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A robust method for generating separate catch time-series for each of the hake species caught in the Namibian trawl fishery

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Merluccius capensis **and** ***M. paradoxus*** **are morphologically very similar and cannot be registered separately by species in the Namibian commercial hake catches. This prevents a biologically plausible single-species stock assessment from being carried out. Here, species-separated data from an observer programme and scientific surveys are used to model the spatio-temporal overlap of the two species, which are then used to predict the catch by species in each commercial trawl. The study presents a method that compensates for both the escapement and codend retention differences in the survey and commercial trawls. The accuracy with which species were identified was found to be considerably higher during scientific surveys compared with that obtained from observers, whereas the seasonal coverage of the observer data was much better than that of the surveys. The estimated spatio-temporal model parameters from each of these two data sources were similar, however, despite these differences. In support of previous findings,** ***M. capensis*** **had a shallower and more northerly distribution than** ***M. paradoxus*** **with depth and latitude together explaining 51% and 85% of the residuals in the models produced from observer and survey data respectively. Model outputs suggest that during the period 1998–2007,** ***M. paradoxus*** **has dominated the annual hake catches. Even though our method is unable to account for abrupt and unexpected changes in the species' geographical distribution, it does open the way for the establishment of a single-species hake assessment in Namibia.**

Keywords: assessment, landings, *Merluccius*, Namibia, single species

Introduction

Three species of hake, *Merluccius capensis*, *M. paradoxus* and *M. polli*, are found off Namibia, but unlike the former two species, which are distributed along the entire coast, the distribution of *M. polli* in Namibian waters is restricted to the northern region (Lloris et al. 2005). Because *M. polli* only occur in low abundance, the Namibian hake fishery is regarded as a mixed *M. capensis* and *M. paradoxus* fishery (Gordoa et al. 2000). A large overlap in morphological characteristics makes species identification of the genus *Merluccius* difficult, and consequently *M. capensis* and *M. paradoxus* were until 1960 classified as one species (Lloris et al. 2005). This similarity makes it impractical to record catches of hake by species in the commercial fishery (Gordoa et al. 2000). Hake are, however, recorded by species during scientific surveys, and trained observers also take species-separated length and biological samples from some commercial hake catches.

In Namibia, an age-structured production model has been used to assess the state of the hake stocks since 1998 (Boyer and Hampton 2001). The key input data for these assessments comprise bottom trawl survey estimates and commercial catch-at-age and catch per unit effort (CPUE) indices, none of which are separated by species in the assessment model. Consequently, any difference in the population dynamics between the species is ignored in both the hake assessment and subsequent management decisions (Butterworth and Rademeyer 2005). Given that the stock dynamics vary with species (Cohen et al. 1990), it is, however, crucial to separate the input data by species to achieve a more realistic hake assessment (Butterworth and Rademeyer 2005).

Despite the morphological similarity, the two species show marked differences in their depth preference and geographical distribution (Gordoa and Duarte 1991, Burmeister 2001, Gordoa et al. 2006, Johnsen and Iilende 2007). Generally, *M. capensis* occupies shallower and more northerly areas than *M. paradoxus*, but the overlap can be large in some areas. The species' distributions may, however, have changed over the years (Burmeister 2001). Additionally, *M. capensis* tend to migrate to shallower waters during the spawning season (Gordoa et al. 2006). As for most demersal fish, the average fish size of both these hake species also increases with bottom depth (Gordoa and Duarte 1991).

The main objective of this study was to establish a robust method for apportioning the time-series of commercial hake catches between the two species to allow for a more realistic hake assessment. Information gathered from the scientific surveys and the observer programme database include catch compositions, bottom depth, time and geographical position.

These are used to analyse and model the spatial and temporal patterns underlying the *M. capensis–M. paradoxus* overlap. The robustness of the method is examined by comparing differences in model output (where the input data are taken either from the scientific surveys or from the observer database) and by examining the sensitivity of the predicted time-series of species-separated catches to the choice of models.

Material and methods

Namibian bottom trawl surveys predominantly target *M. capensis* and *M. paradoxus* during trawl stations that are distributed semi-randomly along transects positioned perpendicular to the coast, spaced 20–25 nautical miles (nmi) apart and lengths ranging from 0 to 80 nmi. Each 100 m bottom depth interval from 90 to 600 m generally contains at least one trawl station, and the distribution of trawls for each depth and latitude interval is kept relatively uniform. A standard 'Gisund Super' bottom trawl with 20 mm outer-codend mesh, lined with 10 mm inner-net, with a vertical net opening of 4.2–4.5 m, is used during the surveys (Jørgensen et al. 2007). The catch of hake is sorted and weighed by species, and information on time, position, depth, catch, length distribution, individual fish weight, etc. is 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). The extent and range of observer, scientific survey and commercial logsheet data used in this study is shown in Table 1.

