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ASSESSMENT OF THE NAMIBIAN HAKE (*MERLUCCIUS CAPENSIS* AND *MERLUCCIUS PARADOXUS*) DEMERSAL LONGLINE FISHERY BASED ON LOGBOOK DATA

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ABSTRACT

In Namibia, hake is one of the most valuable demersal fishing resources and an important source of employment in the fishing industry. The hake demersal longline fishery started in 1991, targeting mostly the cape hakes *Merluccius capensis* and *Merluccius paradoxus*. The Total Allowed Catch (TAC) of hake is approximately 160,000 tonnes, but only about 10,000 tonnes are caught by longliners. Currently, CPUE data from the hake longline fishery are not used for stock assessment purposes, despite the availability of logbook data. In this study, we conducted an exploratory analysis of the demersal longline logbook data and standardised the annual CPUE using Generalised Linear Models (GLMs) and Generalized Additive Models (GAMs). The results showed that the longline fishery operates mostly in the central area of the Namibian coast (between 22°S and 25°S). Since the fishery started to operate in 1991, there have been noticeable changes in the composition and operation of the fishery, characterised by higher effort in the early years (number of vessels and number of sets), followed by a reduction in 2006-2011 and stabilisation thereafter. Standardised CPUE values produced using GLMs and GAMs were very similar and relatively low between 1991-2008, followed by a large increase up to 2015, and a decrease thereafter. GLM is recommended as the method to be used because it has a lower AIC than GAMs. Except for the last three years, the general temporal trend in the standardised CPUE was similar between the longline and bottom trawl fisheries. The longline logbook dataset contains valuable information that can contribute to the management of the Cape hake stock in Namibia.

Key words: Hake fishery, demersal longline, CPUE standardization, GLM/GAM models, logbook data, Namibia.

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1 INTRODUCTION

Since 1967, Cape hake has been one of the most valuable demersal fishing resources in Namibia and an important source of employment (Crawford et al., 1987). The hake demersal longline fishery began in 1991. The main target species are the Cape hakes, *Merluccius capensis* and *Merluccius paradoxus (*Voges, 2005*)*. A small number of other species have been reported as bycatch, including kingklip (*Genypterus capensis*) jacopever (*Helicolenus dactylopterus*), angelfish (*Brama brama*), alfonsino (*Beryx splendens*), large-eye dentex (*Dentex macrophthalmus*), monkfish (*Lophius vomerinus*), Cape gurnard (*Chelidonichthys capensis*), snoek (*Thyrsites atun*), and sole (*Austroglossus microlepis*) (FIMS database). The annual quota of hake longliners (LLs) is approximately 6% of the total allowable catch (TAC) of approximately 160,000 tonnes. In recent years, this has resulted in annual landings for the longline fishery of around 9,000 tonnes. The catch is mainly exported to South Africa, Spain and Portugal. The fishing fleet consists of wetfishers, which are vessels where fish are stored wet in boxes covered with ice. The size of the vessels is less than 540 Gross Registered Tonnage (GRT). Most fishing vessels operate from the harbour of Walvis Bay, and a few from Luderitz. The duration of the fishing trips is approximately six days. The fishery is prohibited from operating within 200 nautical miles of the coastline. An additional measure was introduced in 2006, restricting fishing at bottom depths of less than 300 m south of 25°S (Kathena et al., 2016). A closed season was introduced in 2006, which prohibited hake fishing during October to protect spawners and young fish (Kathena et al., 2016).

2 RATIONALE

The longline fishery for hake has received little attention in Namibia under the assumption that their catches represent a small fraction of the total catch and that their effect on the stock would be minimal in comparison with the trawl fleet. Despite the availability of fishery-dependent information, including logbooks and landing data, no full assessment of the longline fishery for hake has been carried out. The longline fishery is poorly documented, and there is no information available to advise policymakers and fishery managers. Therefore, there is a need to explore the hake longline dataset and characterise the spatial and temporal trends, catch, effort, and catch per unit effort (CPUE).

The Age Structure Production Model (ASPM) is used to assess the status of the Namibian hake stock. The input data used in this model are commercial CPUE, survey biomass CPUE, total catch (landings), weight-at-age, maturity-at-age, selectivity-at-age, survey catch-at-age, and commercial catch-at-age. However, commercial LL CPUE is not incorporated into this model because it has not been standardised. This is a missed opportunity to incorporate an additional index of abundance into the assessment. The hake fishery has been certified by the Marine Stewardship Council (MSC), and a full assessment of the fishery, including longline and trawler data, is required to retain the certification. In addition, this will also enable the division of resource management to provide the best scientific advice for the sustainable utilisation of hake resources to the Minister of Fisheries and Marine Resources when determining TACs and other management measures.

3 RESEARCH OBJECTIVES

The main objective of this project is to assess the Namibian hake demersal longline fishery using logbook data.

3.1 Specific objectives

- Conduct an exploratory analysis of the demersal longline log-book data, examining spatial and temporal trends in fleet structure, hook efficiency, catch, and effort.
- Calculate nominal catch per unit effort (CPUE).
- Standardize annual CPUE using Generalised Linear Models (GLMs) by factors influencing the CPUE such as year, month, gear length, hook size, line depth and vessel identification, and gross registered tonnage (GRT).
- Explore alternative methods for standardizing CPUE, such as Generalized Additive Models (GAMs).

4 LITERATURE REVIEW

4.1 Cape Hake Biology

The Namibian hake fishery targets two species of the Merlucciidae family: *Merlucius capensis* and *M. paradoxus (*Voges, 2005*)*. The whole otolith method is used for the age determination of *M. capensis* and *M. paradoxus* in Namibia (Wilhelm et al., 2015). The von Bertalanffy growth parameters (combined sexes) for *M. capensis* used in the current stock assessment and estimated from otoliths are as follows: $L\infty$ = 149 cm (the asymptotic length); K = 0.0609 per year (growth coefficient per year); and t_0 = -1.28 year (theoretical age at length zero); and those for *M. paradoxus* are as follows: $L\infty$ = 127 cm; K = 0.0731 per year; and t_0 = -1.60 year (Wilhelm et al., 2015). *M. capensis* usually grows faster and matures younger than *M. paradoxus* and in both species females generally grow faster than males. *M. paradoxus* usually shows a higher weight at length and a lower proportion of maturity at length than *M. capensis.* The diet of both Namibian hake species is comprised of krill, crustaceans, cephalopods, Myctophidae (mainly *Lampanyctodes hectoris*), horse mackerel (*Trachurus capensis)*, bearded goby (*Sufflogobius bibarbatus)*, and other demersal and pelagic fish species (Wilhelm et al., 2015). There is an ontogenic shift in the diet (Pillar & Barange, 1995), with juveniles preying on small crustaceans and small pelagic fish and larger individuals feeding mostly on hakes and horse mackerel (Wilhelm et al., 2015). Cannibalism is common in this species (Traut, 1996). Cape hakes are opportunistic feeders, and their diet changes seasonally. Cape hakes breed throughout the year, with peaks of reproductive activity in August and September (Bianchi et al., 1999).

4.2 Fishing area

Hake fishing occurs along the Namibian coast, which extends for approximately 1,500 km between the border with South Africa at the Orange River in the south and the border with Angola in the north (Figure 5). The shelf area between the shore and the 200 m isobath covers approximately 110,000 km^2, and between the 200 and 1,000 m isobaths, approximately 230,000 km^2 (Elago, 2002). This is a highly productive area. The waters of the Namibian coast are cold, with an increased level of biological productivity, which is a result of seasonal southeast winds that induce upwelling in the Benguela current at the coast, making an abundant supply of nutrients available in the upper layers (Elago, 2002).

The fishery operates at depths between 200 and 1,000 m, with no trawling or longlining allowed in waters shallower than 200 m (Paterson and Kainge, 2014). Nearly all the fishery occurs in the shelf area. The hake fishery is located off the west coast of Namibia from latitude 17 °to 30 °south. Longliners target shallow water hake (*M. capensis*) at depths of 200 to 500 m (based on logbook data for 2010) and concentrate in the southern area (between Luderitz and Oranjemund), central area (north and south of Walvis Bay), and northern area off Moewe Bay (19°S) (Paterson & Kainge, 2014). *M. Paradoxus* is mostly targeted by trawlers in deeper water more than 350m.

4.3 Vessel characteristics

The hake longline vessels have a loading capacity of approximately 35 tonnes of fish and are between 20 and 35 m long. They measure approximately 100 to 540 GRT (Gross Registered Tonnage). The average horsepower (HP) is 665, with a range of between 228 and 1,850 HP. Most vessels are typically small, with lengths between 19 and 35 m and an average length of 27 m (Figure 1).

Figure 1 A typical longline fishing vessel. (IMCS Network, 2021)

4.4 What is longlining?

It consists of a long mainline made mostly of nylon monofilament which is attached to thousands of branch lines with baited hooks (Sreedhar, 2019). The line is suspended in the water by float lines connected to floats with flagpoles or lights (IMCS Network, 2021). Longlines are usually set and hauled once daily and allowed to drift and soak for several hours (Sreedhar, 2019). The line is set either by hand or mechanically while the boat steams away from the line. The line is usually hauled mechanically while the boat steams toward it. Longlines can be set near the surface to catch pelagic fish, such as tuna and swordfish, or laid on or close to the seafloor to catch deep-dwelling fish, such as cod and halibut (Sreedhar, 2019). Vessels that deploy longlines and can operate in both coastal and high seas waters are referred to as longliners.

