A robust method to separate Namibian commercial hake catches by species – a necessary step towards a biologically realistic hake stock assessment.

Authors: Espen Johnsen and Johannes Kathena

Espen Johnsen, Institute of Marine Research, P.O. Box 1870 Nordnes, NO-5817 Bergen, Norway.

Johannes Kathena, National Marine Information and Research Centre, Ministry of Fisheries and Marine Resources, P.O. Box 912 Swakopmund, Namibia

Corresponding author: Espen Johnsen, espen@imr.no, Telephone: +4755238500, Fax: +4755238531

Abstract

Merluccius capensis and *M. paradoxus* are morphological similar and not registered by species in the Namibian commercial hake catches, which thereby prevents a biologically plausible single species stock assessment. Here, the species separated data from the observer programme and the scientific surveys are used to produce spatiotemporal models of the species overlap. By inserting logsheet information about depth, latitude, season and year the proportion of hake species in the individual commercial trawl catches were predicted from the models. This study shows a considerably higher species identification quality in the survey data than in the observer data. Conversely, the survey data have a poor seasonal coverage and a computer intensive simulation had to be carried out on the survey data to compensate for differences in escapement and cod-end retentions between the survey and commercial trawls. Despite these dissimilarities, the data sources gave very similar parameter estimates and depth and latitude explained 51% and 85% of the residuals for the observer and survey data models, respectively. All models show a more northerly and shallower distribution for the *M. capensis* than for *M. paradoxus*. More importantly, the final outputs presented as quarterly species separated commercial catches, were almost identical and insensitive to choose model. However, the inclusion of quarter as explanatory variable in the survey models generated a noisy time series due to the poor seasonal coverage. Although the procedures lack flexibility to consider abrupt and unexpected changes in the geographical species distribution, it is evident that the methods make an adequate single species assessment for Namibian hakes possible.

Keywords:

Assessment, hake, *Merluccius*, Namibia, single species,

Introduction

Three hake species *Merluccius capensis*, *M. paradoxus and M. polli* are found off Namibia, but in contrast to other two species which are distributed along the whole coast, the distribution of *M. polli* in Namibian waters is restricted to the northern areas (Lloris et al. 2005). As the latter only occurs in low abundance the Namibian hake fishery is regarded as a mixed *M. capensis* and *M. paradoxus* fishery (Gordoa et al. 2000). However, the large overlap in the morphological characteristics (Lloris et al. 2005) makes species identification of the genus *Merluccius* difficult, and in fact *M. capensis* and *M. paradoxus* were until 1960 classified as one species. This similarity makes it not feasible to registered hakes by species in the commercial catches (Gordoa et al. 2000). Opposite, all hakes are recorded by species during the scientific surveys, and trained observers take species separated length and biological samples of the commercial hake catches.

In Namibia, an age-structured production model has since 1998 been use to assess the state of the hake stocks (Boyer and Hampton 2001). The most important input data are bottom trawl survey estimates and commercial catch at age and CPUE indices, which are not separated by species. Therefore, any difference in the population dynamics between the species is ignored in both the hake assessment and management (Butterworth and Geromont 2001). However, as the stock dynamics vary with species (Cohen et al. 1990) it is crucial to separate the input data by species to achieve a more realistic hake assessment (Butterworth and Geromont 2001), but due to the species identification problems no species separated commercial CPUE time series are available.

Despite the morphological similarity, the two species show a well documented and marked difference in depth preference and geographical distribution (Gordoa and Duerte 1991, Burmeister 2001, Gordoa et al. 2006, Johnsen and Iilende 2007) where the *M. capensis* occupies shallower and more northerly areas than *M. paradoxus*. Still, in some areas the species distributions overlap and for both species the average fish size increase with bottom depth (Gordoa and Duarte 1991). Furthermore, the species distributions may have changed over the years (Burmeister 2001), and change with season as *M. capensis* tend to migrate to shallower waters in the spawning season (Gordoa et al. 2006).

The main objective of this study is to establish a robust method to split the time series of commercial hake catches by species to allow for a more realistic hake assessment. Detailed information in catch compositions, depth, time and geographical position in the survey and observer data will be used to study and model the spatial and temporal patterns and variability in the *M. capensis* - *M. paradoxus* overlap. The robustness of the method is examined by comparing differences in model output and by the examining the sensitivity of the predicted species separated catch time series to the choice of models.

Material and methods

In the Namibian bottom trawl surveys the *M. capensis* and *M. paradoxus* are the main target species, and the trawl stations are distributed semi-randomly along transects 20-25 nautical miles apart perpendicular to the coast with transects length ranging from 20 to 80 nm. Each 100 m bottom depth interval from 90 to 600 m generally has a least one station, and the depth latitude distribution is relatively uniform. A standard *Gisund Super* bottom trawl with 20 mm outer codend mesh, lined with 10 mm inner-net and 4.2 to 4.5 m vertical net opening is used during the surveys (Jørgensen et al. 2007). The catch of hake is sorted and measured by species, and information about time, position, depth, catch, length distributions, individual weight, etc. are stored in the NANSIS database (FAO 2011). All hake surveys since 1997 have been carried out in January-February, whereas some of the earlier surveys were conducted in other seasons (Burmeister 2001). Table 1 shows the number of available observer, survey, and logsheet data, and which depths, latitudes and years used in this study.

The commercial logsheet database of the Namibian hake trawlers includes vessel information and fishing operation data by tow such as date, start and stop time of the tow, positions (latitude and longitude in degrees and minutes), target species, start and stop bottom depth and catch of hake [kg] and other species. The hakes are not separated by species in the logsheets, however, sub-samples of the hake catch are sorted by species by trained observers, who carry out length or biological measurements. For some tows, they do both a length and a biological sample, which generally consists of 200 or 80 fish, respectively, but in most cases they only take either. No individual fish weighting occurs. The hake trawlers use a minimum mesh size of 110 mm in the cod-end, allowing some escapement of smaller hake, and the bulk of the trawlers use trawls with a vertical opening of 4-8 m (Johnsen and Iilende 2007). The ground-gear rigging keep the fishing line close to the seabed to prevent escapement of fish. All commercial hake fishing shallower than 200 m have been prohibited in Namibian waters since 1990, by due to a persistence of small hake in commercial catches the Namibian government introduced additional measures from 2006 which entails that no hake fishing shallower than 300 m from 25° S to the Orange River. In addition a close season was introduced in 2006 which entails that no hake fishing during the month of October.