The commercial logsheet database of the Namibian hake trawlers includes vessel information and fishing operation data for each trawl, such as date, start and end time of the trawl, position (latitude and longitude in degrees and minutes), target species, start and end bottom depth, and catch weight of hake (kg) and other species. An on-board observer sampling programme was fully implemented in 1998 whereby trained observers sort subsamples of some of the commercial hake catches by species. Either length measurements (200 fish) or biological assessments (80 fish) of fish contained in the subsamples are done routinely. No individual fish is weighed and only in some cases are both length and biological data obtained. The hake trawlers use a minimum mesh size of 110 mm in the codend, allowing for 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 keeps the fishing line close to the seabed to prevent escapement of fish underneath. Since 1990, commercial hake fishing has been prohibited in waters shallower than 200 m. Owing to the persistent prevalence of small hake in commercial catches, the Namibian government introduced additional measures from 2006 onwards that disallows hake fishing in waters shallower than 300 m in the area south of 25° S to the Orange River. A closed season was also introduced in 2006, which prohibits 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 by a logistic regression with the logit link function:

$$r(l) = \frac{\exp(\mathrm{a} + \mathrm{b}l)}{1 + \exp(\mathrm{a} + \mathrm{b}l)} \tag{1}$$

where a and b are the selection parameters representing the intercept and slope respectively (Jørgensen et al. 2006).

Whereas length selectivity of hake in the codend of the small-meshed survey trawl (Huse et al. 2001) is assumed to be non-existent, species- and size-dependent escapement does occur under the fishing line (Jørgensen et al. 2007). The selection parameters (Equation 1) estimated by Jørgensen et al. (2007) were used as input values (Table 2) in the 'mvrnorm' function (Venables and Ripley 2004) in R (R Development Core Team 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.

Although no recently published literature is available to describe the codend selectivity of hakes in Namibian commercial trawls, the codend selectivity in gadoid fisheries is well documented (Galvez and Rebolledo 2005, Jørgensen et al. 2006) and several parameter estimates can be found in the literature. A selectivity study on Chilean hake *Merluccius*

Table 1: Number of data containing hake catches by data source, period, depth range and latitude that have been used in this study

Data	Number	Period	Depth (m)	Latitude (°S)
Logsheets	524 840	1998–2007	200–800	17–30
Observer (length samples)	29 614	1998–2009	200–800	17–30
Observer (biological samples)	13 204	1998–2009	200–800	17–30
Survey stations	4 239	1993–2008	90–700	17–30

Table 2: Selection parameters (Equation 1) used as input values in the 'mvrnorm' function to generate a and b parameters to simulate the retention of *M. capensis* (Model I) and *M. paradoxus* (Model II) in the survey trawl, and all hake in a commercial 110 mm codend trawl (Model III)

Parameter	Model I		Model II		Model III	
	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
Covariance	−0.01		−0.005		−0.03	

gayi gayi (Galvez and Rebolledo 2005) was considered highly relevant to the Namibian situation given the species' similarities. The validity of this assumption is strengthened by the conclusions of Bohl et al. (1971) that there are no appreciable differences in escapement between the Cape hake and European hakes. Galvez and Rebolledo (2005) estimated a and b parameters, including variance, of the retention function (Equation 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, however, presented by Galvez and Rebolledo (2005), despite the fact that the a and b parameters are not entirely independent (Jørgensen et al. 2006). Consequently, 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. Note that on account of stochasticity, the simulated selectivity curves varied between trawl stations.

To adjust for size- and species-dependent escapement under the fishing line, the catch rate (*d*) by species (*s*) and length class (*j*) at each survey station (*i*) was divided by a simulated survey selectivity (sr):

$$\mathrm{da}_{sji} = d_{sji} / \mathrm{sr}_{sj} \tag{2}$$

where da_{sji} is the estimated catch rate if there was no escapement under the fishing line. If the survey trawl was replaced by a commercial trawl at survey station (*i*) the estimated catch rate (dr) was expressed as:

$$\mathrm{dr}_{sji} = da_{sji} \times \mathrm{cr}_j \tag{3}$$

where cr_j is the simulated codend selectivity of hakes in the commercial trawl. Furthermore, the simulated dr_{sji} was converted to a total retained catch weight (dw) by species (*s*), and length class (*j*) for each station (*i*):

$$\mathrm{dw}_{si} = \sum_{j=1}^{80} \mathrm{dr}_{sji} \times w_{sj} \tag{4}$$

where w_{sj} is the individual fish weight (g) by species for each length class (cm). The a and b parameters of the length–weight relationship by species (*s*) were estimated using biological data in the survey database:

$$\mathrm{w}_s = \mathrm{a}_s l_s^{\mathrm{b}} \tag{5}$$

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

$$\mathrm{spr}_i = \frac{\mathrm{dw}_{\mathrm{cap},i}}{\mathrm{dw}_{\mathrm{cap},i} + \mathrm{dw}_{\mathrm{par},i}} \tag{6}$$

where $\mathrm{dw}_{\mathrm{cap}}$ and $\mathrm{dw}_{\mathrm{par}}$ are the total retained catches (kg) of *M. capensis* and *M. paradoxus* respectively. Finally, the spatial and temporal information for survey station (*i*) was merged with the corresponding spr_i value.

Species separation using observer data

First, the individual length measurements were converted to weight using Equation 5 and summed by species. Then for each commercial trawl that had matching species-separated observer data, the species proportion spro_i in each of the length frequency and biological subsamples was estimated as:

$$\mathrm{spro}_i = \frac{c_{\mathrm{cap},i}}{c_{\mathrm{cap},i} + c_{\mathrm{par},i}} \tag{7}$$

where $c_{\mathrm{cap},i}$ and $c_{\mathrm{par},i}$ is the total weight (kg) of all *M. capensis* and *M. paradoxus* individuals measured in the sample *i* respectively. The spro_i values were merged with the corresponding logsheet information.