4.5 The bottom set longline.

Bottom-set longlines are deployed near the sea bottom, targeting demersal species such as sharks, sea breams, sea bass, goupers, snapper, cod, haddock, halibut, hake, and flatfish (Sreedhar, 2019). They are widely used in Europe and the Mediterranean area as well as in the Far East. The total length of the line can be more than 30 km, with 20,000 to 30,000 hooks. Baiting hooks is a labour-intensive activity (350 hooks/hour) (Gabriel et al. 2005). When using bottom longlines, the ground must be regular because rocks or corals may entangle the lines and break them (Bjordal, 1989). Where muddy bottoms are found, longlines are not set to remain on the bottom and are held off the seabed by floats. They can be set to suspend bait at any desired distance from the bottom. The efficiency of longlines is influenced not only by the design of the hook and the type, size, and shape of the bait, but also by the material, length, and spacing of the branch lines (Bjordal, 1981). Bottom-set longlines, where branch lines are set at wider spacings, are more efficient and use less bait than those where branch lines are set more closely together (Bjordal 1981) (Figure 2). The length of the branch line must be selected appropriately. The branch line cannot be too short because short branch lines are less effective than long ones. The length of the branch line is related to the hooking space and the free space of the vessel used in longline fishing (Sreedhar, 2019).

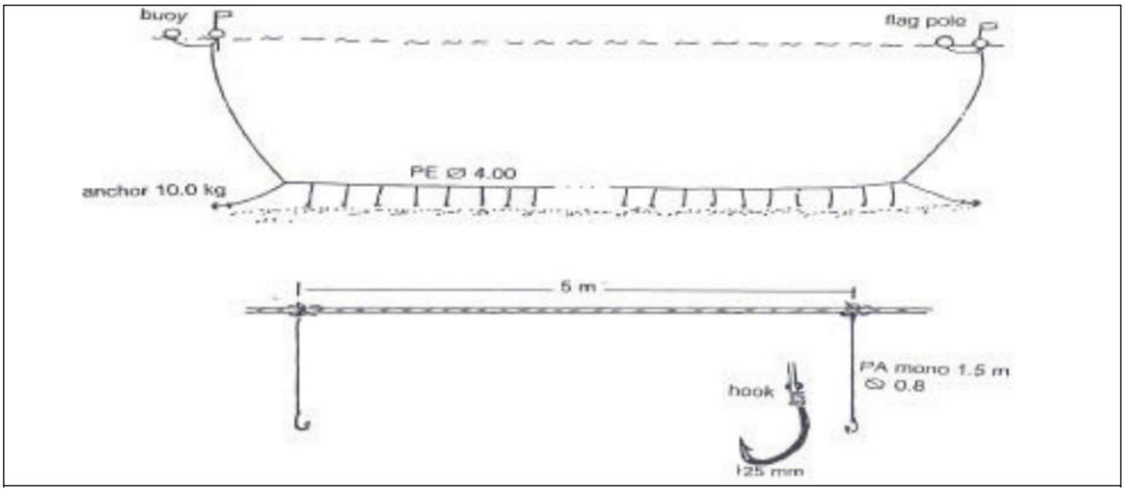

Figure 2 Bottom-set longline, hook spacing, and mainline set on the bottom by buoy and anchors. (Sreedhar, 2019)

In the cape hake fishery, longline vessels deploy one or two lines daily. Approximately 80% of the sets are deployed early in the morning (04:00 hours) before sunrise. The line is mostly hauled during midday (Figure 3) (Voges, 2006).

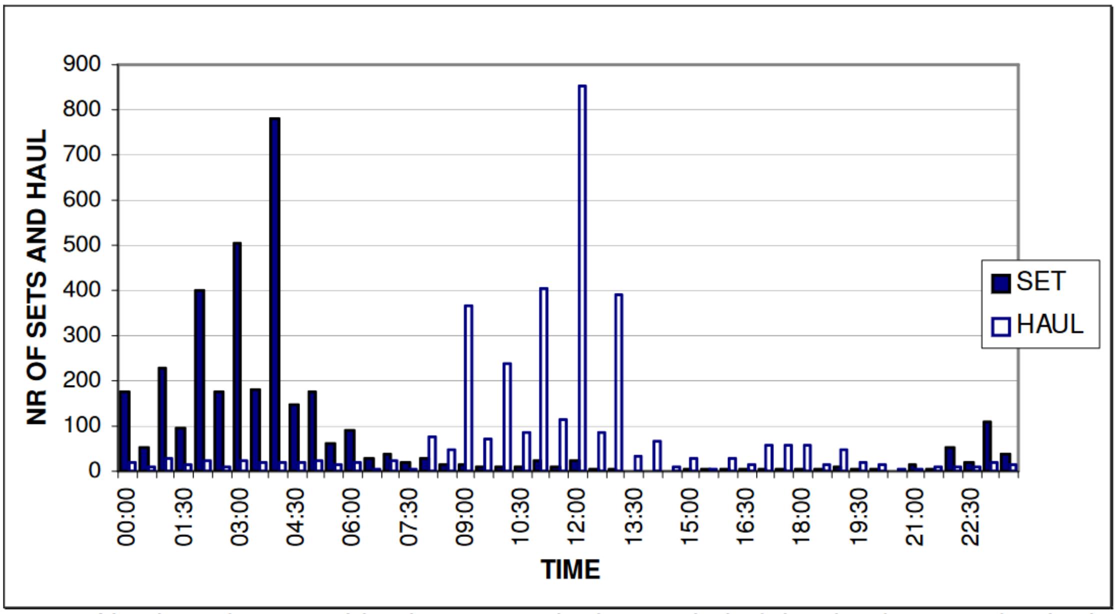

Figure 3 Number of sets and hauls per 30 min period of the day for hake longline. (Voges,2006)

4.6 Standardisation methods

Catch per Unit of Effort (CPUE), defined as the ratio between the catch (C) by the fishery and the fishing effort (E), is used as an index of fish abundance under the assumption that is proportional to the stock size (N) and that the catchability coefficient q is constant:

C/E =qN, (Maunder & Punt, 2004).

Nevertheless, different factors can influence the catchability coefficient over time and space, such as changes in stock size, vessel size, fleet efficiency, targeted species, environmental variability, captain experience, and dynamics of the fishing fleet. Therefore, to use CPUE as an index of fish abundance, it is necessary to adjust the CPUE values and remove the effects of factors other than abundance. This process is known as CPUE standardisation (Song et al., 2012). Different statistical methods have been developed for standardising CPUE, such as the use of Generalisedd Linear Models (GLMs),Generalisedd Additive Models (GAMs), statistical habitat-based standardisation (statHBS) (Maunder et al., 2006), and more complex models that can account for spatial and temporal effec,ts includinGeneraliseded Linear Mixed Models (GLMMs) with spatial and temporal random fields (Anderson et al., 2022) and Vector-Autoregressive Spatio-Temporal (VAST) models (Thorson, 2019).

Generalised Linear Models are defined by the statistical distribution of the response variable (usually catch rate) and how some linear combination of a set of explanatory variables relates to the expected value of the response variable. GLMs can be represented as

$$g(\mu_i) = x_i^T \beta$$

where g is a link function from the exponential family, μ_i is the expected value of the random variable Y_i (in this case, CPUE), x_i is the vector that specifies the explanatory variables for the ith value of Y_i, and β is a vector of the parameters. Several known statistical methods are particular cases of GLMs, including ANOVA, linear regression, and logistic regression. The steps needed to fit a GLM to a particular response variable include 1) the selection of the sampling distribution for that variable from the exponential distribution (e.g. normal, exponential, gamma, or Poisson distributions), 2) selection of an appropriate link function, and 3) selection of a set of explanatory variables (Maunder & Punt, 2004).

Generalised Additive Models (GAMs) are extensions of GLMs in which the linear predictor involves a sum of smooth functions of covariates (Wood, 2017). In general, the model has a structure in which the linear predictor of GLMs is replaced by an additive predictor as follows:

$$g(\mu_i) = \mu + \sum_{j=1}^{p} f_j\,(x_i)$$

where f_j is a smooth function (such as a spline or loess smoother) calculated from the data. The degree of smoothing of each function is selected by cross-validation to achieve a balance between describing the effect of each variable and avoiding overfitting. GAMs are more complex than GLMs which have the advantage of modelling nonlinear effects.

5 METHODS

5.1 Data sources

The analysis is based on fishery-dependent data from the hake longline fishery. A total of 59,680 hake records were used in this study after removing bad data from a total of 65,769 hake records obtained from the FIMS database between 1997 and 2020. The information recorded included catches and operational descriptors (e.g. geographic positions, number of hooks deployed, and set and haul times). An onboard fisheries observer verified the information recorded on the log sheets. Some smaller vessels do not accommodate observers, and their logbooks are not verified. These log sheets were collected and checked for errors by fisheries scientists before being forwarded to data typists to be entered into the Fisheries Information Monitoring System (FIMS) database at the National Marine Institute Research Center (NatMIRC) in Swakopmund. Scientists regularly update the database using Structured Query Language (SQL) queries created in Microsoft Access, linked to the FIMS database through a live table.

5.2 Data cleaning and processing

The fields or variables of interest for this study were as follows:

- Log-sheet Number (id)
- License number
- GRT (tons)
- Date (day, month, and year)
- Soaking time (≥24 hours)
- Line depth 900m ≤ 200m
- Latitude degree 29°S ≤ 17°S
- Catch (kg)
- Hook size
- Longline (m)
- Number of hooks set (#)

Records with errors in duration, catch (converted product), line length, and number of hooks were identified by sorting data in each field and corrected by cross-referencing with the logbook. Records that could not be corrected were excluded from the analysis. New fields were added to the data, including season, area (Table 1), and vessel category (Table 2).

Table 1 Description of the new variables (season and area) added to the dataset (1997-2020).

Season	months	Area	Latitude (°S)
1	November, December, and January	North	17-21
2	February, March, and April	Central	22-25
3	May, June, and July	South	26-30
4	August, September, and October		

5.3 Analysis of spatial and temporal trends in the hake longline fishery

A preliminary analysis was conducted to describe the main characteristics of the information stored in the longline logbooks. The analysis included examining temporal trends in a series of variables, including the number of fishing days, vessel GRT, fishing effort, and CPUE, and examining differences in temporal trends among the three areas. Maps of the annual distribution of fishing effort and CPUE were produced by computing the annual mean of the records summarised in a spatial grid with a resolution of 0. degrees. All analyses were performed using R statistical software (R Core Team, 2022).