Species separation using survey data

In selection studies, the retention (*r*) as a function of fish length (*l*) is often described with a logistic regression with the logit link function:

$$r(l) = \frac{\exp(a+bl)}{1+\exp(a+bl)} \qquad (1)$$

where a and b are the selection parameters representing the intercept and slope, respectively.

In the cod-end of the small-meshed survey trawl there is assumedly no length selectivity of hake (Huse et al. 2001), but a species and size dependent escapement occur under the fishing line (Jørgensen et al. 2007). The selection parameters (Eq.1) estimated by Jørgensen et al. 2007) were used as input values (Table 2) in the *mvrnorm* function (Venables and Ripley 2004) in R (2008) to generate *a* and *b* parameters from a multivariate normal distribution to simulate the retention of *M. capensis* and *M. paradoxus* in the survey trawl.

No recent published literature describes the cod-end selectivity of hakes in Namibian commercial trawls, however, the cod-end selectivity in gadoid fisheries is well documented (Galvez and Rebolledo 2005, Jørgensen et al. 2006) and adequate parameters values can be found in the literature. A selectivity study on Chilean hake (*Merluccius gayi gayi*) (Galvez and Rebolledo 2005) was considered as highly relevant due to the species similarities. The validitys of this assumption is strengthen by the early study of Bohl et al. (1971) who concluded that there is no appreciable difference in escapement between the Cape hake and European hakes. Galvez and Rebolledo (2005) estimated *a* and *b* parameters with variance for the retention function (Eq. 1) for several mesh-sizes. Their estimates for 110 mm mesh-size, which is the standard mesh size in the Namibian hake fishery (Johnsen and Iilende 2007) were used as the basis values (Table 2) in the simulations. No covariance estimates were presented by Galvez and Rebolledo (2005) despite the fact that the *a* and *b* parameters are not entirely independent (Jørgensen *et al.* 2006). Thus, a range of covariance values were tested in the preliminary runs. In the final runs, a covariance value estimated for cod by Jørgensen et al. (2006) was used (Table 2). Again, the *mvrnorm* function was used to generate the *a* and *b* parameters from a multivariate normal distribution to simulate the retention of hake in the commercial trawls.

To adjust for size dependent escapement below the fishing line a simulated survey retention curve (*sr*) was multiplied with the number of individuals caught by area swept [nm^2] (*d*) by centimetre group (*j*) and species (*s*) at each survey trawl station (*i*):

$$da_{sij} = sr_{si} \cdot d_{sij} \qquad (2)$$

where *da* is the estimated number of individuals caught if no escapement under the fishing line had occurred.

The simulation of number of individuals caught by area [nm^2] (*dr*) by length (*j*) and species (*s*) if the survey trawl had been replaced by a commercial trawl in station (i) is expressed as:

$$dr_{isj} = da_{isj} \cdot cr_{ij} \qquad (3)$$

where cr is the simulated cod-end selectivity of hakes in the commercial trawl.

Furthermore, the simulated *dr* was converted to a total retained catch in weight (*dw*) by station (*i*), species (*s*) and length (*j*):

$$dw_{is} = \sum_{k=1}^{80} dr_{isj} \cdot w_{sj} \qquad (4)$$

where *w* [g] is the weight by species (*M. capensis* and *M. paradoxus*) and centimetre group:

$$\mathrm{w}_{sj} = a \cdot l_{sj}^{\,b} \qquad (5)$$

and the parameters of the length-weight relationship by species were estimated using biological data in the survey data base.

Thereafter, the species ratio (*spr*) by survey station (*i*) was calculated as:

$$spr_i = \frac{dw_{ci}}{dw_{ci} + dw_{pi}} \qquad (6)$$

where dw_c and dw_p are the total retained catches of *M. capensis* and *M. paradoxus*, respectively. Finally, the spatial and temporal information for survey station (*i)* was merged with the appurtenant *spr* value.

Species separation using observer data

First, the individual length measurements were converted to weight using Eq.5 and summed by species. Then, for each commercial tow with species separated observer data the species ratio was defined as:

$$spr' = \frac{c_c}{c_c + c_p} \qquad (7)$$

where c_{ci} and and c_{di} is the total weight [kg] of all *M. capensis* of *M. paradoxus* individuals measured in tow *i*, respectively. A *spr* was made for each of the length and biological samples.

From SPR to species separated commercial catches

To investigate the species overlap in time and space, a logistic regression with a binominal response (Venables and Ripley 2004) was used to examine the effect of the explanatory variables latitudal position (*lat*), depth, year (factor), quarter (factor) on the response variable *spr* (from Eq. 6 and 7). The explanation powers of the various variables and chi-square based tests of the residual deviance were used in the model selection. A species ratio $s\hat{p}r_k$ for each commercial tow was predicted by feeding the selected logistic regression models with spatial and temporal log-sheet information of tow (*k*).

Based on the $s\hat{p}r_k^{'}$ values, the *M. capensis* ($\hat{c}_{cap}$) and *M. paradoxus* ($\hat{c}_{par}$) catches by commercial tow (*k*) were calculated as:

$$\hat{c}_{cap,k} = s\hat{p}r_k \cdot c_k \ , \ \hat{c}_{par,k} = (1 - s\hat{p}r_k) \cdot c_k \qquad (8)$$

where *c* is the recorded catch of hakes in the logsheets. To study the sensitivity of the choice of data source and model selection on these predictions a time series of the percentage *M. capensis* in the quarterly hake catches were calculated as:

$$pct.mc_{q,y} = \frac{\sum_{k \in M_{q,y}} \hat{c}_{cap,k}}{\sum_{k \in M_{q,y}} c_k}$$

where $M_{q,y}$ is the set of values at given year y and quarter q.

Results

The range of variations in the simulated retention curves is illustrated by depicting 20 random runs (Figure 1), which show a marked variation between runs. In contrast, the length weight relationships were consisted between surveys (Figure 2) and were kept constant for all years ($w_{capensis} = 0.0067 \cdot l^{3.004}$, $w_{paradoxus} = 0.0058 \cdot l^{3.061}$). These relationships were also used to convert the individual length data to weight in the observer data.