Spatio-temporal models of the species overlap

Modelling of the spatio-temporal overlap in hake species was carried out separately for the survey (spr_i) and observer (spro_i) species proportions. Logistic regressions with a binomial response (Venables and Ripley 2004) were used to examine the effect of the explanatory variables latitudinal position (latitude: degrees, minutes), depth (m), year (factor; 1998–2007) and quarter (factor; 1–4) on the response variable (from Equations 6 and 7). The explanatory power of the different variables and χ^2-based tests of the residual deviance were used in the model selection.

For each commercial tow (*k*), a species proportion spr'_k was predicted by feeding the selected logistic regression models with spatial and temporal data contained in the logsheet of the *k*th trawl, and the catches of *M. capensis* ($\hat{c}_{\mathrm{cap}}$) and *M. paradoxus* ($\hat{c}_{\mathrm{par}}$) by commercial trawl were estimated as:

$$\hat{c}_{\mathrm{cap},k} = \mathrm{spr}'_k\, c_k,\ \hat{c}_{\mathrm{par},k} = (1 - \mathrm{spr}'_k)\, c_k \tag{8}$$

where c_k is the combined recorded catch of hake (kg) recorded in the logsheet. To investigate the sensitivity to the choice of data source and model selection on these catch predictions, a time-series of the percentage *M. capensis* (pct.cap) in the quarterly hake catches was calculated as:

$$\mathrm{pct.cap}_{q,y} = 100 \frac{\sum_{k \in M_{q,y}} \hat{c}_{\mathrm{cap},k}}{\sum_{k \in M_{q,y}} c_k} \tag{9}$$

where $M_{q,y}$ is the set of values in the logsheets within a given year *y* and quarter *q*.

Results

The extent of variation in the simulated retention curves is illustrated by depicting 20 random runs (Figure 1). The length–weight relationships were consistent between surveys for each species (Figure 2) and consequently the regressions obtained from pooled observations over the entire period ($w_{\mathrm{cap}} = 0.0067 l^{3.004}$, $w_{\mathrm{par}} = 0.0058 l^{3.061}$) were applied for all years to convert the individual length data to weight in the survey and observer data.

Unless the hake catch in the *i*th survey station consisted of one hake species only, the average spr_i value varied

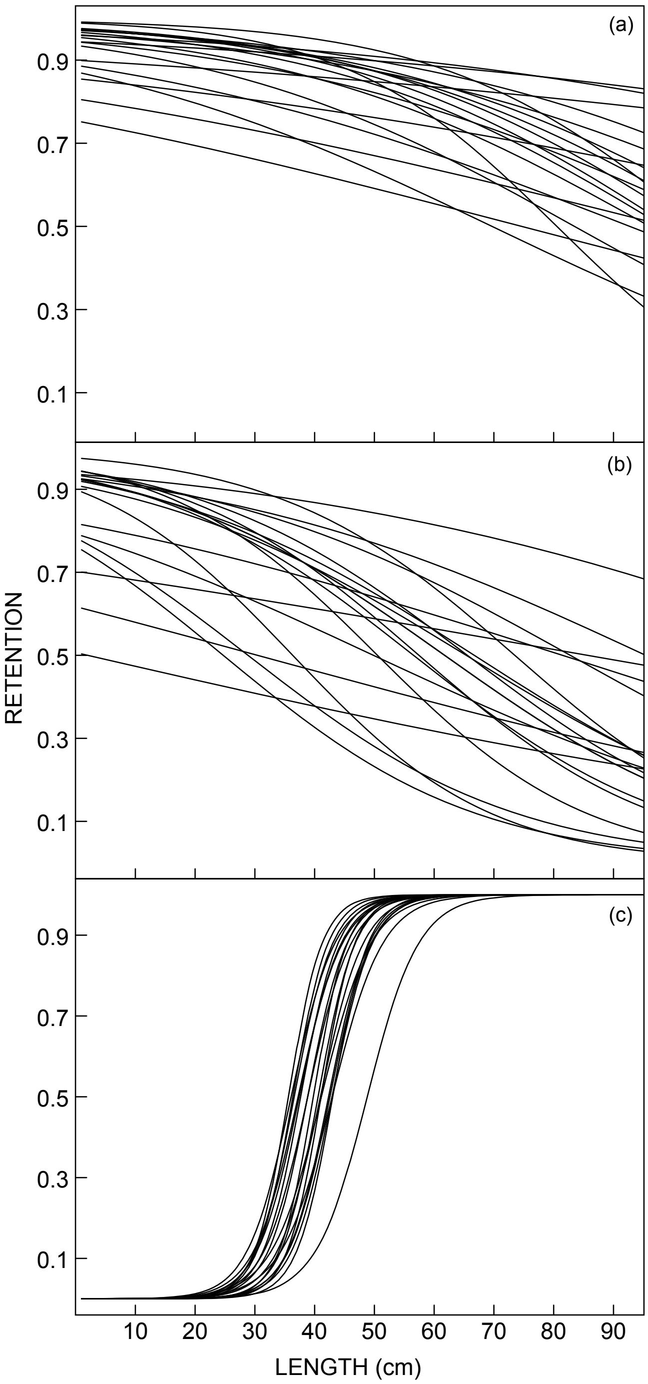

Figure 1: Simulated retention curves (n = 20) in the Namibian survey trawls for (a) *Merluccius capensis*, (b) *M. paradoxus* and (c) hakes in a commercial trawl with a 110 mm codend