Table 2 Vessels are divided into categories based on their GRT (tons)

Category	GRT (tons)
1	<200
2	>=200 and <400
3	>=400 and <600
4	>=600 and <800

5.4 Nominal and standardised indices using GLM.

The nominal CPUE, also referred to as raw CPUE, is defined as the total catch divided by the sum of the fishing efforts associated with the catch (Maunder, Sibert, et al., 2006). In the case of the hake longline fishery, the fishing effort is measured in hook-hours, defined as the product of the number of hooks set and the soaking time. The nominal CPUE is calculated by dividing the catch in each set by effort.

Here, the CPUE for the commercial longline fishery was modelled as a function of year, area, line depth, season, hook size, gear length, and vessel identification using a GLM with a Gamma error distribution and logarithm link function**.** The Gamma family was selected because it can be used to model highly skewed, non-negative variables. Year was one of the explanatory variables included in all models because the primary objective of standardising catch and effort data is to detect trends in abundance over time (Maunder & Punt, 2004). The model evaluation was performed by examining the diagnostic plots.

5.5 The GAM model standardised index

A similar approach was used similar to GLM to apply GAM on the hake longline dataset to standardise their CPUE. Here, the smooth function was applied to non-factor explanatory variables namely month, line depth, GRT, hook size, and longline length. GAM models were fitted using generalised cross-validation, adding an extra penalty term to each term so that they could be penalised to zero (Wood, 2017).

6 RESULTS

6.1 Spatial distribution of fishing effort

The annual distribution of fishing effort of the hake longliner fleet is shown in Appendix 1. The overall distribution patterns of fishing efforts are relatively constant during the period 1997-2020. To highlight this, the distribution of fishing efforts for these years is shown in Figure 4. In these four years, the number of vessels operating was 20, 26, 13, and 14, and the number of longline sets deployed was approximately 1,880, 1,860, 2,350, and 1,700, respectively. Despite these differences in the number of vessels and sets, the distribution of effort was similar. The longline fleet operates between 19°S and 30°S within Namibian waters, mostly in the central region close to Walvis Bay Harbour. The fishery spent most effort fishing in the central area of the Namibian coast (between 22°S and 26°S). Fishing efforts further north (19°S -17°S) were very low during these years. Effort was low in the vicinity of the Luderitz area (27°S), especially in recent years.

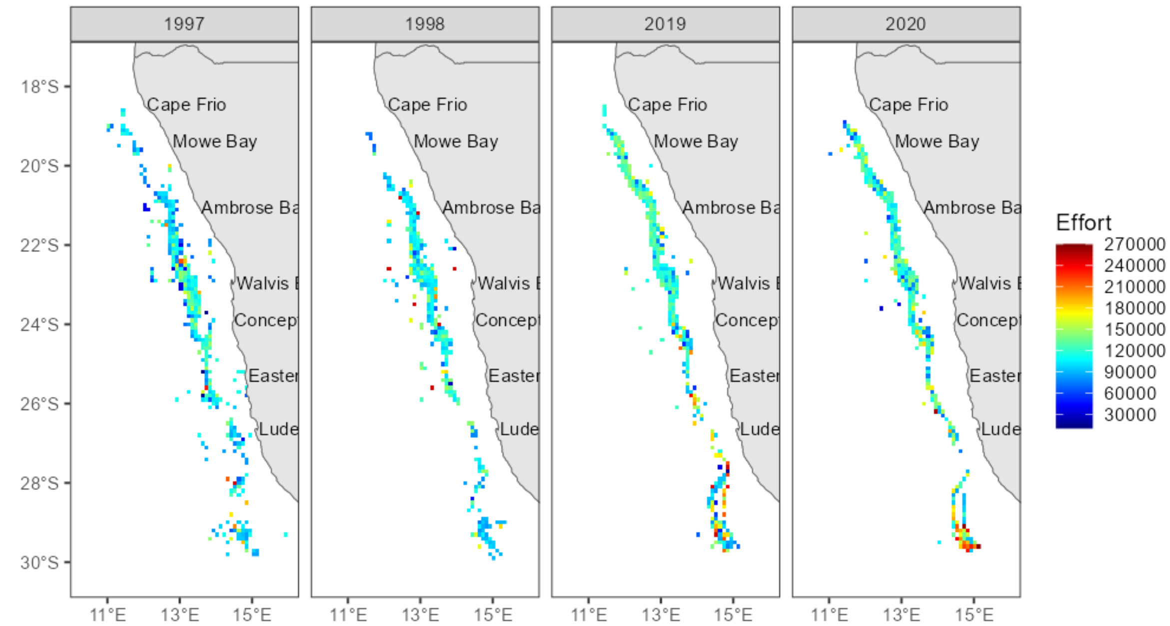

Figure 4 Fishing effort distribution for hake longliners during 1997,1998,2019 and 2020. Effort was measured in hook hours.

6.2 Fleet dynamic analysis

An analysis of the number of hake longline vessels, vessel categories, and number of fishing days indicated significant changes in the composition and operation of the fishing fleet in the period 1997-2020. The number of vessels (Figure 5) and fishing days (equivalent to the number of sets deployed) were higher in the early years (1997–2010) than in the recent years (2011–2020) (Figure 6). Between 1997 and 2000, the number of vessels increased from 20 to 38. Subsequently, the fleet size contracted to 11 vessels in 2011. Since then, the number of vessels in the fishery has remained relatively stable, fluctuating between 11 and 15 vessels. The driver of this shift is the reduction in the number of vessels in category 1 that occurred between 2000 and 2009, when many small vessels left the fishery (Figure 5). During the same period, the number of vessels in category 2 increased. The number of vessels in both categories has been similar since 2010, and very few vessels (<2) of categories 3 and 4 participate in the fishery. The total number of fishing days followed a similar pattern, although there was higher variability.

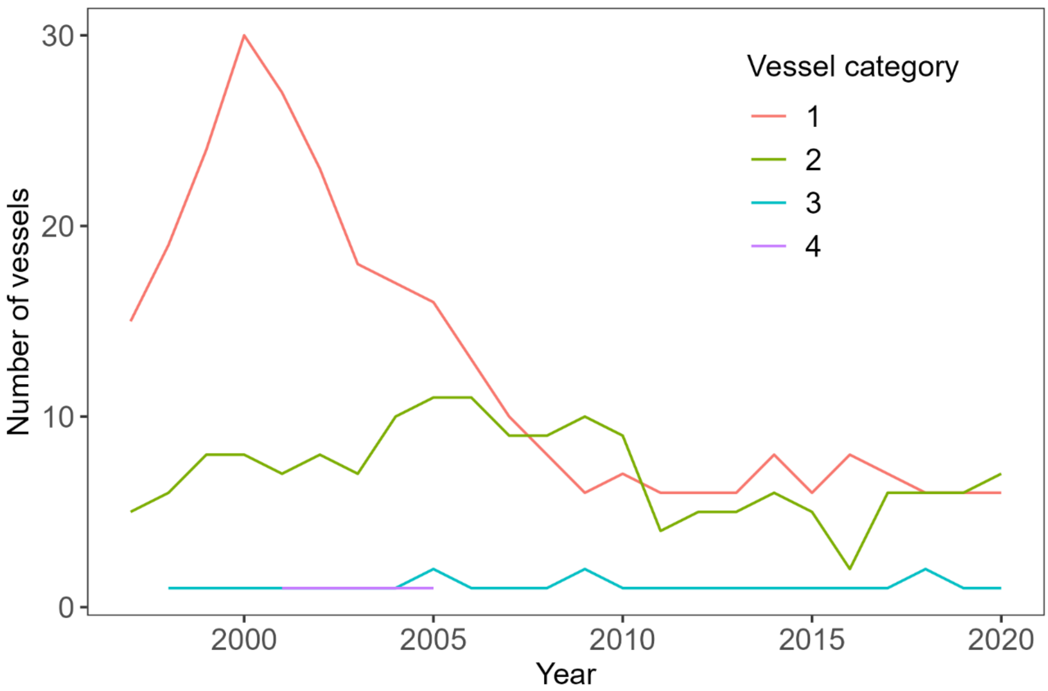

Figure 5 Number of hake longline vessels per category between 1997 and 2020.

The change in the size distribution of the fishing fleet can also be seen in the shift in the proportion of fishing days (equivalent to the number of sets deployed) for each vessel category (Figure 6). During 1997-2005, most fishing days were carried out by vessels in category 1. However, since 2006, the proportion of fishing days by vessels in category 2 has increased, becoming the predominant vessel category in most years of the period. There are few larger vessels (categories 3 and 4); therefore, their participation in the number of fishing days is relatively small.

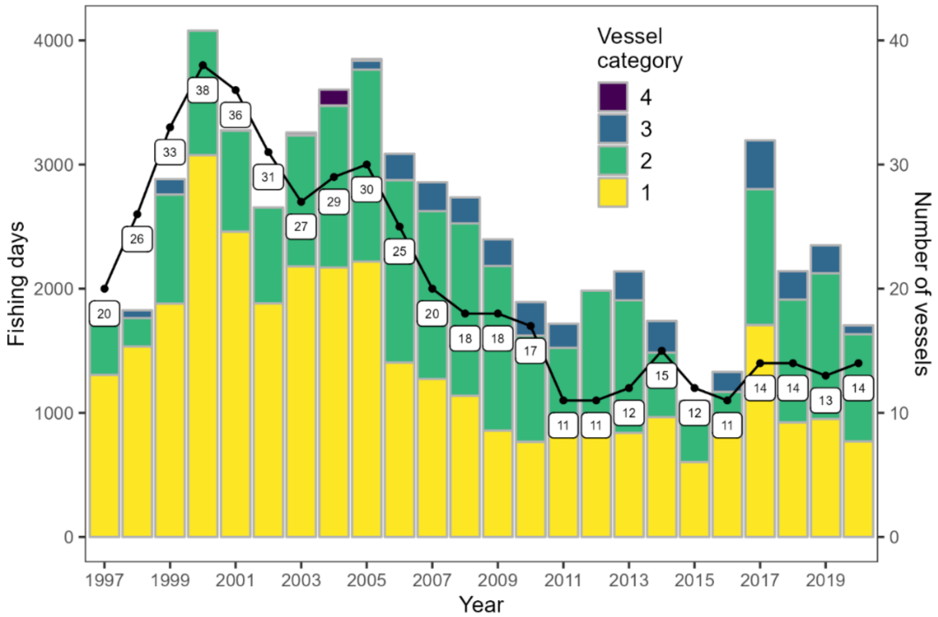

Figure 6 Total number of longline vessels, vessel categories, and sets deployed per year between 1997 and 2020.

