

**Establishing a baseline for evaluating changes in fish
body condition and population dynamics of Cape hake
(*Merluccius capensis* and *M. paradoxus*) in South Africa**

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Signed by candidate

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Table of contents

Section	Page
Abstract	5
Introduction	6
Materials and methods	9
Results	12
Discussion	20
References	23
Appendix	26

Abstract

Standard weight (W_s) equations were developed and relative weight (W_r) indices calculated for both shallow-water (*Merluccius capensis*) and deep-water (*M. paradoxus*) Cape hake. The aim was to provide fixed baselines and W_r indices to aid understanding of temporal and spatial variability in fish condition. Baselines were calculated using the empirical percentiles (EmP) method applied to length (L) – weight (W) data collected by research surveys on the South African west and south coasts, from 1983 to 2013. Four quadratic W_s equations for each species were generated, based on the following weight statistics for each size class j : first quartile, median, third quartile and mean. Median W_s equations were chosen for the baseline for shallow-water hake ($\log_{10} W_s = -2.491 + 3.338*(\log_{10}L) - 0.065*(\log_{10}L_j)^2$) and deep-water hake ($\log_{10} W_s = -2.161 + 2.930*(\log_{10}L) + 0.0456*(\log_{10}L_j)^2$). Shallow-water hake was found to be the heavier of the two species at the same length. W_r indices display good condition values (>100%) for both species throughout all analyses. Fish condition for both species was best between 1988 - 2009, ranging from 50 - 165% for individual fish and 100 - 109% for annual averages. Monthly mean W_r indices peaked in June and October for shallow-water hake and July and October for deep-water hake. Mean W_r values were different for shallow-water hake on the south (105%) and west (103%) coasts. Deep-water hake showed no spatial variability in mean W_r values. There were no differences between mean W_r values of males and females between, and within, species. Future hake data may be compared to these W_s equation baselines and W_r indices to show changes in body condition for this commercially important stock.

Keywords: Cape hake, *Merluccius capensis*, *Merluccius paradoxus*, empirical percentile (EmP) method, standard weight, relative weight, ecological indicators, South Africa

Introduction

The dynamics of change in the marine environment are poorly understood. Thus, an improved understanding of ecosystem functioning is needed to complement the single-species approach taken regarding the management of many fisheries. Incorporating marine ecosystem complexity into management actions is important to ensuring long-term sustainability. The inherent potential for variability within ecosystems requires a baseline against which new changes can be compared and attributed to environmental or anthropogenic factors with some degree of certainty. However, even these baselines are liable to change with new techniques (Pauly 1995). Due to the logistical challenges involved in understanding the marine environment, ecological indicators can be used as proxies for ecological health (Large *et al.* 2013).

Marine ecosystems are influenced by environmental pressures as well as fishing, and both should be considered in terms of suitable indicators (Large *et al.* 2013). Link *et al.* (2010) investigated the value of indicators for detecting change. They considered three criteria to be necessary for indicators: there must be long-term data available, ecosystem changes must be detectable and the indicator must be specifically linked to the ecosystem. Ndjaula *et al.* (2013) stated that ecological indicators need to be evident, accessible and easy to understand. They should also be considered pertinent to management objectives as well as being important to ecological functioning.

Long-term data are required to produce the necessary baselines, and this is most commonly sourced from various single-species fisheries operations. Various mathematical length-weight relationships have been developed to model the growth rates of fish from these data (Punt and Leslie 1991). Standard weight (W_s) equations describe the species predicted weight at a given length and these equations can form the foundation for more complex fisheries models (Fulton *et al.* 2005). The derivation of these W_s equations was investigated (Gerow *et al.* 2004) and a new method to generate them with reduced bias was proposed by Gerow *et al.* (2005). This new method, named the empirical percentiles method (EmP), requires the data to be divided into discrete populations, for example, separate analysis of annual population samples. W_s equations can also be used to develop fish condition indices.