Unless the hake catch in the i^{th} survey station consisted of one hake species only, the spr_i value varied between simulation runs and the between simulation runs variation increased with the species overlap (Figure 3). In the observer data, the species composition in the length and biological for the same tow revealed a large inconsistency in the estimated *spr* (Figure 4). Furthermore, a surprisingly large number of *M. capensis* identified in deep waters suggest dubious species identification by the observers; no *M. capensis* has been found deeper than 602 meters during the surveys whilst about 19% of the commercial hauls with observer samples contained *M. capensis* in the depths between 600 and 800 meters. Nevertheless, both data sets were dominated by samples containing only one species as about 77% and 68% of the *spr* values from the survey and observer data, respectively, were either one or zero. Only 10% and 18% of survey and observer stations, respectively, had a *spr* value between 0.1 and 0.9 (Figure 3). *M. paradoxus* was the dominating species in the observer data and 57% of all samples consisted solely of this species. In the survey data, 33% of the station consisted only of *M. paradoxus*.

The *spr* varied with depth and latitude (Table 3) for both the survey and observer data, where *M. paradoxus* dominated the catches in deeper and more southerly waters (Figure 5a). Depth and latitude, explained 51% and 85% of the residuals for the observer and survey data, respectively (Table 4). Although *spr* changed significantly between seasons (quarters) and years (Table 3) the inclusion of year and quarter as exploratory variables explained only about 4% extra to the residuals in the survey data. For the observer data, the inclusion of these variables explained less than 1.5% extra.

The latitudal-depth distribution of the commercial tows is patchy as the fleet concentrates its effort in some areas (Figure 5b), which mainly corresponds to areas that are dominated by either of the species (Figure 5a). In fact, less than 20% of the commercial tows had a predicted species ratio $s\hat{p}r_k$ (predicted from the logistic regression models) in the range between 0.2 and 0.8. The histograms of these $s\hat{p}r_k$ values also suggest (Figure 6) that the trawlers mainly target either of the species.

Therefore, in spite of the relatively high variation in *spr* in some areas (Figure 4), the predicted percentage of *M. capensis* in the quarterly hake catches (Eq. 9) were consistent and robust to variation in retention simulation model parameters and to choice of explanatory variables to predict the $s\hat{p}r_k$ (Figure 7). However, due to the poor seasonal coverage of the surveys, which mainly have covered the first quarters, the inclusion of quarter as an explanatory variable caused considerable noise in the predicted catches (Table 5). Still, as shown in Figure 7, this inclusion did not have a marked effect on the results of the percentage of *M. capensis* in the first quarter of the year.

By using the tempo-spatial species distribution models it is also possible produce a likely geographical commercial catch statistics of *M. capensis* and *M. paradoxus* (Figure 8), which shows that *M. paradoxus* has dominated in the overall annual hake catches in the 1998-2007 period (Table 6). The estimated percentage of *M. paradoxus* was at maximum in 2002 with 69% and minimum in 1999 (52%). These number corresponds well with the recorded landings by species (Numbers from unpublished annual hake TAC-reports, see an example in Republic of Namibia 2007, page 26) (Pearson correlation, r=0.87) (Table 6), but the percentage of *M. capensis* in the catches is about 5.6 percentage points higher than the average percentage of *M. capensis* in the official landings ranging from 20 to 43% .

Discussion

In consistency with previous works (e.g. Gordoa 1995, Burmeister 2001), the estimated species ratio from the observer and survey samples show that *M. capensis* is generally distributed shallower and more northerly than *M. paradoxus*. The survey data suggest that catches deeper than 600 m consist only of *M. paradoxus*, whereas the observer frequently identified *M. capensis* also in deeper waters. All the scientific survey personnel have good taxonomy knowledge and therefore it is likely that misidentification rate is considerable higher in the observer data. By comparing the species compositions in the biological and length samples from identical commercial tows it is evident that species misidentification have been relatively common amongst observers (Figure 4), but from the data available it has not been possible to quantify the misidentification rate. In contrast to survey data, the geographical coverage of the observer data is relatively poor in the northern areas as 80% of the data are collected south of 23.2°, whereas only 48% and 60% of the survey and logsheet data, respectively are from south of the 23.2°. The reason for this latitudal skewness in the observer data relates to the general pattern that the larger vessels with available space for observers operate more frequent in the southern areas. On the other hand, the observer data have a full seasonal coverage and the observer species ratios have the strength that they are directly derived from the samples and not affected by any retention modelling uncertainty. The use of empirical based and realistic wide range of selectivity curves cannot compensate for unknown factors such as individuals' position in the water column and reaction towards the vessel and catching equipment. Furthermore, the availability and escapement vary between species and size, changes in the environment, and an individual's motivation for spawning, feeding et cetera and may affect the relationship between caught and true population (Hjellvik et al. 2003). Hence, the catch in a bottom trawl is seldom presenting an accurate picture of the true population. One specific concern is related to the lifting of hakes off the bottom at night (Payne and Punt 1995, Huse et al. 1998; Iilende et al. 2001) which affect the size and species dependent diel variation in the catch rates (Johnsen and Iilende 2007). As the commercial trawlers are fishing 24-h and most survey stations are carried out at daytime in shallow waters (< 450 m) (Johnsen and Iilende 2007) the estimated species ratios may be biased.

Despite these shortcomings, parallel trawling shows that the repeatability is high (Strømme and Iilende 2001, Hjellvik et al. 2002) in stable environments. It is reasonable to assume that variable conditions would have had resulted in unpredictable species ratios, but in accordance with previous studies (Gordoa et. al. 1995, Burmeister 2001) it is evident that the distributions of fishable *M. capensis* and *M. paradoxus* are predictable. There is a consistent species distribution overlap in depths between 280 m and 500 m along the Namibian coast, and *M. paradoxus* dominates deeper and more southerly waters. Furthermore, the size dependent depth distribution of hake (Gordoa and Duarte 1991, Gordoa et. al. 1995) where similar size groups are distributed closer in space (Johnsen 2003) is also consistent between surveys (Burmeister 2001). Also the fact that the spatiotemporal species ratios model outcomes are similar for the two independent data sources support reliability of the methods in this study.

The spatiotemporal distribution variability reported for both hakes (e.g. Gordoa et al. 1995, Johnsen and Iilende 2007) are considered in the model selected, but the procedure may have a lack of flexibility for abrupt species displacement which was the case in 1994 when large amounts of juvenile *M. capensis* migrated offshore to avoid hypoxia waters and caught by commercial trawlers Hamukuaya (1998). In accordance with the law of parsimony (Dobson 2002), the models selected in this study do not consider all the complexity of the system. Still, the species ratio predictability of most commercial catches are likely to be high as the effort of the commercial trawlers seems to be more directed to a single species fishery and a vast fraction of the commercial hake catches were carried out in depths and areas dominated by either of the hake species. Although it is challenging task to make an adequate and realistic species separation within in the overlapping distribution belt, the final output presented as the percentage of *M. capensis* in the hake catches by quarter seems robust and insensitive to selection curves and models to predict species proportions in the commercial catches. The predicted proportion of *M. capensis* in the annual hake catches ranges from 30 % to 44 %, which correspond well to species proportion in the official landings presented in the TAC reports.