The change in the relative proportion of the size of vessels in the Cape hake fishery can also be seen in the distribution of the GRT values between 1997 and 2020. The median vessel GRT increased from approximately 150 to 200 tons (Figure 7). The increase in the proportion of larger vessels between 2000 and 2009 is evidenced by the increase in the range of vessel sizes during this period. This indicates an increase in the fishing capacity of the longline fleet.

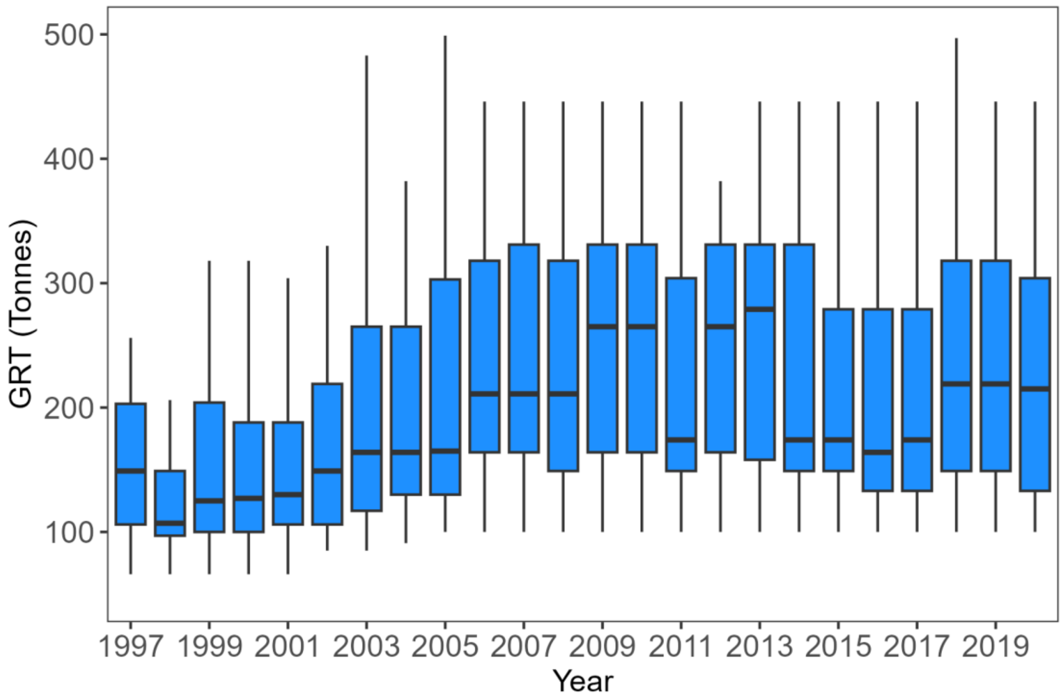

Figure 7 Boxplot showing GRT of hake longliners per year between 1997 and 2020.

6.3 Gear fleet analysis

An analysis of the trends in the mean lengths of the longlines and hook sizes indicated a noticeable change in fishing methods from 1997 to 2020 (Figure 8). On average, in the early years of the fishery, hake longliners used larger hooks (~ 6 cm) and deployed shorter longlines (~ 18,000 m). However, starting in 2012, fishermen switched to smaller hooks (3 cm) and increased the length of the longlines to ~ 27,000 m.

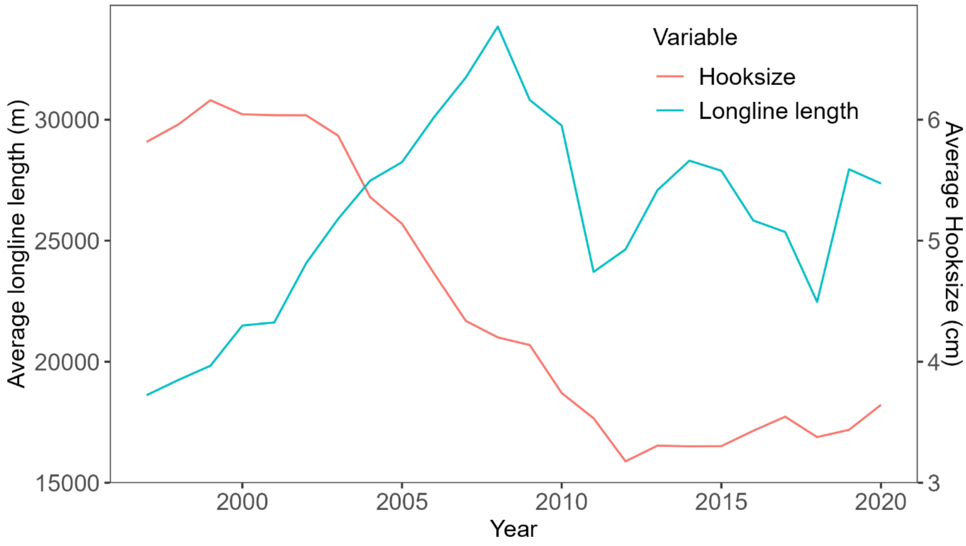

Figure 8 Average gear length and hook size of the hake longline between 1997 and 2020.

6.4 Spatial distribution of Fishing Effort and CPUE

The logbook was used to map the distribution of the annual nominal CPUE for hake longline fishery (Appendix 2). The maps show that in some years, there were noticeable differences in the distribution of CPUE on the shelf along the Namibian coastline. In particular, in the later years of the series, CPUE tended to be higher in the north and lower in the south (Figure 9).

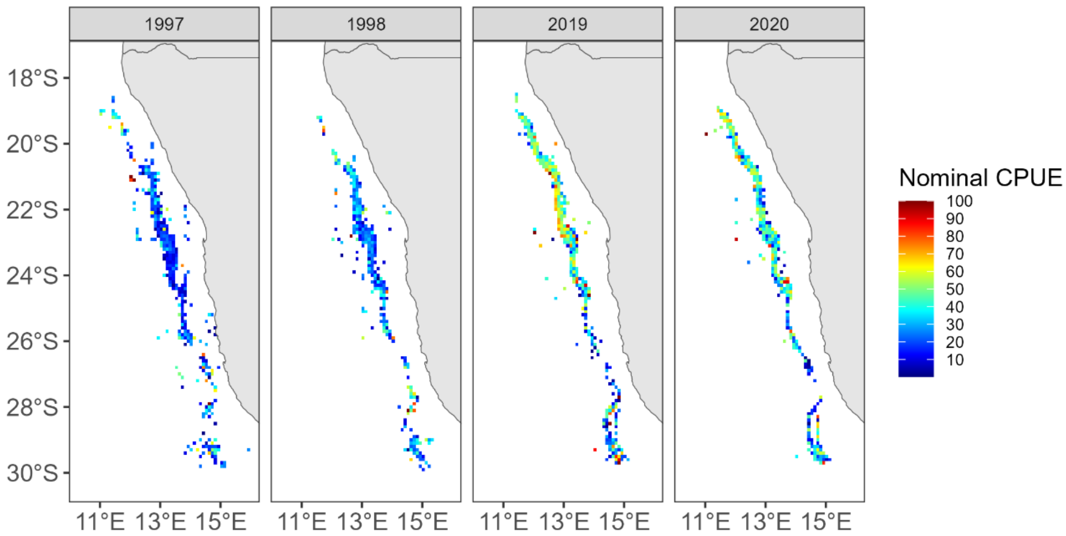

Figure 9 Relative nominal CPUE distribution for hake longliners years 1997, 1998, 2019 and 2020.

For management purposes, Namibian fishing grounds are divided into three regions (Table 1). Between 1997 and 2003, the longline fishing effort increased in all regions, with more effort spent in the central and southern areas (Figure 10). During this period, the least effort was spent in the northern area. Fishing efforts decreased in all areas from 2003 to 2010. Since then, fishing effort has been more variable in the southern area than in other areas. Compared with fishing efforts, the regional CPUE values showed more consistent trends. The CPUE first increased in the period 1997-1997, followed by a rapid decline until 2002 and relatively low CPUE values until 2006 (Figure 11). Between 2007 and 2015, CPUE values increased almost linearly, reaching values almost three times higher than those observed in the early years of the fishery. Between 2015 and 2020, CPUE values decreased. During most of the period analysed, there was a north-south gradient in CPUE values, with higher CPUEs observed in the northern region, intermediate values in the central region, and lower values in the southern region.