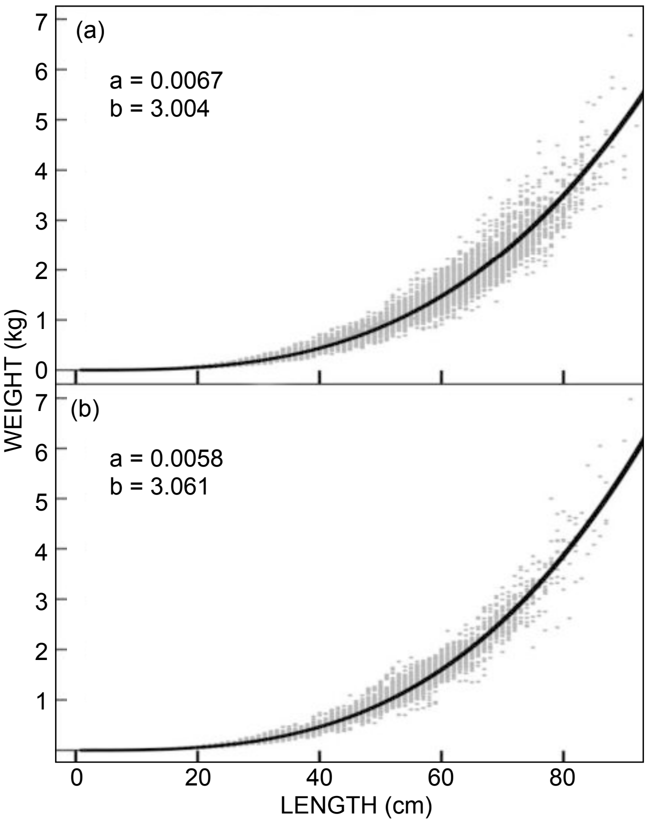

Figure 2: Estimated length-weight relationship of (a) *M. capensis* and (b) *M. paradoxus* using the recorded survey length and weight measurements

between simulation runs. This variation increased with the degree of species overlap (Figure 3). For the observer data, the length and biological samples from the same commercial trawl revealed a large inconsistency in the estimated $spro_i$ (Figure 4). A surprisingly large proportion of *M. capensis* identified in deep waters suggests dubious species identification by the observers; *M. capensis* has never been found deeper than 602 m during the surveys whereas about 19% of the observer samples from depths between 600–800 m contained *M. capensis*. Nonetheless, samples containing only one species dominated both datasets with 77% and 68% of the species proportions estimated from the survey (Equation 6) and observer (Equation 7) data respectively having a value of either one or zero. Only 10% and 18% of survey and observer stations respectively had species proportion values between 0.1 and 0.9. *Merluccius paradoxus* dominated the observer samples with 57% of all samples consisting entirely of this species. In the survey data, 33% of the stations consisted only of *M. paradoxus*.

The species proportions varied with depth and latitude for both the survey and observer data (Table 3), with *M. paradoxus* dominating catches in deeper and more southerly waters. Depth and latitude explained 51% and 85% of the residuals for the observer and survey data respectively (Table 4). Although the species proportions changed significantly between seasons (quarters) and years (Table 3), the inclusion of year and quarter as explanatory variables only reduced the residual deviance in the survey data by about 4%. The inclusion of these variables explained <1.5% of the residual deviance in the observer data.

The latitude vs depth distribution of commercial trawls is patchy as the fleet concentrates its effort in areas that are mainly dominated by either of the species (Figure 5). In fact, <20% of the commercial tows had a predicted species proportion (spr'_k) in the range 0.2–0.8. The histograms of

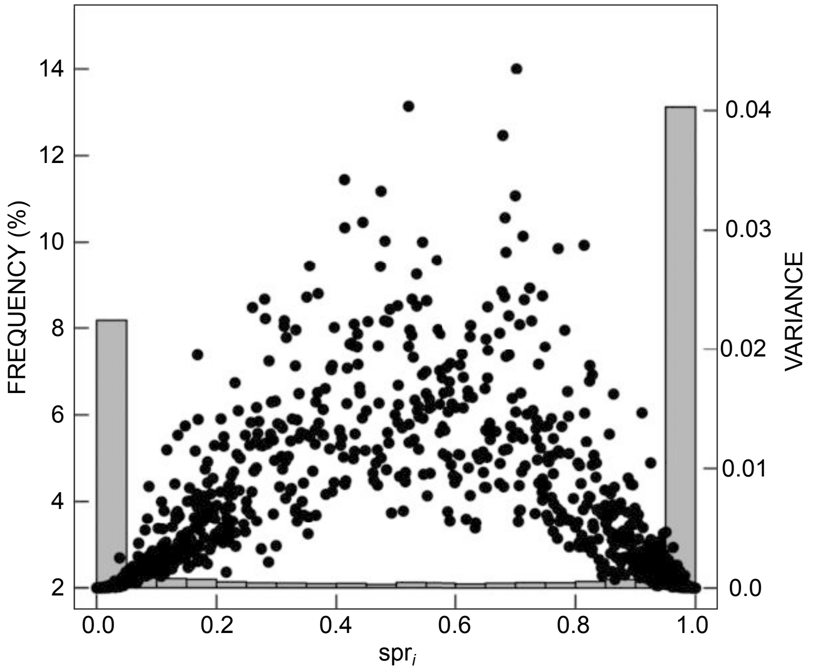

Figure 3: Histogram of the average spr$_i$ (20 simulation runs), and a scatterplot (dots) of the average spr$_i$ versus the variance of the simulation runs