A common and widely applicable fish condition index is relative weight (W_r). Easily calculable, this index can be used by a range of invested stakeholders, which makes it useful in supporting fisheries management decisions (Murphy *et al.* 1990, Murphy *et al.* 1991). Another advantage is that W_r is not species-specific, and can be used to compare populations and population dynamics between species or habitats. Blackwell *et al.* (2000) addressed the practical implementation of W_r and showed how and why it has steadily gained popularity. This study will also use the EmP method to generate W_s equations and W_r condition indices for South African hake.

There are two species of Cape hake in South African waters: *Merluccius capensis*, hereafter referred to as shallow-water hake, and *M. paradoxus*, hereafter referred to as deep-water hake. Shallow-water hake are found closer inshore at depths of up to 380 m. Deep-water hake occur from depths of 150 m to at least 800 m. Both species increase in size with increasing depth, and large shallow-water hake begin to overlap distributions with small deep-water hake from a depth of 150 m (Payne 1989). The life history parameters of hake were summarised by Punt and Leslie (1991), and they concluded both species of hake reach sexual maturity at ~ 60 cm (total length).

Large populations of hake occur on South Africa's west and south coasts. The west coast of South Africa is characterised by the cold upwelling Benguela ecosystem (Nelson and Hutchings 1983). Upwelling supports periods of intense primary and secondary production, in turn supporting small pelagic fish such as sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*). These species form the primary prey of hake, along with juvenile hake (Payne 1989). Adult hake undergo diel vertical migration through the water column, residing near the bottom during the day and swimming upwards to feed on plankton-feeders at night (Pillar and Barange 1997). Because of this behaviour, they support a demersal fishery during the day, while being characterised as a pelagic species (Payne 1989).

The demersal fishery for hake was initially small and only exceeded 10,000 tons in 1932 (Payne 1989). However, the development of new technologies allowed international fishing vessels to access the west coast hake resource and, by 1972, annual landings increased to >1 million tons (Payne 1989). The declaration of South Africa's Exclusive Economic Zone (EEZ) in 1977 ensured hake stocks were relieved from intensive fishing pressure from foreign demersal trawlers. Rebuilding of the hake stocks became a priority and initial total

allowable catches (TACs) were implemented (Payne 1989, Shannon *et al.* 2006). This sparked an intense period of study (1980s and 1990s) on hake and the majority of published literature is from this period.

South Africa's hake resources are the country's most economically lucrative marine resources and are being actively managed to ensure the best possible trade-off between economic utilisation, social benefit and long-term sustainability (Shannon *et al.* 2006). Hake is considered to be recovering and stable since its crash in the 1970s (Shannon *et al.* 2006). However, past experience has shown it is good practice to leave an error margin within TACs for environmental catastrophe, such as a Benguela Niño or major low oxygen event (Cury and Shannon 2004). Despite this active management and bi-annual research surveys, not many papers have recently been published on hake in peer-reviewed journals.

This study aims to establish fixed length-weight baseline relationships for South African hake species, using the EmP method to reduce length-related bias. This method requires a large, long-term dataset that includes representatives of the full range of possible fish conditions for hake. The two species will be compared to investigate weight-at-length differences. A second aim is to calculate W_r indices, which can provide quantitative descriptions of fish condition (Punt 1992). These indices can aid in assessing the population dynamics of hake and wider ecological variability over the last 30 years, allowing comparisons with future changes. Lastly, these indices can be compared with similar studies, such as those produced by Ndjaula *et al.* (2013) for South African sardine, allowing consideration of predator-prey interactions or correlations between hake and sardine.

Materials and methods

Length and weight data for both species of hake were obtained from South Africa's Department of Agriculture, Forestry and Fisheries (DAFF). These data were collected by annual research surveys performed by the F.R.S. Africana and the R.V. Dr Fridtjof Nansen from 1983 to 2013. A total of 30 years' worth of data was collected, as no survey was run in 1998, because of technical difficulties with the F.R.S. Africana. These surveys sampled the South African west and south coasts, ranging from the Namibian border to beyond East London in the Eastern Cape.