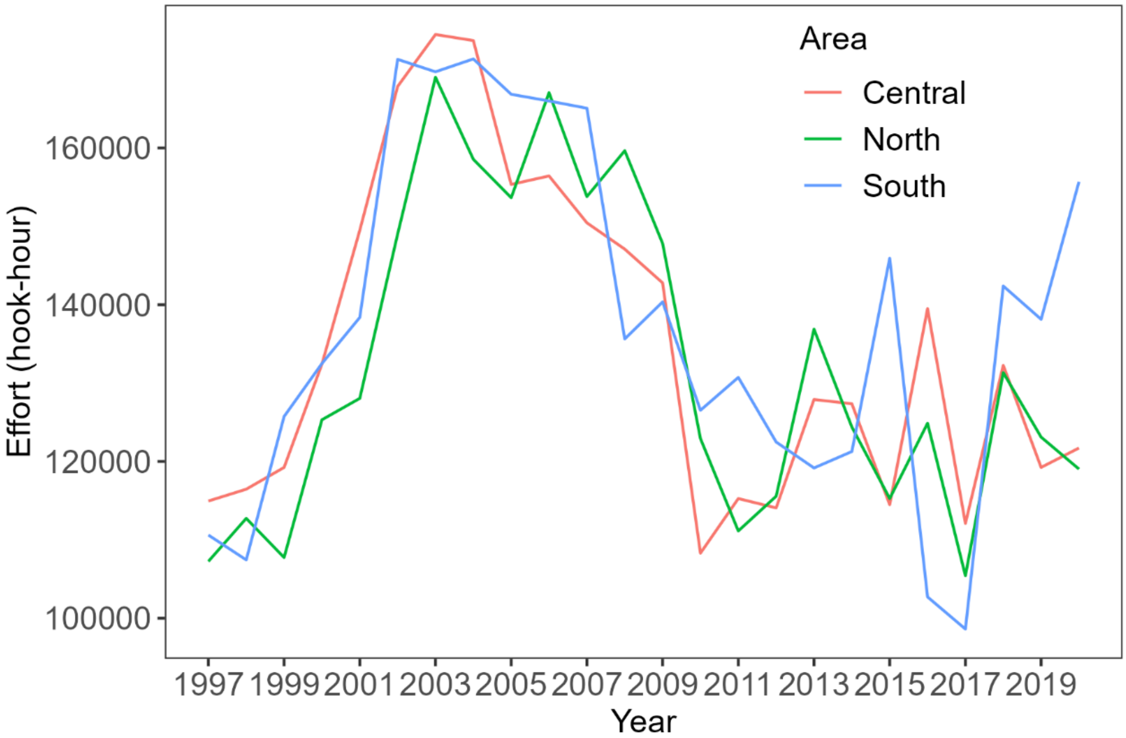

Figure 10 Trends in average fishing effort (hook-hours) for hake longliners by area between 1997 and 2020.

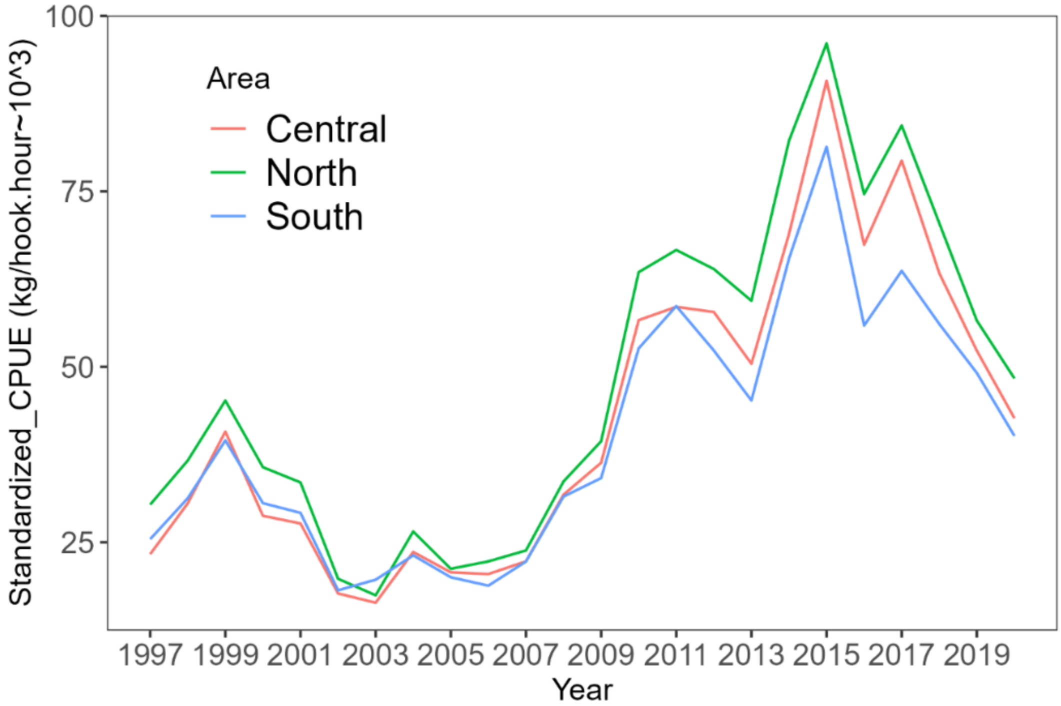

Figure 11 Trends in average CPUE for hake longliners by area between 1997 and 2020.

6.5 CPUE standardisation using GLMs.

In general, linear models, including GLMs and GAMs, do not perform well when the predictors are highly correlated (Maunder & Punt, 2004). To evaluate the correlation among the predictors, we utilised the Variance Inflation Factor (VIF), which is a measure of multicollinearity, that is, the degree of correlation between the independent variables in the model. The results indicated that four variables had relatively high VIF values close to 5 (Table 3), indicating a moderate degree of correlation: Gross Registered Tonnage (GRT), latitude, vessel category, and area. This is expected because the two later variables are derived from the two former variables expressed as intervals. To select between these two pairs of variables, the preliminary analysis indicated that GRT and area as predictors produced models with lower AIC values than those with vessel category and latitude as predictors. These two variables were also included in the final model. The correlations among the numerical variables were low (<0.8). The final model was fitted using the selected variables.

Table 3 The linear model VIF correlation test results data set (1997-2020)

Variable	GVIF	Df	GVIF^(1/(2*Df))
Year	5.063958	23	1.035893
Month	1.671388	1	1.292822
Latitude	6.383708	1	2.5266
Depth	1.106096	1	1.051711
Vessel category	9.840831	3	1.463879
Area	6.706983	2	1.609281
Season	1.751369	3	1.0979
Hook size	4.135326	10	1.073558
GRT	8.364139	1	2.892082
Longline length	1.358694	1	1.16563

Variable selection was performed by fitting a full model, removing each variable in turn, and testing for a significant difference in the model fit, using a chi-square test to identify which variables caused a significant reduction in deviance. The results indicated that removing year, area, line depth, season, hook size, longline, and vessel identification caused a significant reduction in fit, and suggested removing month and GRT, since these variables did not affect model fit significantly (Table 3). The final GLM was built after removing these variables (Table 4). This model was used to predict the standardised CPUE (Figure 12).

Table 4 Summary of the significant covariates GLM fitted from the data set (1997-2020).

	Df	Deviance	Resid. Df	Resid.Dev	Pr(>Chi)	
NULL			59679	67303		
Year	23	14433.7	59656	52869	2.20E-16	***
Area	2	156.9	59654	52713	2.20E-16	***
LDEPTH	1	36.9	59653	52676	4.68E-07	***
Season	3	167.6	59650	52508	2.20E-16	***
HOOKSIZE	10	228.6	59640	52280	2.20E-16	***
LONGLINE	1	22.3	59639	52257	9.11E-05	***
L_NUM	73	2863.1	59566	49394	2.20E-16	***
Signif. codes:	0‘***’	0.001‘**’	0.01‘*’	0.05‘.’	0.1‘	’1

The nominal CPUE of the hake longline fishery decreased between 1999 and 2001, followed by consistently low levels between 2001 and 2007, after which it increased, except for a dip in 2013 (Figure 12). From 2015, a downward trend in CPUE was evident, with a slight increase in 2017.

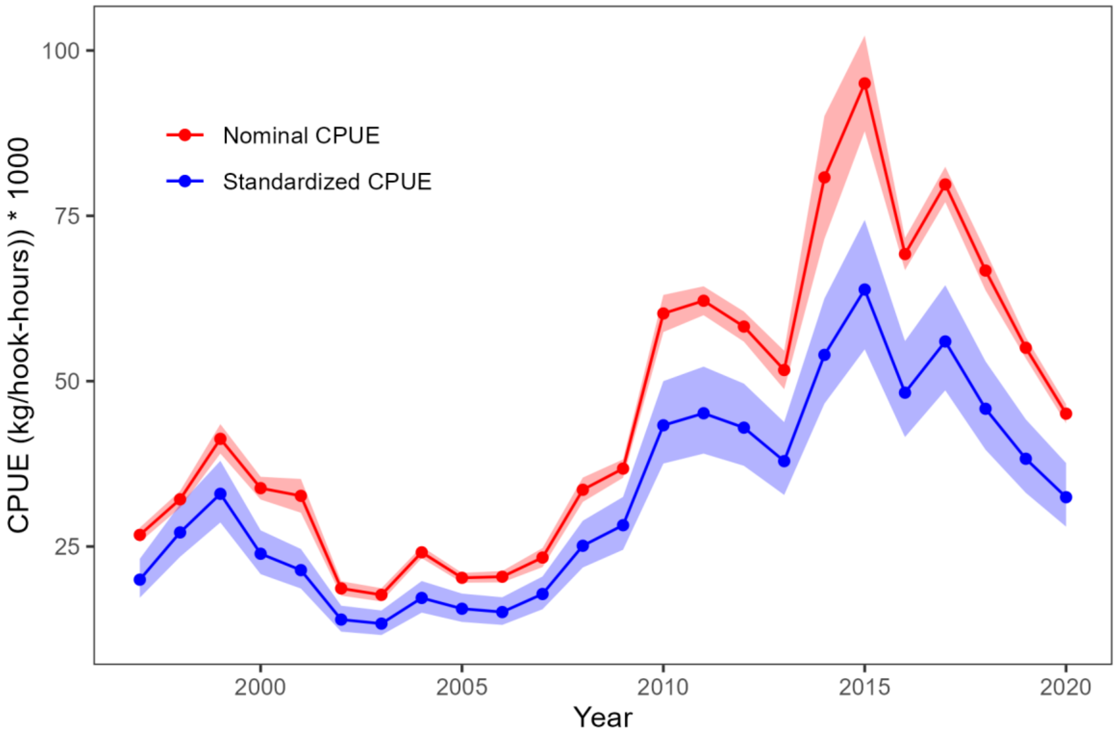

Figure 12 Nominal and standardised abundance index (GLMs) of hake longliners from 1997 to 2020.