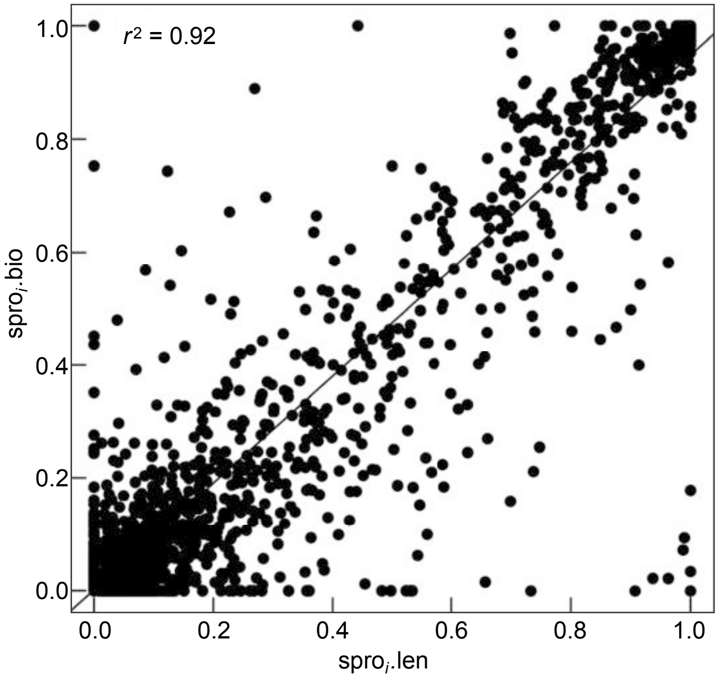

Figure 4: Hake species proportions estimated from the observer length samples (spro$_i$.len) versus the observer biological samples (spro$_i$.bio) from commercial trawls for which both samples were available

these spr$'_k$ values (Figure 6) also suggest that the trawlers mainly target either of the species.

Therefore, in spite of the relatively high variation in spr$_i$ in some areas (Figure 3), the predicted percentage of *M. capensis* in the quarterly hake catches (Equation 9) were consistent and robust to both variation in the retention simulation model parameters and ability of the explanatory variables to predict spr$'_k$ (Figure 7). However,

Table 3: Parameter estimates with standard errors (SE) and *p*-values for the explanatory variables in the best fit logistic regression model obtained from the observer and survey datasets

	Estimate	SE	*p*
	Observer		
(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		
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 the explanatory variables with species ratio as response variable for both the observer and survey datasets

	df	Deviance	% Explained
		Observer	
Null	42 817	40 694	
Depth	1	16 515	40.6
Latitude	1	4 194	10.3
Quarter	3	46	0.1
Year	11	557	1.4
		Survey	
Null	4 238	5 144	
Depth	1	4 008	77.9
Latitude	1	350	6.8
Quarter	3	78	1.5
Year	15	114	2.2

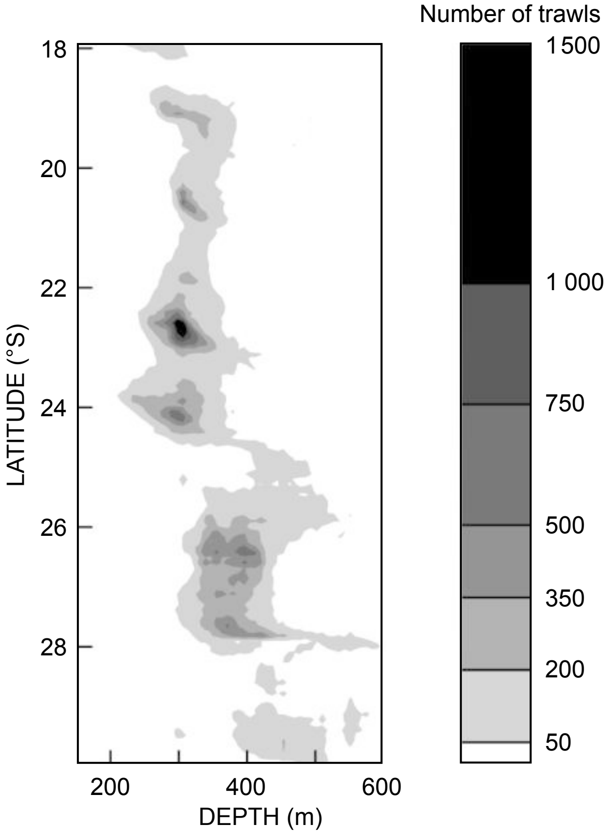

Figure 5: Number of commercial trawls conducted by grid cell (5 nmi × 0.1° resolution) from 1998 to 2007