Summary

Large differences in geographical distribution and migration (Burmeister 2001), spawning behaviour (Gordoa et al. 2006), growth (Chłapowski 1982) and recruitment (e.g. Voges et al. 2002, Kainge et al. 2007) between *M. capensis* and *M. paradoxus* are ignored in the single hake stock assessment model used currently in Namibia. This study has presented a procedure to separate the commercial hake catches by species using scientific survey and observer data information to make a spatiotemporal species ratio model. There no reason to believe that any bias is introduced by the procedure, and the final output given as percentage of *M. capensis* of the total hake catch by quarter show that the method seems robust. Although the models lack the flexibility to predict abrupt changes in the geographical species distribution, the prediction robustness of the presented procedures indicate that a biologically realistic single species hake assessment is now possible.

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Tables

Table 1: Number of available data with hake catches by data source, and which years, depths and latitudes that have been used in this study.

Data	Number	Years	Depths	Latitude
Logsheets	524840	1998-2007	200-800	17 - 30°
Observer (length samples)	29614	1998-2009	200-800	17 - 30°
Observer (biological samples)	13204	1998-2009	200-800	17 - 30°
Survey stations	4239	1993-2008	>90, <700	17 - 30°

Table 2: Selection parameters (Eq.1) used as input values in the *mvrnorm* function to generate *a* and *b* parameters to simulate the retention of *M. capensis* (I) and *M. paradoxus* (II) in the survey trawl, and hakes in a commercial 110 mm cod-end trawl (III).

	I		II		III	
Parameter	Value	Variance	Value	Variance	Value	Variance
a	3	1	2	1	-11.86	2.00
B	-0.03	0.0002	-0.03	0.0002	0.30	0.001
Covar	-0.01		-0.005		-0.03	

Table 3: Parameter estimates with standard errors and p-values for the explanatory variables of the best fit of the logistic regression model with species ratio as response variable.

	Observer		
	Estimate	Std.error	P
(Intercept)	16.909	0.192	< 0.001
depth	-0.023	0.000	< 0.001
latitude	0.353	0.006	< 0.001
quarter2	0.268	0.039	< 0.001
quarter3	0.053	0.039	0.175
quarter4	0.044	0.055	0.428
year1999	0.143	0.070	0.041
year2000	-0.373	0.079	< 0.001
year2001	-0.488	0.082	< 0.001
year2002	-1.123	0.114	< 0.001
year2003	-0.568	0.085	< 0.001
year2004	-0.357	0.070	< 0.001
year2005	-0.338	0.069	< 0.001
year2006	-1.212	0.074	< 0.001
year2007	-0.721	0.071	< 0.001
year2008	-0.714	0.067	< 0.001
year2009	-0.546	0.063	< 0.001

	Survey		
	Estimate	Std.error	P
(Intercept)	28.269	1.278	< 0.001
depth	-0.043	0.002	< 0.001
latitude	0.482	0.030	< 0.001
quarter2	0.566	0.368	0.124
quarter3	-0.704	0.564	0.211
quarter4	0.842	0.393	0.032
year1994	0.033	0.364	0.928
year1995	-1.435	0.492	0.003
year1996	-1.618	0.444	< 0.001
year1997	-2.765	0.487	< 0.001
year1998	-1.750	0.428	< 0.001
year1999	-0.890	0.428	0.038
year2000	0.135	0.504	0.800
year2001	-0.693	0.485	0.153
year2002	-1.420	0.497	0.004
year2003	-1.164	0.499	0.019
year2004	-1.435	0.494	0.003
year2005	-0.774	0.508	0.128
year2006	-2.442	0.499	< 0.001
year2007	-2.017	0.494	< 0.001
year2008	-2.740	0.489	< 0.001

Table 4: Analyses of deviance for different explanatory variables with species ratio as response variable.

	Observer			Survey		
	Df	Deviance	% Explained	Df	Deviance	% Explained
NULL	42817	40694		4238	5144	
depth	1	16515	40.6%	1	4008	77.9%
latitude	1	4194	10.3%	1	350	6.8%
quarter	3	46	0.1%	3	78	1.5%
year	11	557	1.4%	15	114	2.2%

Table 5: Correlations of the quarterly estimates of the percentages of *M. capensis* in the commercial hake catches predicted from four logistic regression models estimated from observer and survey data, respectively. Mod I: depth and latitude as explanatory variables. Mod II: depth, latitude and quarter as explanatory variables. Mod III: depth, latitude, quarter and year as explanatory variables. Mod IV: depth, latitude and year as explanatory variables.

		Observer				Survey			
	Model	I	II	III	IV	I	II	III	IV
Observer	I	1.00	0.99	0.88	0.89	0.99	0.59	0.77	0.88
	II	-	1.00	0.89	0.89	0.99	0.65	0.79	0.87
	III	-	-	1.00	0.99	0.90	0.62	0.85	0.90
	IV	-	-	-	1.00	0.91	0.58	0.84	0.91
Survey	I	-	-	-	-	1.00	0.58	0.77	0.88
	II	-	-	-	-	-	1.00	0.74	0.53
	III	-	-	-	-	-	-	1.00	0.93
	IV	-	-	-	-	-	-	-	1.00

Table 6: Predicted percentage of *M. capensis* in the annual hake commercial catches versus the official percentage of *M. capensis* in the Namibian hake landings (Numbers from unpublished annual hake TAC-reports, see an example in Republic of Namibia 2007, page 26) The presented catch species proportions are predicted using the survey data and depth and latitude as explanatory variables.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Catch	42	48	47	33	31	34	47	39	47	29
Landings	NA	NA	43	34	20	31	41	33	36	24

Figure legends

Figure 1: Simulated retention curves (n=20) in the Namibian survey trawls for *Merluccius capensis* (top), *M. paradoxus* (centre) and hakes in a commercial trawl with a 110 mm cod-end.

Figure 2: Estimated length-weight relationships (line) of *M. capensis* (top) and *M. paradoxus* (bottom) using the recorded survey length and weight measurements (grey dots).

Figure 3: Histogram of the *spr* (average of 20 simulation runs), and a scatterplot (dots) of the average *spr* versus the variance of the simulation runs.

Figure 4: Hake species ratio estimated from the observer length samples (*len.spr*) versus observer biological samples (*bio.spr*) for all tows with both type of samples.