Fish length L was measured as total length (TL) to the nearest 1 cm, and the total body mass W was weighed to the nearest 1 g. Annual population samples were identified and length-weight relationships for each of these 30 population samples were estimated through individual L - W regressions of the form $\log_{10} W_{s(j)} = a + b \log_{10} L_j + c (\log_{10} L_j)^2$ where a , b and c are constants. The fitted data were scrutinised by plotting regressions for each species' annual population samples. The measurements that were clearly incorrect, when viewed in this context, were removed. Incorrect measurements were considered to be the result of measuring or recording errors. In addition, because of a higher prevalence of errors presumed to be involved in the weighing of very small fish, the data were truncated and all measurements corresponding to fish ≤ 10 cm TL were removed from both datasets. Length measurements with no corresponding weight measurements were also removed.

The fish were grouped according to length classes of 1 cm, and the means of the measured weights for each sample population's length classes were calculated. A minimum of 30 fish was considered necessary for sufficient representation of each length class. This led to further truncation of the datasets with respect to large specimens, by excluding all shallow-water hake ≥ 95 cm TL and all deep-water hake ≥ 85 cm TL.

Standard weight equations were calculated using Gerow *et al.*'s (2005) Microsoft Excel EmP tool, which contained several pre-programmed macros which perform the iterative calculations efficiently (available from <http://www.sdafs.org/fmsafs/interactive-excel-tool-for-computing-assessing-and-using-emp-ws-equations/>). These equations are initially

produced on a \log_{10} - \log_{10} scale and describe the lower first quartile (25%), median (50%), upper third quartile (75%), arithmetic mean and standard error of the quadratic term.

Ndjaula *et al.* (2013) describe the process behind the EmP tool's generation of standard weights in a simplified format, and was adapted for this analysis. All the L - W data were \log_{10} -transformed according to each population i . Individual fish k were sorted into their appropriate length class L_j between the minimum and maximum acceptable lengths for each species. The means of the measured (empirical) weights of fish in each length class for each sample population were then used to calculate the four weight statistics W_j for all length classes, these being the first, second and third quartiles and the arithmetic mean. Not all sample populations were represented in every length class, especially for the smallest and largest fish. To account for this, the W_s equation is weighted in relation to the number of contributing populations. The standard weights for all length classes $W_{s(j)}$ were calculated by fitting a quadratic regression to the \log_{10} -transformed L - W data, as seen in Equation 1 below:

$$\log_{10} W_{s(j)} = a + b\log_{10}L_j + c(\log_{10}L_j)^2 \quad (1)$$

Where a , b and c are constants (Table 1). The median standard weight equation was chosen to represent the two species of hake. A bootstrap analysis using 1000 replicates was used to assess the accuracy of the $W_{s(j)}$ values (from Equation 1). The relative margin of error (RMoE) was calculated as twice the standard deviation among the bootstrap sample estimates, divided by the average of these estimates. The RMoE was plotted against L for both species of hake to show these confidence intervals.

Relative weight (W_r) values were generated for both species using only the median standard weight regressions. W_r for an individual fish k in each length class j from each annual population i was calculated using Equation 2 below:

$$W_{r(ijk)} = 100 \times (W_{ijk} / W_{s(j)}) \quad (2)$$

Trends relating to W_r were analysed by plotting W_r against L . Temporal, spatial and sex-related variation within and between hake species were analysed by calculating mean values of W_r per year, per month, per coast and per sex. For the spatial W_r analysis, the South African west and south coasts were separated at the conventional longitude of 20°E (Punt *et*

al. 1995). The sex-related W_r analysis only incorporated males and females, omitting juveniles and other categories that could not be assigned sexes. These comparisons were interpreted in conjunction with their relative sample numbers, to ensure variation was not attributed to disproportionate samples.

Results

A total of 30 annual population samples, from 1983 to 2013, was used in the development of standard weight equations and relative weight analysis, using the measurements of 36,120 shallow-water hake and 21,160 deep-water hake. The shallow-water hake dataset initially had 36,498 individual measurements and the deep-water hake dataset had less with 21,632 measurements. Overall, the eliminated values comprised 378 fish (1.04% of the dataset) for shallow water hake and 472 fish (2.18% of the dataset) for deep-water hake. The coefficient of determination (R^2) of the annual L - W regressions was greater than 0.97 for all populations across both species (once the incorrect measurements were removed).