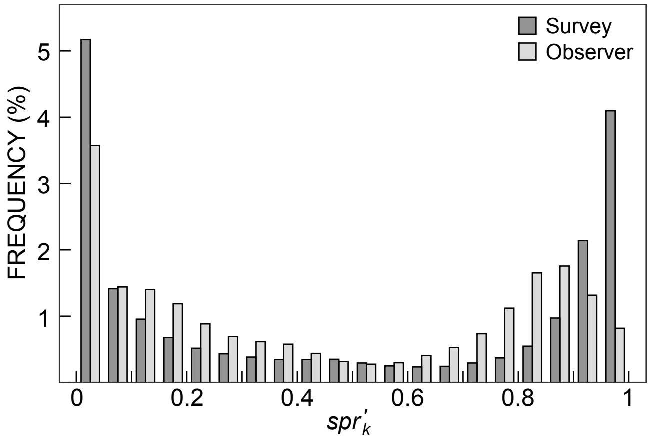

Figure 6: Histograms of the predicted species ratio (spr'_k) for the commercial logsheet tow using survey and observer logistic regression models with depth and latitude as explanatory variables

on account of the poor seasonal coverage of the surveys, which were mainly conducted during the first quarter, the inclusion of season (quarter) as an explanatory variable caused considerable noise in the predicted catches (Table 5). Nonetheless, this inclusion did not have a marked effect on the results of the percentage of *M. capensis* in the first quarter of the year (Figure 7).

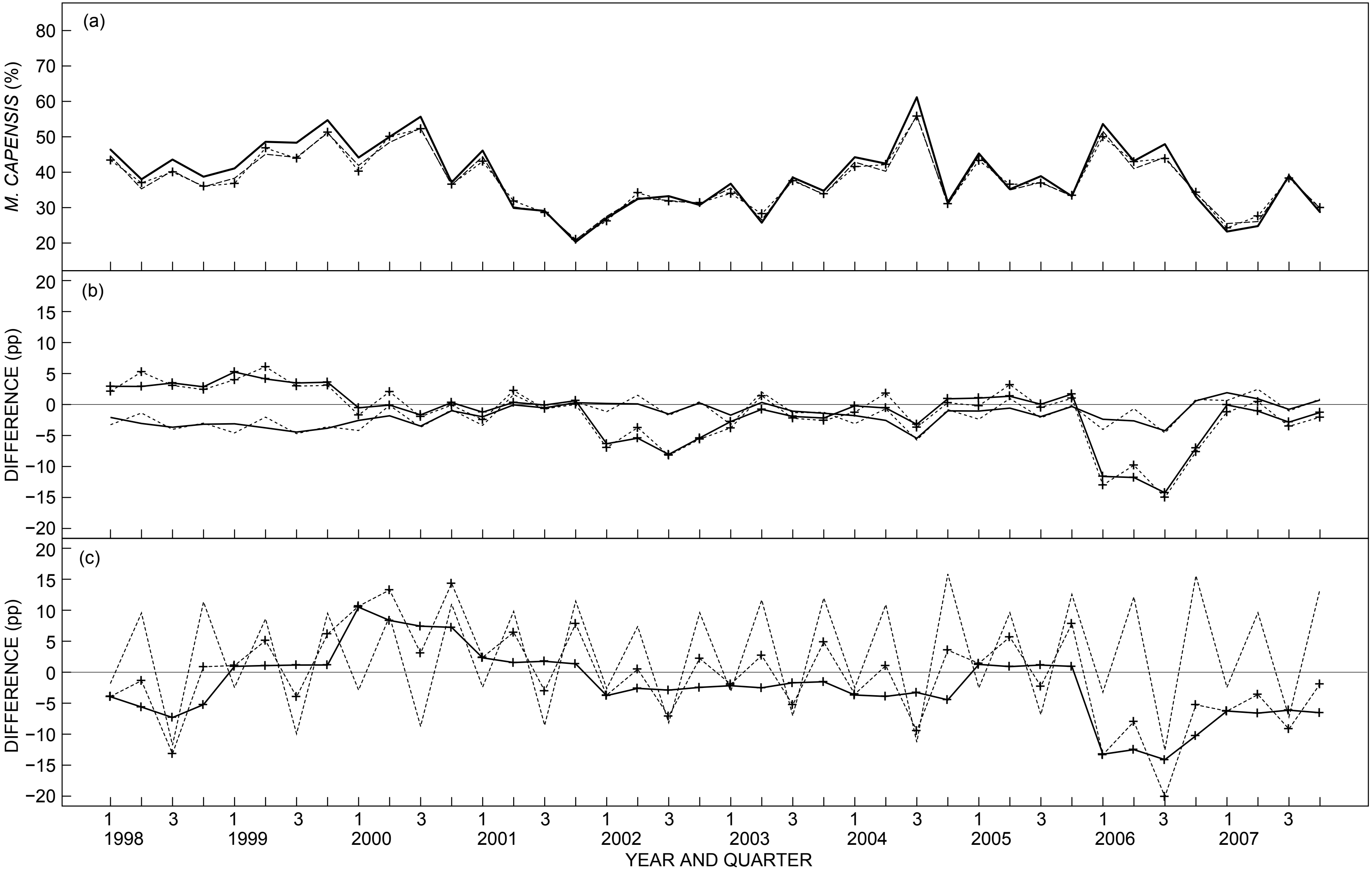

Figure 7: (a) Percentages of *M. capensis* in the commercial logsheet hake catches by quarter using predictions based on logistic regression models: 10 time-series with individual retention simulations by tow estimated from the survey data with depth and latitude as explanatory variables (continuous lines superimposed), time-series when predicted species ratios are based on observer data using models that include the variables depth and latitude (dashed line), and quarter (dotted line and plus signs); (b) difference in percentage points (pp) between the time-series estimated from the survey data with depth and latitude as explanatory variables presented in (a) and the predicted species ratios based on observer data using models with the explanatory variables depth and latitude (continuous line), and quarter (dotted line) and year (plus sign included); (c) difference in percentage points between the time-series estimated from the survey data with depth and latitude as explanatory variables presented in (a) and the predicted species ratios based on survey data using models with the explanatory variables depth and latitude (continuous line), and quarter (dotted line), and year (plus sign included)