6.6 CPUE standardisation using GAMs.

Generalised additive models were fitted using the same variables as the GLM. Smooth functions and diagnostic plots were used to evaluate which variables were included or removed from the model. The smooth diagnostics plot suggested removing month and GRT, since the confidence intervals included zero across the range of the predictor variable (Figure 13). This was the same result as that obtained after plotting the smooth functions. The final model consisted of the following variables: (year, area, line depth, season, hook size, vessel identification, and longline).

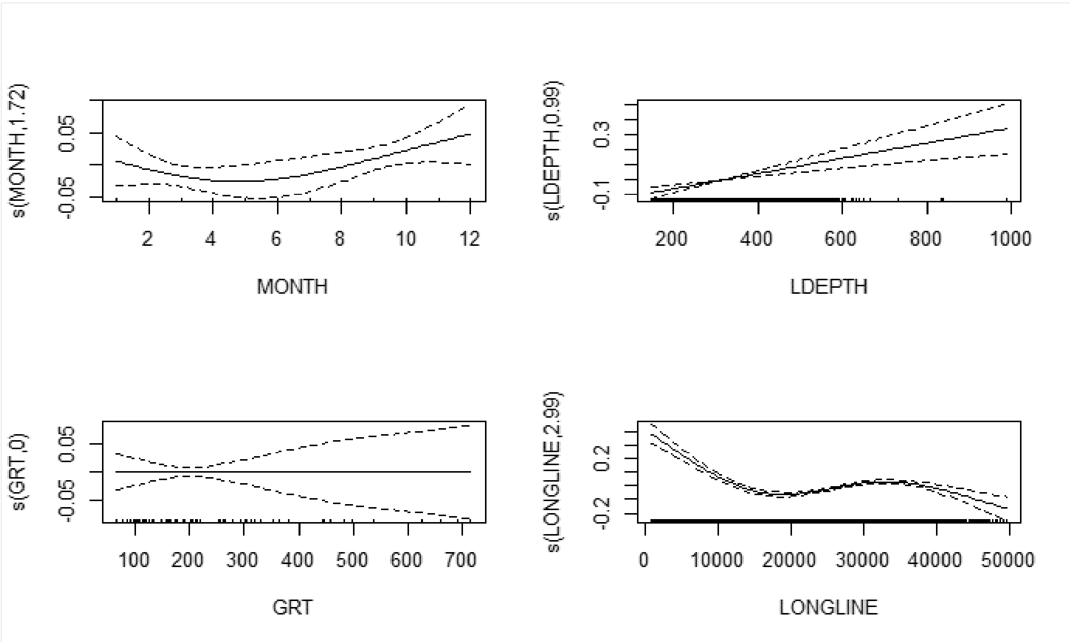

Figure 13 GAM smooth function plot

The predicted and nominal CPUE means were calculated and grouped by year (Figure 14). Both predicted and nominal CPUE were low from 1997 to 2009, less than 50 (kg/hook-hours)$10^{\wedge 3}$). Thereafter, both started increasing until 2015, followed by a downward trend until 2020.

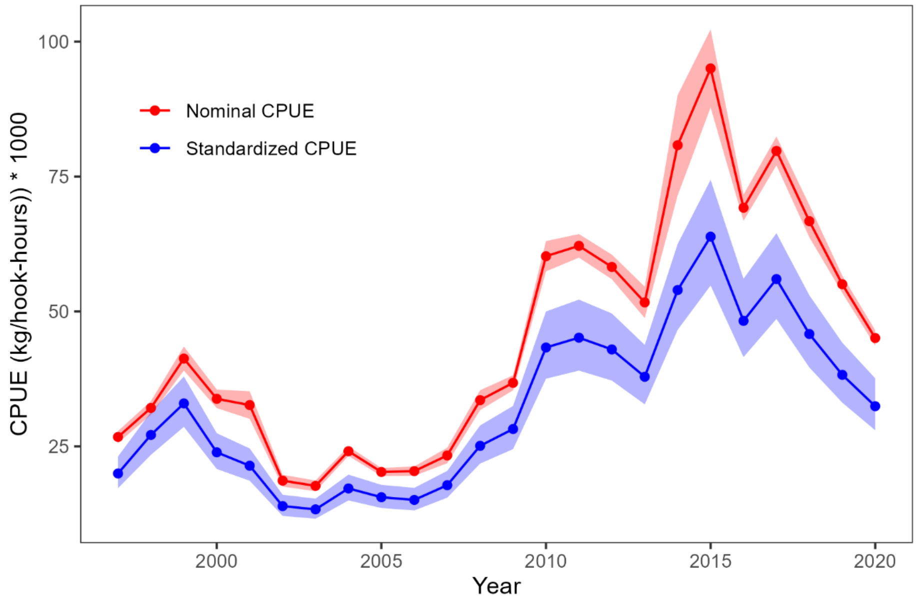

Figure 14 Nominal and standardised CPUE index (GAMs) of hake longliners from 1997 to 2020.

6.7 Comparison of commercial hake trawl and longline GLM standardised CPUE

The catch per unit effort (CPUE) data standardised by applying Generalized Linear Modelling (GLM) were compared with the standardised CPUE values from the bottom trawl fishery (Figure 15). The hake bottom trawl fishery time series is available for the period 1992-2020. The bottom trawl CPUE drastically declined between 1993 and 1996, with a slight increase in the late 1990s and the mid-2000s. However, for the first time after seven years of relatively constant low-level CPUEs in both fisheries, the CPUEs increased remarkably from 2009 to 2011, before a sharp decrease in 2012. The standardised CPUE for both fisheries showed similar trends between 1997 and 2020, except for the last three years (2018-2020) where the bottom trawl CPUE displayed an increasing trend, whereas the longline CPUE decreased.

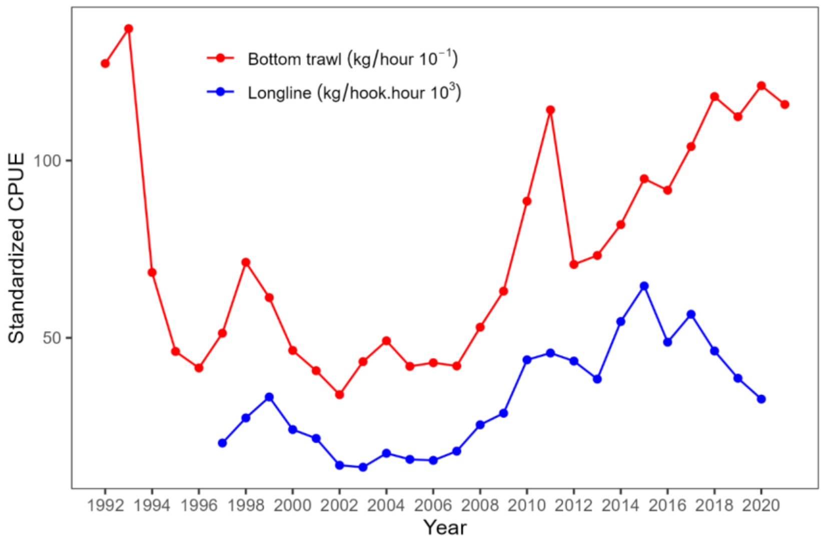

Figure 15 Hake commercial GLM standardised CPUE for hake trawlers (1992-2021) and longliners (1997-2020).

7 DISCUSSION

7.1 Fishing effort distribution, fleet dynamic and gear analysis

Assessment of the Namibian hake longline logbook dataset (1997-2020) has produced useful information on fishing effort distribution, fleet dynamics, and gear analysis. The distribution maps indicate that most of the fishing effort is spent in the central region close to the Walvis Bay harbour (Figure 4). This is because the vessels in the longline fleets carry out short fishing trips, mostly around six days, and smaller wetfisher vessels cannot travel far from their home ports. Therefore, they cannot sail far north and return without compromising the quality of the fish, as fish are kept on ice for whole-round export purposes. Fishers also consume less fuel when operating near the docking and offloading sites. There is little fishing effort close to the Luderitz area (latitude 26°S) because of strong winds which can move the lines and even cause entanglement. The longliners have invested more effort in fishing in the southern area in recent years, but their catch rate is low compared to other areas (Figures 10 and 11). However, they obtain high-quality fish in return, regardless of the effort. Namibian longline skippers distinguish between several morphotypes of M. *capensis*, which they refer to as "white" (or "silver"), "brown", and "black" hake (Paterson & Kainge, 2014). The white and brown *capensis* are both caught in the southern area and are considered to be of the best quality in comparison to the black *capensis* caught north of Walvis Bay.

The hake longline fleet analysis shows that the number of longline vessels has decreased in recent years compared to the early years (Figure 6). Some of the longline vessels that left the fishery have been converted to tuna longline vessels. The vessels that left the fishery were mostly smaller in category 1 (Figure 5). This resulted in an increase in vessel GRT over the years, as only larger vessels remained in category 2. This information was provided by fishers during the Hake Working Group meetings between scientists (Ministry of Fisheries and Marine Resources), fisheries observers (Fisheries Observer Agency), and fishers (fishing industry). The number of fishing days has reduced in recent years because there are few fishing vessels compared to the past, as shown in Figure 6.

The hake longline gear has changed from the past to the present (Figure 8). Since 2005, longliners have started using smaller hook sizes (number 2,3, and 4 hooks). Smaller hooks catch more fish than larger hooks do (Uysal & Öztekin, 2021).Fishers prefer smaller hook sizes because they are less expensive and have the same efficiency as larger hooks. Researchers have also found that the number of fish caught with longline gear decreases as the size of the hooks used in tackles increases (Ayaz, 2020). In addition, fish with a mouth gap smaller than the hook gap have a low possibility of being angled and retained (Queirolo et al., 2009). The use of monofilament lines since 2007 may have resulted in the use of shorter lines, but they are more efficient and have increased catch rates.