Figure 5: (a) The variance in *spr* of the simulation runs by depth and latitude, (b) number of commercial tows conducted by cells of 5 m and 0.1° from 1998 to 2007.

Figure 6: Histograms of the predicted species ratio ($\hat{spr}$) for the commercial logsheet tow using survey (black bars) and observer (grey bars) logistic regression models with depth and latitude as exploratory variables.

Figure 7: Upper: Percentages of *M. capensis* in the commercial logsheet hake catches by quarter using predictions based on logistic regression models. Ten time series with individual retention simulations by tow estimated from the survey data with depth and latitude as exploratory variables (continuous lines on top of each other). Time series when predicted species ratios are based on observer data using models with the exploratory variables; depth and latitude (dotted line), and quarter (dotted line and plus signs). Centre: Difference in percentage points (pp) from the time series presented in the upper panel when predicted species ratios are based on observer data using models with the exploratory variables; depth and latitude (continuous line), and quarter (dotted line), and/or year (plus sign). Lower: Difference in percentage points (pp) from the time series presented in the upper panel when predicted species ratios are based on survey data using models with the exploratory variables; depth, latitude and quarter (dotted line), and/or year (plus sign).

Figure 8. Predicted catch of *M. capensis* and *M. paradoxus* by depth and latitudal interval for the period 1998-2007. The numbers (%) in upper left corners present the predicted percentage of *M. capensis.* The presented catch species proportions are predicted using the survey data and depth and latitude as explanatory variables.

