreement with tuna-directed observer data analysed by Petersen (2009). Petersen reported a significant reduction in blue shark CPUE from 2001 to 2005, suggesting a decline in abundance of this species in South African waters. However, this data may not represent true changes in blue shark abundance, as shark landings in the tuna fishery have been influenced by the introduction of shark bycatch restrictions (DEAT 2008). The reduction in blue shark catch rates reported by Petersen (2009) may be as result of the introduction of a 10% bycatch limit, whereby shark landings could not exceed 10% of the total mass of landed tuna (MCM 2008). Fluctuations in CPUE as a result of new regulations are less likely to be portrayed in the shark fishery. Therefore CPUE from the shark-directed fishery would better represent changes in blue shark abundance, as this fishery's permit conditions have remained constant throughout the time period. Henceforth, it appears that blue shark abundance has remained relatively stable from 1998 to 2008, suggesting the blue shark population within South African waters is not declining. This is in agreement with the ICCAT stock assessment, which found no evidence of overfishing for blues sharks within the South Atlantic (ICCAT 2009).

However, Petersen reported a decreasing trend in length of blue sharks caught on tuna vessels. A decline in average length is a biological indicator of high exploitation rates (Campana *et al.* 2008), suggesting that the blue shark population is overfished. In addition to this, Petersen reported that a high proportion of blue shark CPUE in the tuna fishery were of immature individuals. This is a cause for concern as a demographic study undertaken by Aires-da-Silva & Gallucci (2007) on North Atlantic blue sharks found that blue shark population growth is highly dependent on the survival of juvenile individuals.

Status of blue shark populations

Such inconsistent findings on the status of blue shark stocks are apparent in the literature with many studies providing contradictory results. Several studies have reported declines of between 60 and 80% in blue shark abundance in the Northwest Atlantic Ocean (Baum *et al.* 2003, Simpendorfer *et al.* 2002). However, an ICCAT stock assessment (ICCAT 2009) found no evidence of overfishing for the North Atlantic blue shark.

In the tropical Pacific Ocean, Ward & Myers (2005) suggested that blue shark abundance is 13% of that in the 1950's. However, a stock assessment for the Pacific Ocean blue shark stated that the population may be approaching the maximum sustainable yield (Klieber *et al.* 2009), and that this population is not overfished. Additionally Clarke *et al.* (2006) suggested that global harvesting rates of the blue shark is near or possibly slightly exceeding those of MSY.

Evidence from stock assessments undertaken by RFMO's as well as a study assessing the fishing rates of the blue shark at a global scale reveal no evidence of over-exploitation. Therefore the blue shark population residing in South African waters as well as the population globally are not threatened by stock collapse.

Mitigating the magnitude of blue shark catch

DAFF's decision to terminate the targeting of pelagic sharks as a result in the concern of the susceptibility of sharks to over-fishing was the first step in attempting to improve the management of shark catches in South Africa. However the setting of such a large bycatch limit may be counter-productive and may encourage the retention of sharks.

The most viable option may be to reduce the probability of catching blue sharks, by identifying areas and times of the year when there is a high abundance of blue shark and then limiting the fishing effort within these particular zones. Grantham *et al.* (2008) considers the implementation of temporary spatial closures to be the most effective strategy for mitigating bycatch within the South African pelagic longline fishery. The high blue shark catches off the west coast of South Africa during autumn and summer reported in this study suggests that this area warrants consideration for the creation of a time-area closure in order to reduce blue shark bycatch. The importance of creating time-area closures off the west coast of South Africa has been highlighted by Grantham *et al.* (2008) who stated that the creation of such areas could reduce bycatch (including seabirds, turtles and sharks) by 50% in the longline fishery.

Additionally, the recognition that juvenile survival is important for blue shark population growth implies that the protection of this life stage is essential in the management of this species. Cortes (2008) suggests that management plans should focus on the protection of juveniles. Additionally, Aires-da-Silva & Gallucci (2007) state that a key step in optimising the design of a marine protected area is in understanding the movement of juvenile blue sharks, as well the time spent within nursery areas.

In South Africa, da Silva *et al.* (2010) has confirmed the existence of a nursery area for blue sharks off Cape Point, however the residence time of juveniles within this area is unknown. Although there is no evidence to suggest that blue sharks are over-exploited in South Africa, there is some value in considering a closed area corresponding with the nursery ground of this species.

Future assessment of the status of the South African blue shark stock

Successfully assessing the status of a population is highly dependent on the quantity and quality of the data on which the model is based (Anderson 1990, Walker 1998). In order to obtain meaningful estimates, models require reliable and high quality data. Such information required are data from which an index of abundance can be estimated. In most cases this is based on CPUE often calculated using fishery-dependent data (Hoggarth *et al.* 2006). There are several problems with using fishery-dependent data as it may underestimate the total catch of a species, as bycatch and discards are not recorded (Bonfil 2005, Lewison *et al.* 2004).

Reliable fishery-dependent data are collected by observers which provide higher resolution information by recording all catches and length of landed individuals. However, observer coverage is low, with the monitoring of only 10% of all trips undertaken by domestic tuna-directed vessels (Petersen 2009).

In order to properly assess the status of the South African blue shark, it is essential to increase observer coverage and possibly consider the implementation of log books that record the total catch of a species and not only those landed. These data can then be used to assess the status of the blue shark population using an age-structured approach, thereby identifying the vulnerability of particular cohorts to fishing, as well as determining cumulative mortality rates (Walters & Martell 2004).

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