By using these spatio-temporal species distribution models, it is possible to establish an historical catch time-series of *M. capensis* and *M. paradoxus* (Figure 8). *Merluccius paradoxus* dominated the annual hake catches in the period 1998–2007 (Table 6). The estimated percentage of *M. paradoxus* was at a maximum in 2002 (69%) and a minimum in 1999 (52%).

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. Model I: depth and latitude as explanatory variables; Model II: depth, latitude and quarter as explanatory variables; Model III: depth, latitude, quarter and year as explanatory variables; Model 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

Discussion

Consistent with previous findings (e.g. Gordoa et al. 1995, Burmeister 2001), the species proportions estimated from the observer and survey samples show that *M. capensis* is generally distributed shallower and farther north than *M. paradoxus*. The survey data suggest that catches deeper than 600 m consist only of *M. paradoxus*, whereas the observers frequently identified *M. capensis* in deeper waters. All the scientific survey personnel have an excellent knowledge of hake taxonomy and therefore it is feasible that observers are more likely to make identification errors when sorting species. This is borne out in the results of our species composition comparisons between biological and length subsamples from single commercial trawls. In contrast to survey data, the geographical coverage of the observer data is relatively poor in the northern areas: 80% of the data being collected south of 23.2° S, whereas only 48% and 60% of the survey and logsheet data respectively were from south of 23.2° S. This latitudinal skewness in the observer data is mainly on account of the tendency of larger vessels — with available space for observers — to operate more frequently in the southern areas. However, the seasonal coverage of the observer data is much higher than that of the survey data. Another advantage of using observer data is that the species compositions are derived directly from the samples and therefore not affected by retention modelling uncertainty. The use of empirically based and realistically wide-ranging selectivity curves cannot compensate for unknown factors such as the position of fish in the water column and their reaction to the survey vessel and catching equipment. Furthermore, both availability to and escapement from the trawl probably vary between species and with fish size, and are also affected by individual behavioural and ecological factors such as changes in the environment, and an individual's motivation, for example, spawning and feeding. All these factors will certainly affect the relationship between the numbers caught and the true population (Hjellvik et al. 2003). Hence, the catch in a bottom trawl is seldom accepted as an accurate reflection of the true population size of the targeted species.

A specific concern, related to the rising of hake off the bottom at night (Payne and Punt 1995, Huse et al. 1998, Iilende et al. 2001), affects the size- and species-dependent diel variation in catch rates (Johnsen and Iilende 2007). Whereas the commercial trawlers commonly fish around the clock, most survey trawl stations are conducted during the day in shallow waters (<450 m) (Johnsen and Iilende 2007). For this reason, the estimated species proportions based on the survey data may be considered to be biased.

Despite these limitations, parallel trawling experiments using the same type of trawl have shown high repeatability (Strømme and Iilende 2001, Hjellvik et al. 2002) when environmental conditions are stable. It is reasonable to assume that variable conditions would have resulted in unpredictable species proportions, 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 overlap in the distribution of these two species in Namibian waters in areas where the bottom depth varies between 280 and 500 m, with *M. paradoxus* dominating farther offshore as well as in the southern parts. Furthermore, the size-dependent depth distribution of hake (Gordoa and Duarte 1991, Gordoa et al. 1995), where similar-sized fish are clumped together (Johnsen 2003), is also consistent between surveys (Burmeister 2001). This predictability, in addition to the robustness of the modelled species proportions derived in this study from two independent data sources, lends support to the credibility of our method.

The spatio-temporal variability in distribution reported for both hakes (e.g. Gordoa et al. 1995, Johnsen and Iilende 2007) is considered in the selected models, but the procedure may still lack flexibility during periods of abrupt species displacement, as occurred in 1994 when large amounts of juvenile *M. capensis* migrated offshore to avoid hypoxic water and were subsequently caught by commercial trawlers (Hamukuaya et al. 1998). In accordance with the law of parsimony (Dobson 2002), the models selected in this study do not fully consider the complexity of this system. Nonetheless, the species proportion's predictability of most commercial catches is likely to be high as commercial trawlers appear to direct their efforts mainly in areas dominated by one of the two hake species.