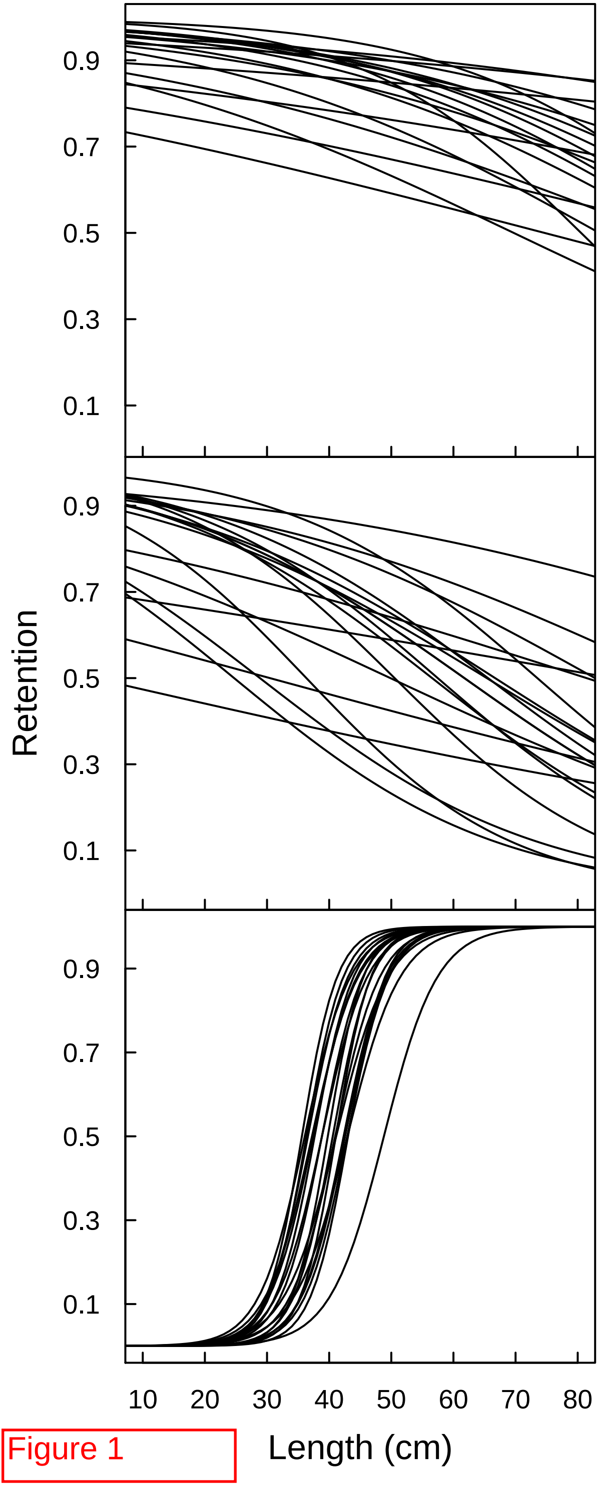


Figure 1

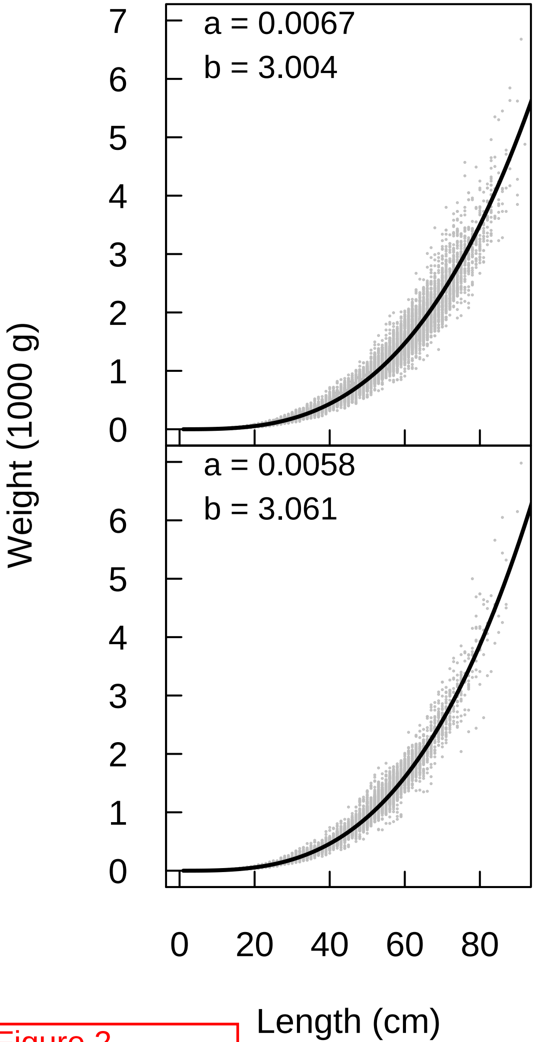
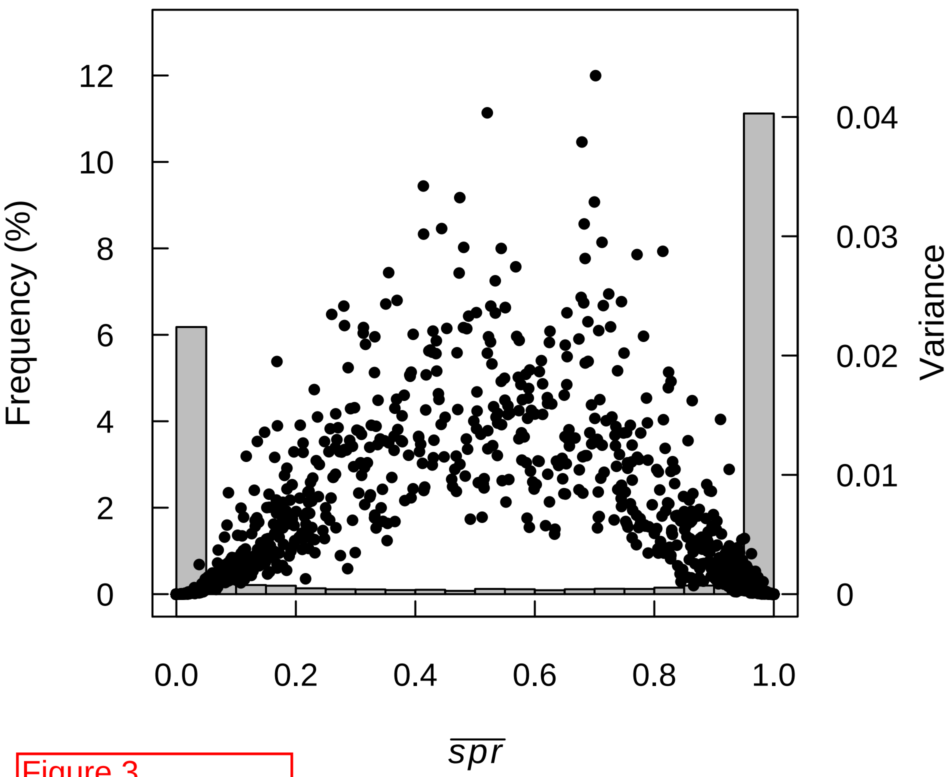

a = 0.0067
b = 3.004
a = 0.0058
b = 3.061
Weight (1000 g)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
0
20
40
60
80
Length (cm)

Figure 2



12
10
8
6
4
2
0
Frequency (%)
0.04
0.03
0.02
0.01
0
Variance
0.0
0.2
0.4
0.6
0.8
1.0
$\overline{spr}$

Figure 3

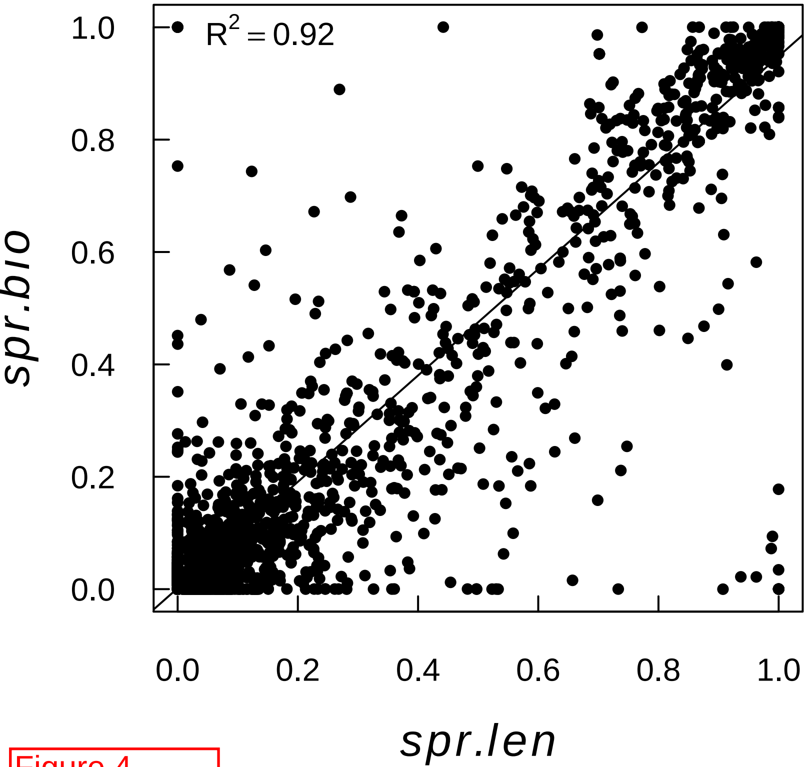
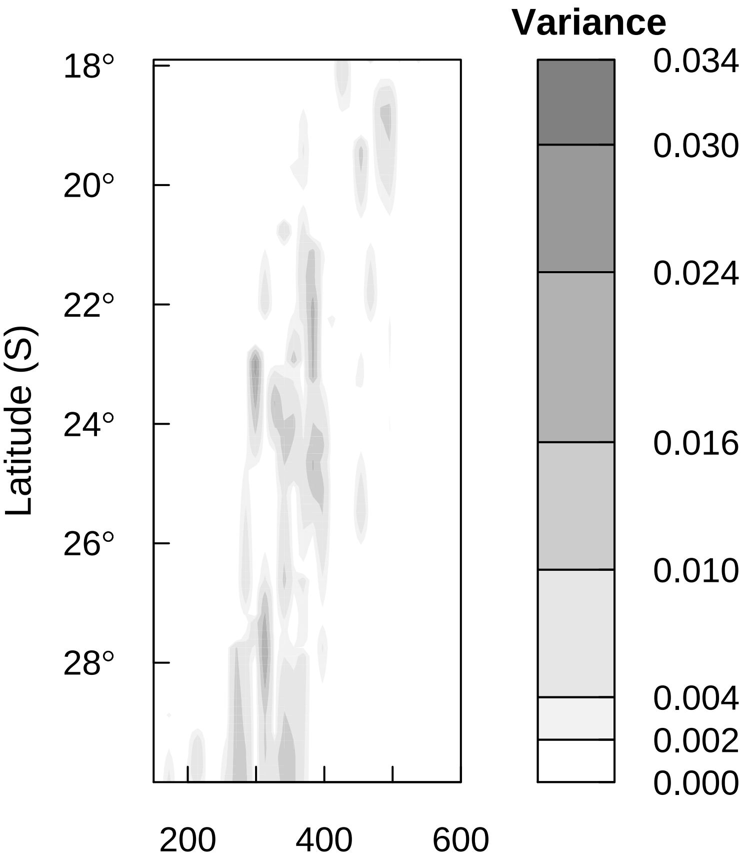