The regression parameters for the standard weight equations can be found in Table 1 and the four \log_{10} - \log_{10} standard weight equations are illustrated in Figure 1. For both species, there is a greater range between the quartiles at both ends of the \log_{10} -length scale, with the first quartile staying below the median and the third quartile above the median (Figure 1). This variation is more pronounced in fish with shorter lengths. The mean equation is hardly visible due to an overlap with the median equation, and can only be differentiated at the ends of the length scale.

Table 1: Parameters of the four quadratic regression equations for calculating standard weights on a $\log_{10} W_S$ - $\log_{10} L$ scale for hake along the South African coast. Q1 and Q3 refer to the first and third quartiles.

	Log ₁₀ - log ₁₀ standard weight regression parameters			Standard error of c (g.cm ⁻²)
	a (Intercept, g)	b (Linear, g.cm ⁻¹)	c (Quadratic, g.cm ⁻²)	
(a) Shallow-water hake				
Q1	-2.629	3.495	-0.114	0.013
Median	-2.491	3.338	-0.065	0.016
Q3	-2.302	3.114	0.004	0.020
Mean	-2.431	3.264	-0.043	0.015
(b) Deep-water hake				
Q1	-2.361	3.170	-0.029	0.013
Median	-2.161	2.930	0.046	0.012
Q3	-1.970	2.702	0.117	0.014
Mean	-2.124	2.885	0.059	0.012

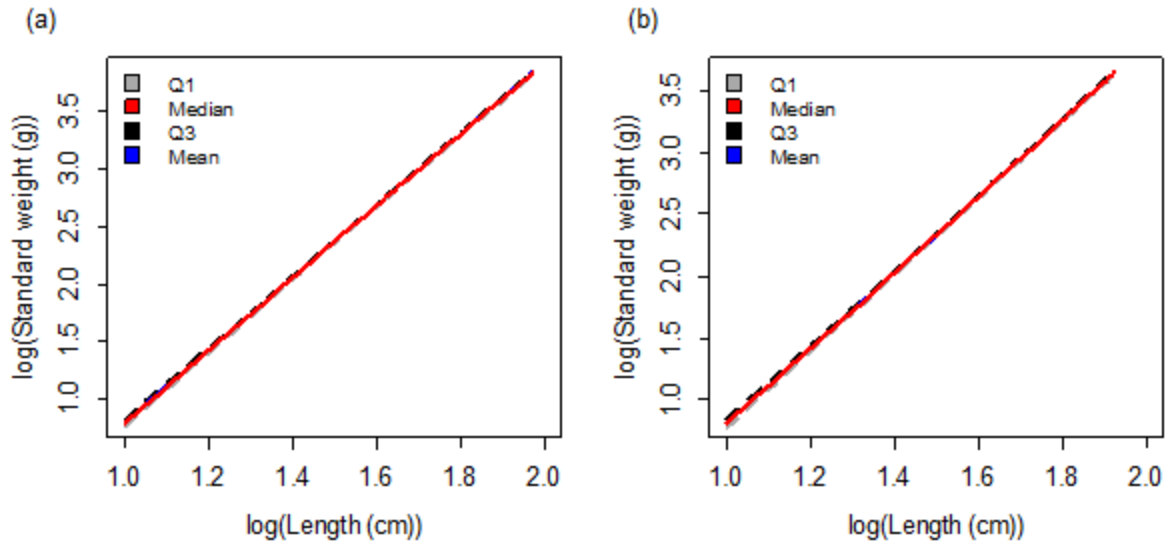


Figure 1: $\text{Log}_{10}\text{-log}_{10} W_S$ regression lines for (a) shallow-water and (b) deep-water hake along the South African coast. First quartile (Q1): dashed gray line, median: solid red line, third quartile (Q3): dashed black line and mean: solid blue line (if unseen it lies underneath the median line).

The median quadratic equation for predicting standard weights produced a reasonable fit to the data (Figure 2). The data for shallow-water hake (black circles) showed more scatter around the median standard weight regressions (solid red line) than deep-water hake, especially for fish between 25 and 60 cm. This variation is considered a consequence of the larger number of shallow-water hake ($N_a = 36,120$) used in this analysis compared to deep-water hake ($N_b = 21,160$). Smaller fish show greater variation from the median equation for both species in both figures.