7.2 Comparison of commercial hake trawl and longline GLM standardised CPUE

The CPUE derived from trawl and longline commercial logbook data was standardised using GLM. Standardisation aims to remove most of the annual variation in the data that are not attributable to changes in abundance, such as seasonality, crew technique, and fleet strategy (Maunder et al.,2006). CPUE has been used as an index of fish abundance in fisheries assessments, although it should be interpreted with caution due to improvements in fishing gear, changes in fishing strategies, and variations in the migration patterns of fish stocks (Johnsen & Iilende, 2007).

Fishing gear in longline and bottom trawl fisheries has changed over time (Paterson & Kainge, 2014). The introductory use of monofilament lines, which are less visible, have less smell, and produce less vibration in the water, and the use of swivels whichkeeps the hook away from the line and reduce entanglement has resulted in increased fishing efficiency and CPUE in the longline fishery, while the increase in the net openings from 3.6 to 14.0 m had the same effect in the trawl fishery (Paterson & Kainge, 2014). This resulted in an increase in the CPUEs of both fleets since 2008 (Figure 15). The longline logbook data confirm that, while the hook-hour effort per year has decreased since 2005, the CPUE has increased on average (Figures 10 and 11), suggesting an increase in efficiency. In addition, improved fish-finding equipment, knowledge of fish movements, and aggregation are likely to increase fishing efficiency relative to abundance, offsetting the effects of the resource decline.

Between 2002 and 2008, CPUEs from both fisheries did not show greater variations as they fluctuated around 60 kg/h/10 (bottom trawl) and 18 kg/(hook-hour10$^{\wedge-3}$) (bottom longline) (Figure 15). The catch rates for that period are the lowest of the time series and indicate that the stock was in poor condition without any improvement. Despite the low CPUE during that period, the Namibian hake industry further invested in vessels and factories, especially in 2007/2008 (Wilhelm et al., 2015). This resulted in an increased catch and process capacity of approximately 205,000 t (fishing season 2008/2009), 137,000 t for wet fish, and 68,000 t for freezer vessels per year for bottom trawl fishery (Wilhelm et al.,2015).

The decline in 2012 may have been a result of the two previous years (2010 and 2011) of high TACs (Wilhelm et al.,2015). However, it should be noted that experience with codfish has shown that as abundance decreases, the stock tends to aggregate. Fishers then target these aggregations, resulting in high CPUEs. In the recent three years (2018 to 2020), the bottom longline CPUE showed a downward trend, whereas there was an increase in the bottom trawl CPUE. This can be attributed to the increasing number of seals that prey on fish from the line when retrieving the line (based on logbook remarks). This may have resulted in a reduction in catch rates for the longline fishery in recent years. This hypothesis requires further investigation.

7.3 Comparison between GLM and GAM indices.

The CPUE was standardised using GLM and GAM by factors influencing the CPUE, such as month, gear length, hook size, season, area, line depth, vessel identification, and GRT from 1997 to 2020. However, to make a comparative analysis between the GLM standardised index and GAM models, the AIC values were determined for comparison purposes. The AIC values suggested that the GLM model is recommended as the method to be used as an index of abundance because the AIC value is lower than that of the GAM model. However, both models provided very similar standardised CPUE values (Figures 12 and 14).

8 CONCLUSION AND FUTURE RESEARCH

The longline logbook dataset contains valuable information that can contribute to the management of the cape hake stock in Namibia. GLM and GAM provided very similar standardised CPUE values, and GLM is recommended as the method to be used. The standardised CPUE for both fisheries showed similar trends, except for the last three years, where the bottom trawl CPUE displayed an increasing trend, while the longline CPUE decreased. In the future, we will attempt to incorporate environmental parameters as additional explanatory variables into the two models to test their influence on the catch rates for the hake longline fishery. However, the dataset has some limitations. Environmental parameters were not recorded in the logbook, especially in the old years. There is also a need to study the impact of longlining on hake spawning stock biomass, as the fishery mostly targets large hakes.

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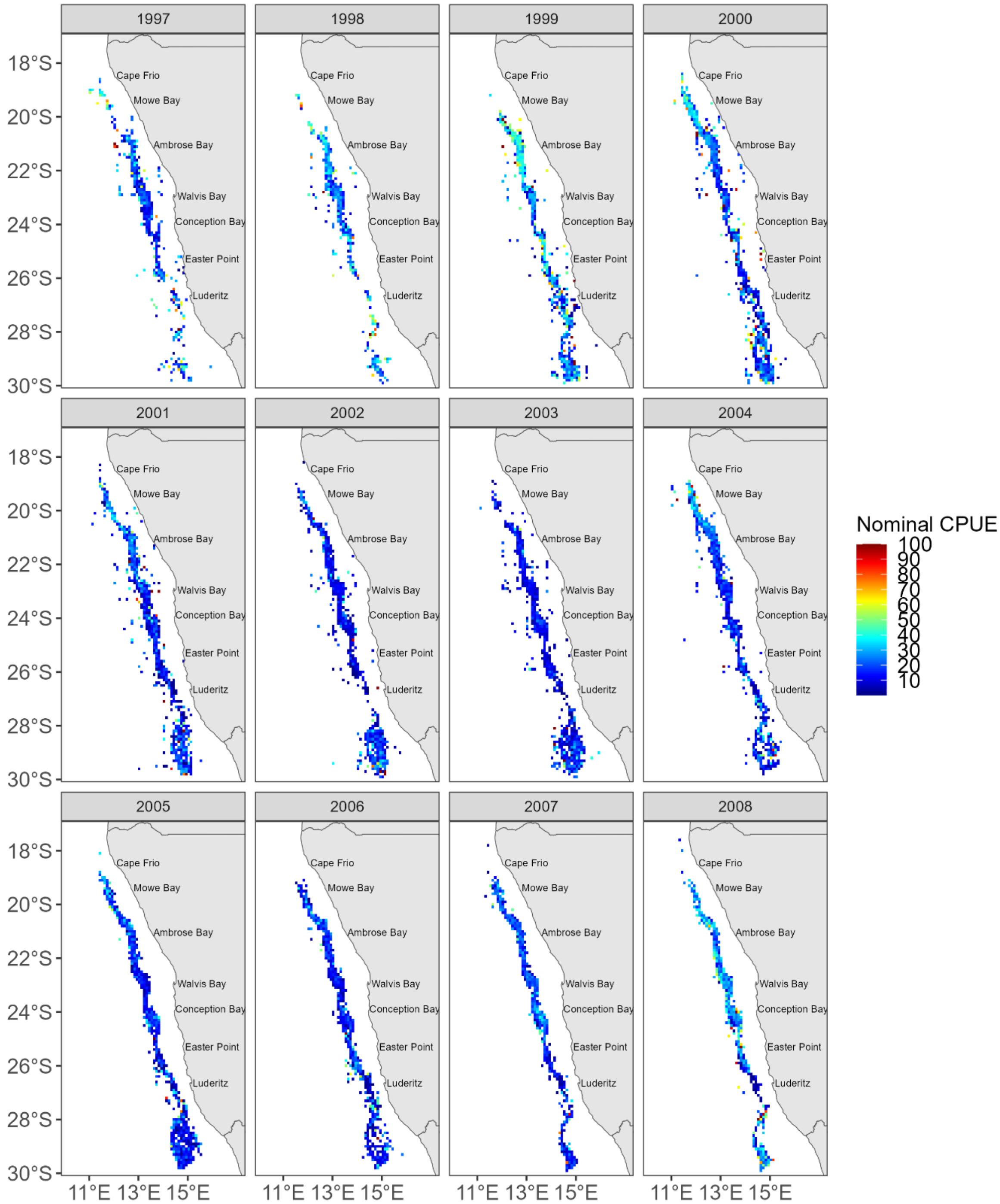
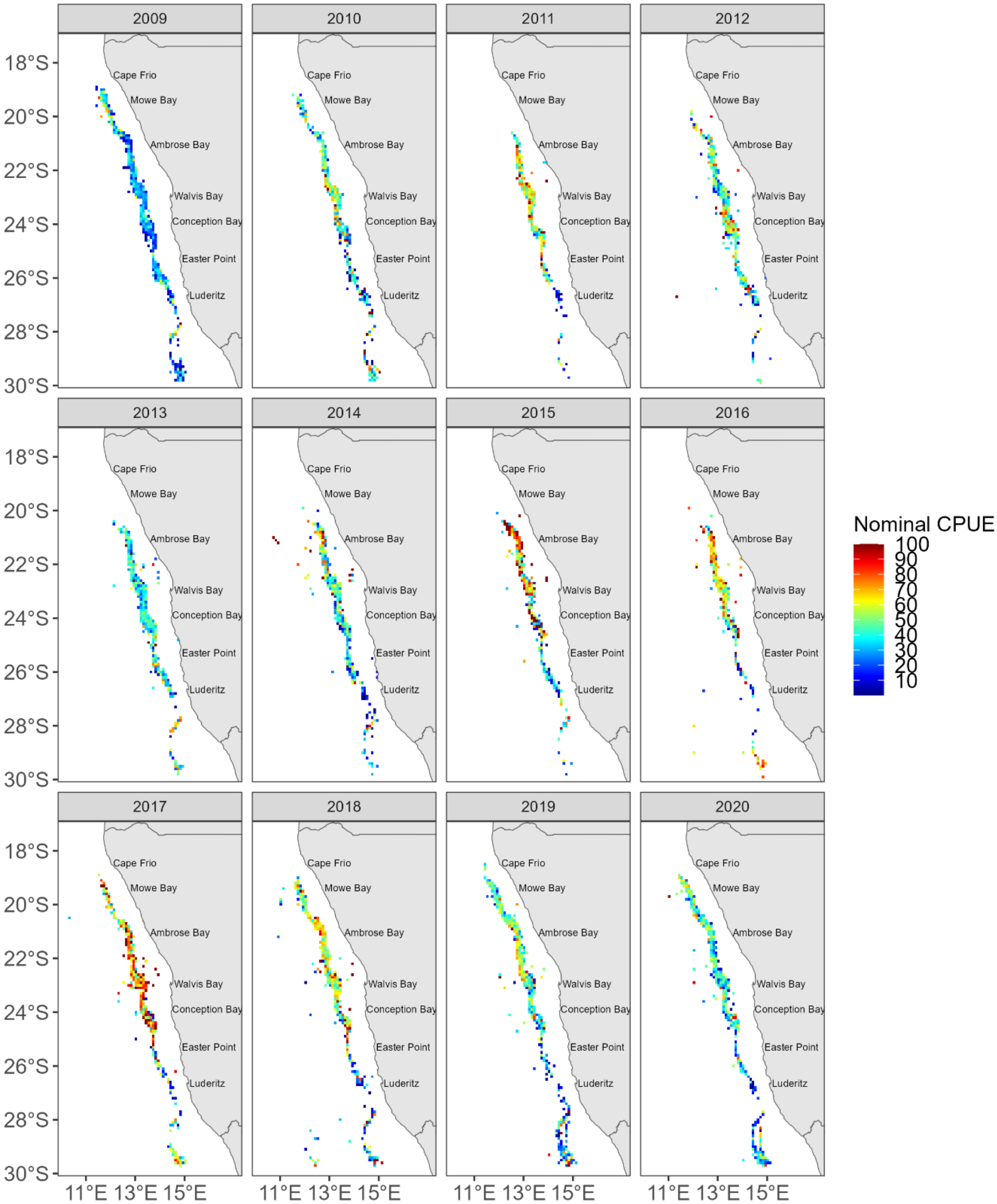
APPENDICES