Figure 4



Variance
0.034
0.030
0.024
0.016
0.010
0.004
0.002
0.000
18°
20°
22°
24°
26°
28°
Latitude (S)
200
400
600
Depth (m)

Figure 5a

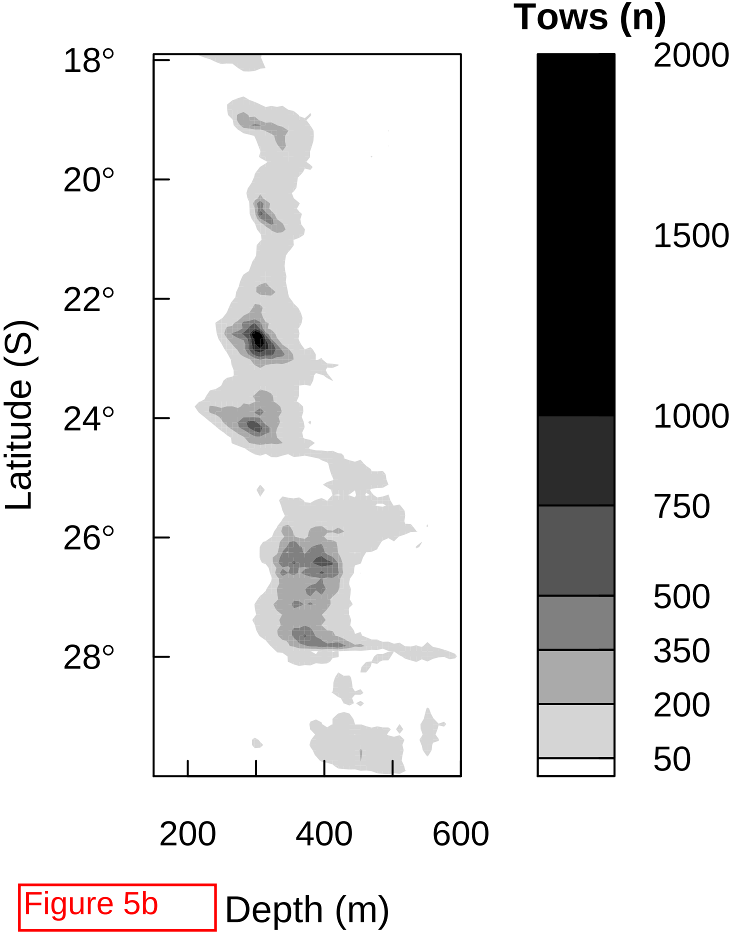

Tows (n)
2000
1500
1000
750
500
350
200
50
18°
20°
22°
24°
26°
28°
Latitude (S)
200
400
600
Depth (m)

Figure 5b

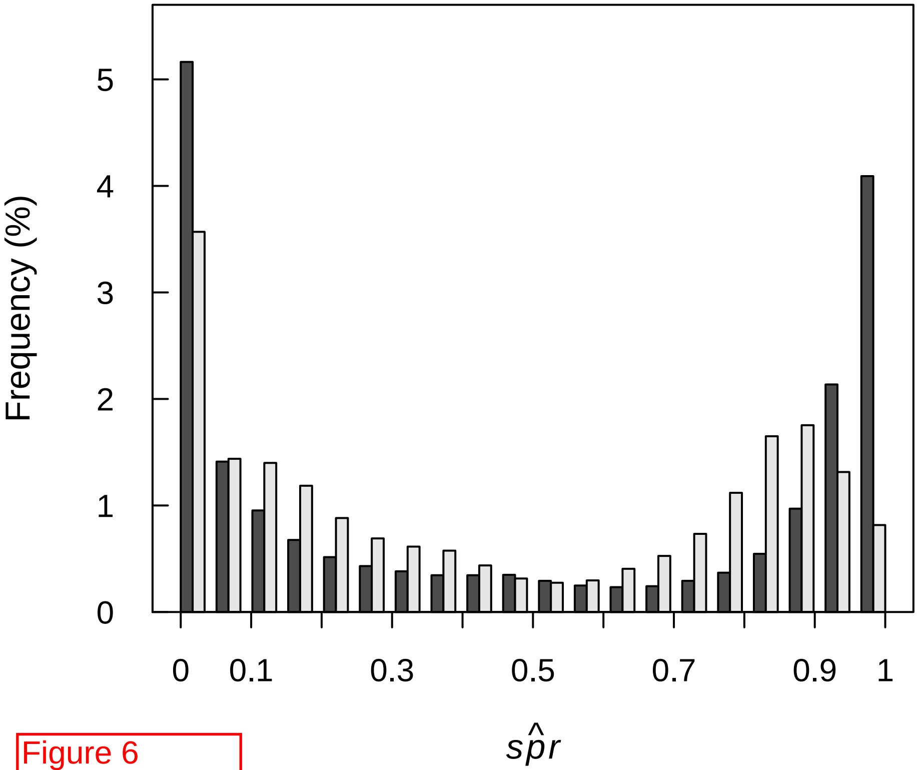
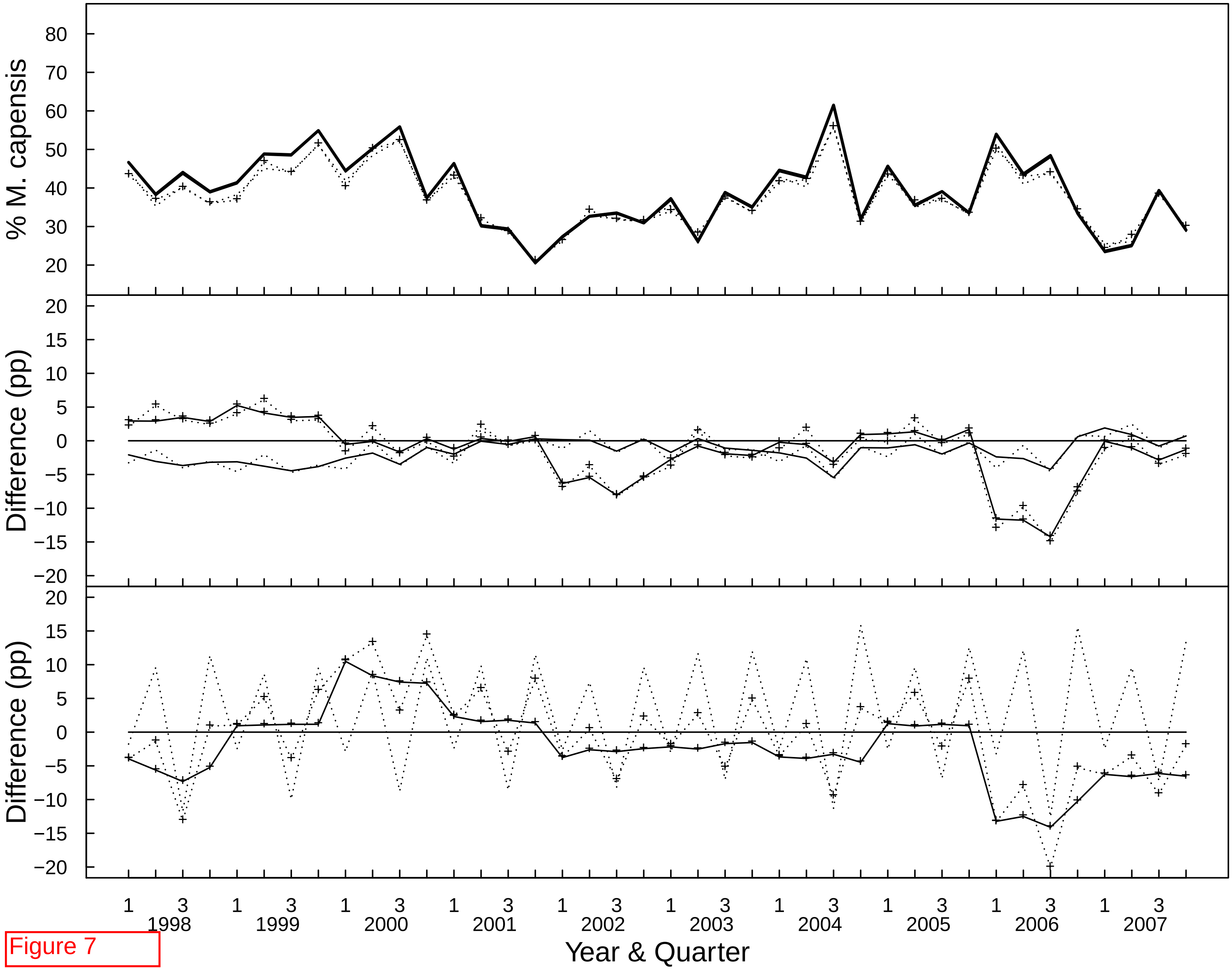