Although reliable partitioning of commercial catches by species remains challenging, particularly within the overlapping distributional zone, the predicted percentage of *M. capensis* in the hake catches by quarter appears to be robust and insensitive to selection curves or model selection. The predicted proportion of *M. capensis* in the annual hake catches ranges from 30% to 44%. These values correspond well with the species proportions listed in the official landings (Pearson correlation *r* = 0.87, Table 6). Still, the estimated percentage of *M. capensis* in the hake

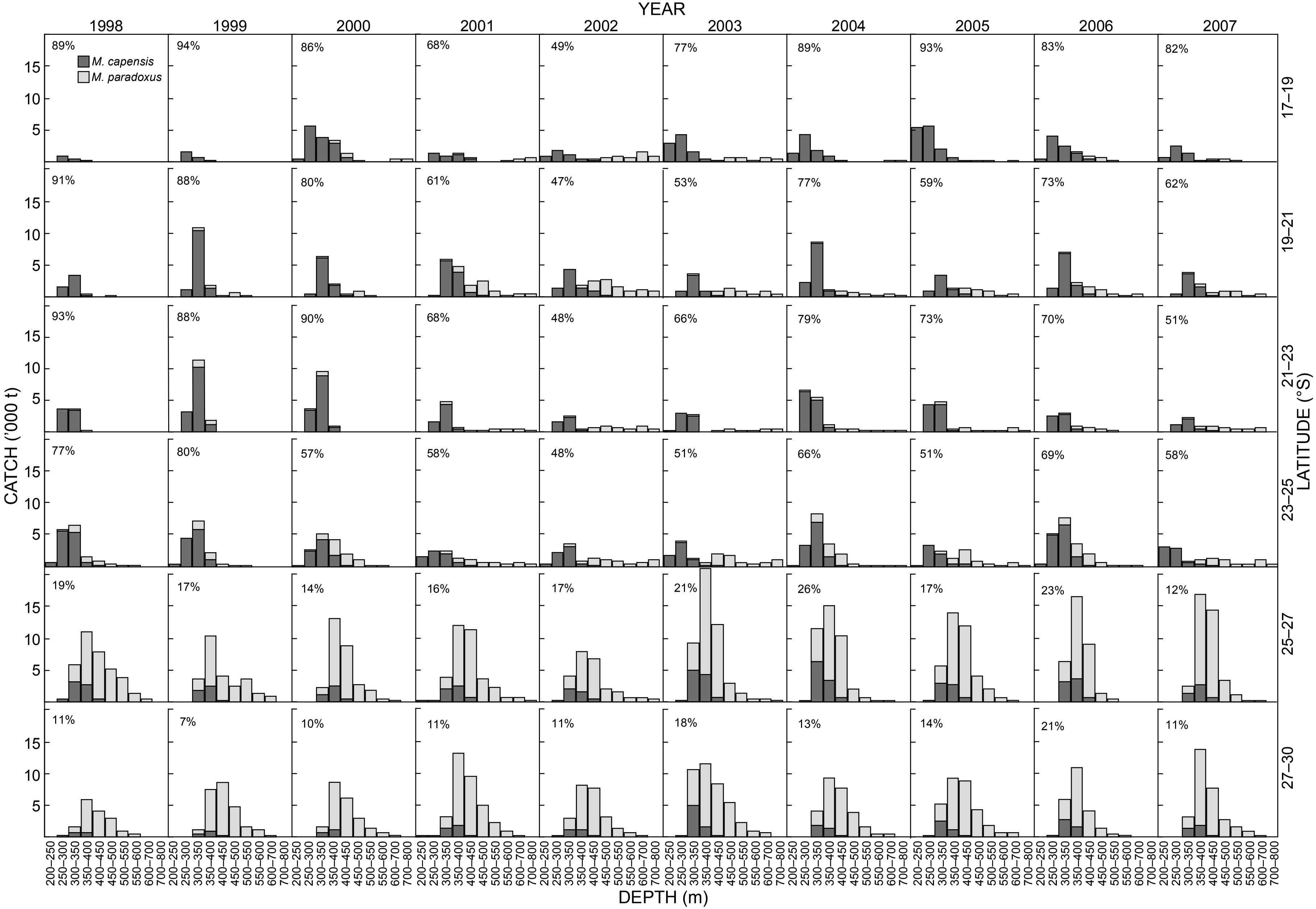

Figure 8: Predicted catch of *M. capensis* and *M. paradoxus* by depth and latitudinal interval for the period 1998–2007. The numbers (%) in upper left corners present the predicted percentage of *M. capensis*. The presented catch species proportions are predicted using the survey data and depth and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

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, p. 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

NA = Not available

catches is about 5.6% higher than the average percentage of *M. capensis* in the official landings, which range from 20% to 43%. In contrast to this low-resolution species separation of landings, our method predicts the species proportion in each commercial trawl. This allows for the introduction of a species-specific CPUE time-series and the compilation of reliable catch-at-age data by species. The spatio-temporal models could also be used to separate the hake catches by species in the old Namibian logsheet data (1994–1997) as these data include daily information pertaining to vessel license, date, latitude, depth, number of trawls, hake catch, effort, type of vessel, horsepower and tonnage (Gordoa et al. 2000). Such a long time-series of species-specific CPUE and catch-at-age indices, in combination with the species-specific survey estimates, should provide the necessary impetus for a new hake assessment for each of the two hake species.

Summary

The 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 current combined hake stock assessment model used in Namibia. This study presents a method that can be used to split the commercial hake catches by species using scientific survey and observer data information. There is no evidence to suggest that any bias is introduced by the method, and the final output given as percentage of *M. capensis* of the total hake catch by quarter suggests that the method is robust. The output appears to be insensitive to the stochasticity in the trawl-selectivity simulation, which may therefore be excluded in future spatio-temporal modelling of the species overlap. Although the models lack the flexibility to predict abrupt changes in the geographical species distribution, the prediction robustness of the method indicates that a biologically plausible single-species hake assessment for Namibia is now possible.

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