Appendix 1 Spatial Nominal CPUE for hake longliners (1997-2008) and (2009-2020)

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Cape Frio
Mowe Bay
Ambrose Bay
Walvis Bay
Conception Bay
Easter Point
Luderitz
Nominal CPUE
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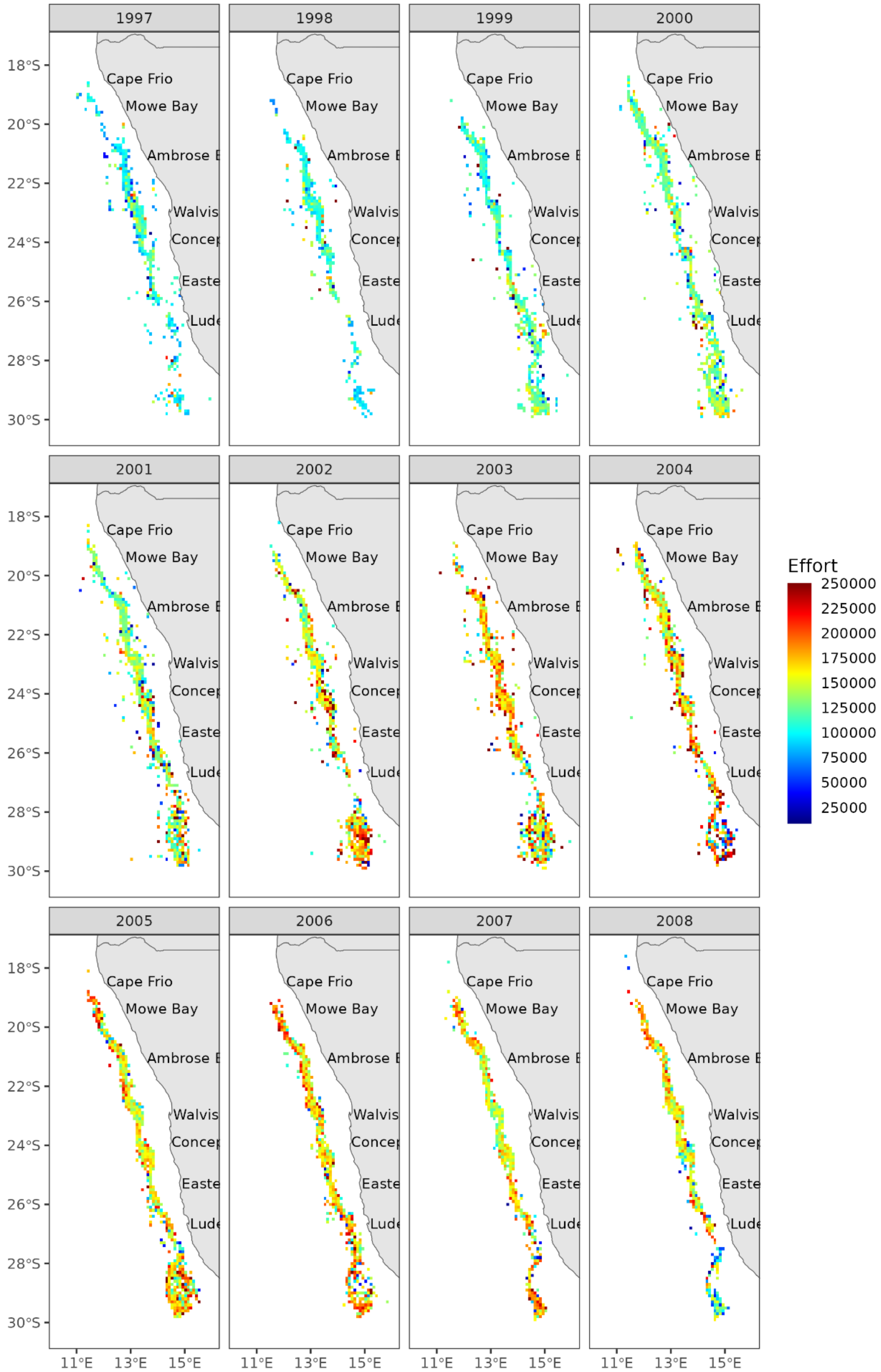
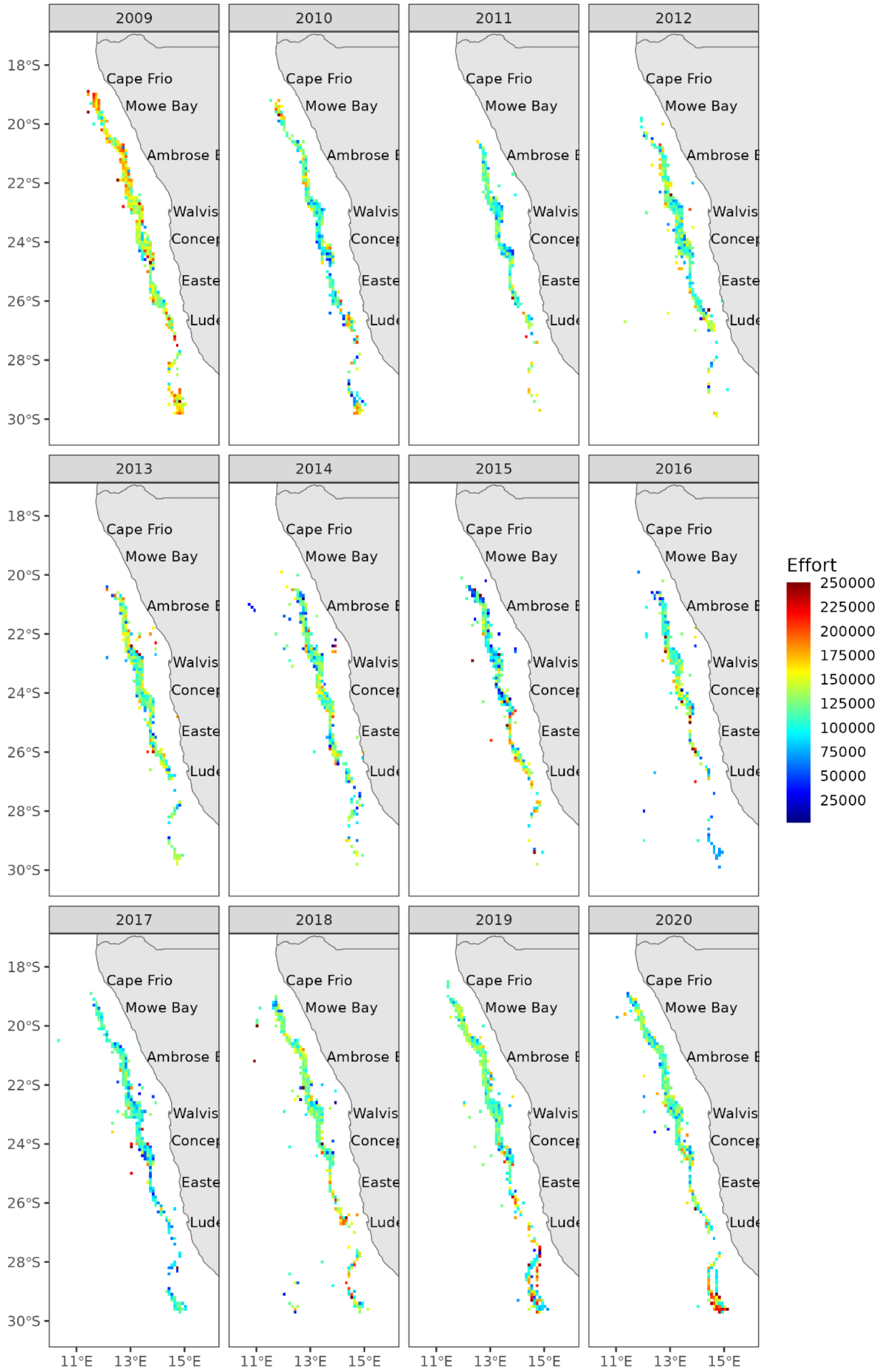
Appendix 2 Spatial effort distribution for hake longliners (1997-2008) and (2009-2020)





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175000
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100000
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