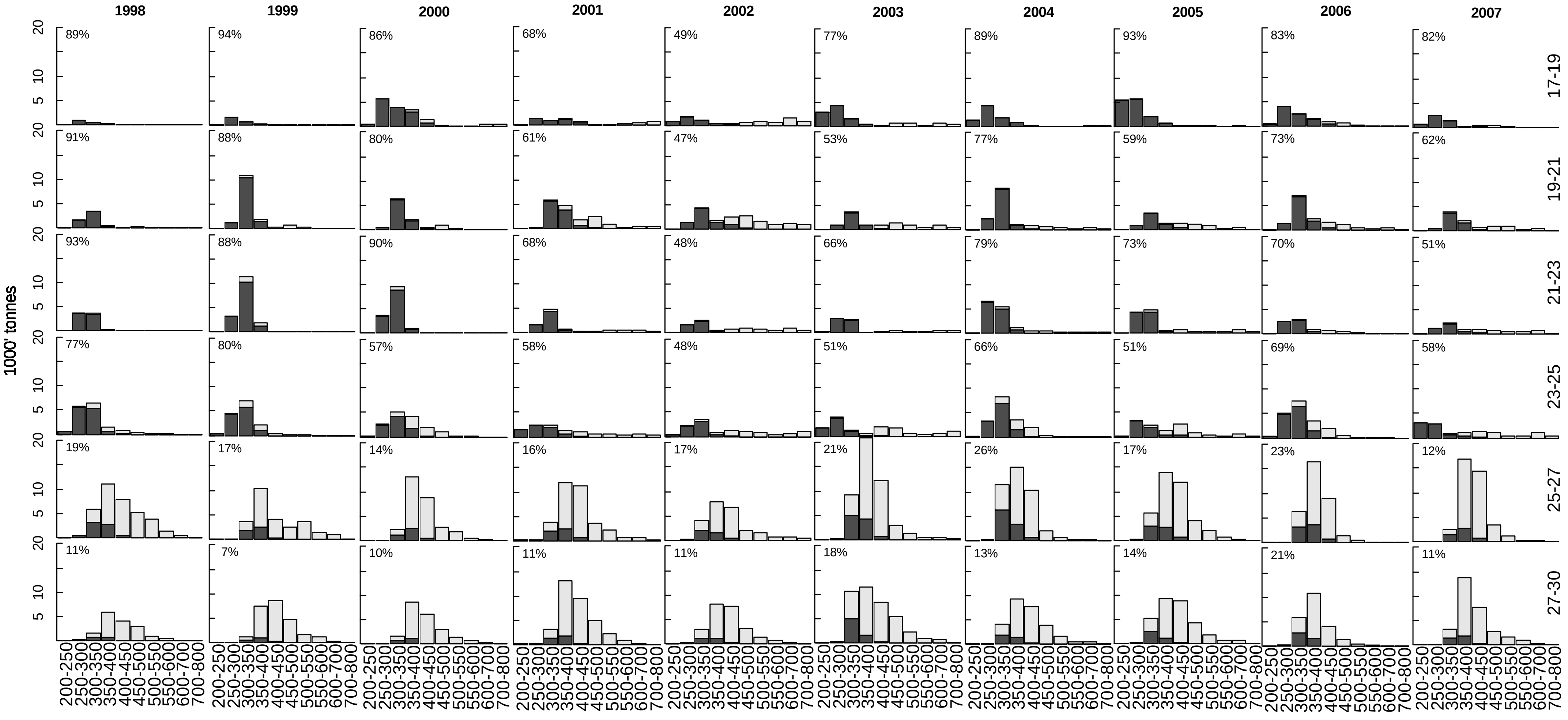
Figure 6



% M. capensis
Difference (pp)
Difference (pp)
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year & Quarter

Figure 7

Figure 8


1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
1000' tonnes
17-19
19-21
21-23
23-25
25-27
27-30
200-250
250-300
300-350
350-400
400-450
450-500
500-550
550-600
600-700
700-800