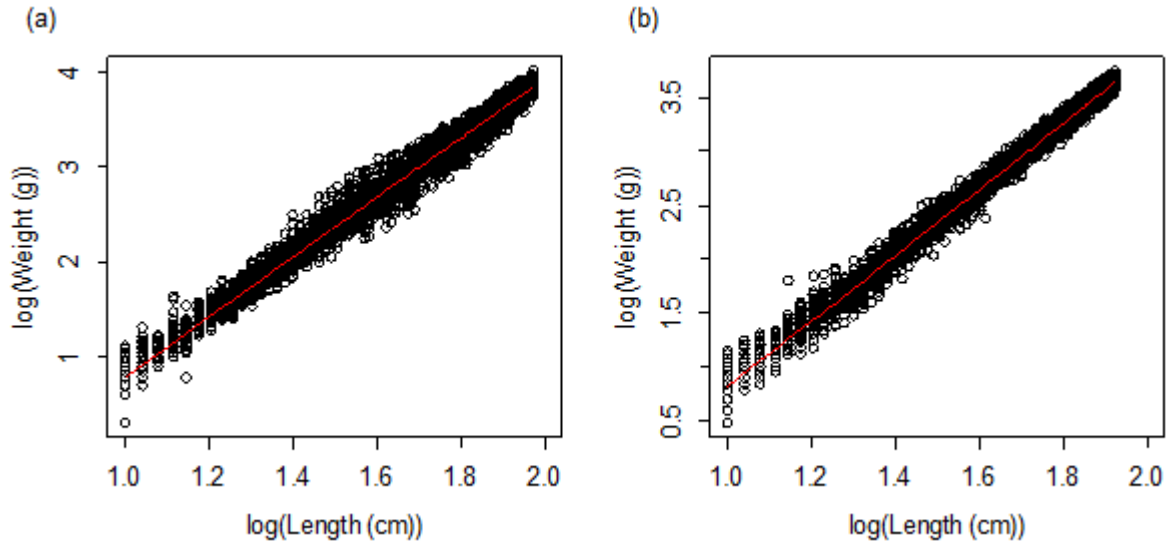


Figure 2: Median W_s equation (solid red line) for (a) shallow-water and (b) deep-water hake along the South African coast. Black circles depict the logged measurements for all fish ($N_a = 36,120$, $N_b = 21,160$) used in the analysis.

Comparison between standard weight regressions for the two species of hake shows that shallow-water hake generally has greater weight at length than deep-water hake (for the median model, Figure 3).

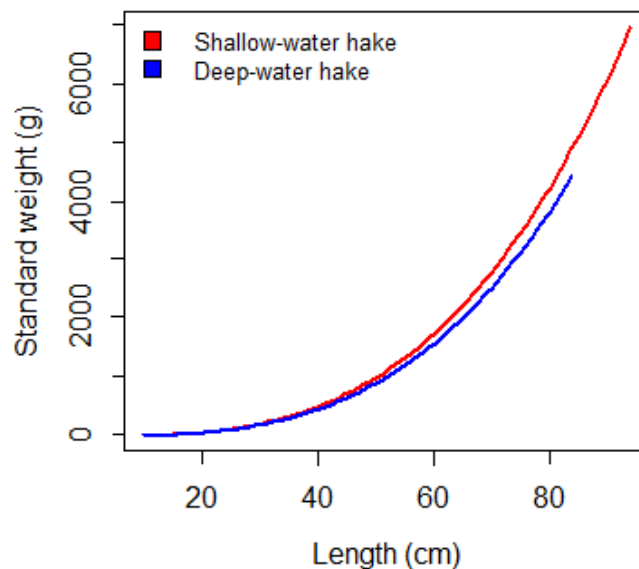


Figure 3: Comparison between W_s equations for shallow-water and deep-water hake along the South African coast.

The RMoE of the W_s estimates for shallow-water hake (Figure 4) ranged from 0.5% to 2.75%, and was smallest (<1.0%) for fish >18 cm. For deep-water hake, RMoEs ranged from 0.7% to 3.25%, and were also smallest (<1.0%) for fish >18 cm.

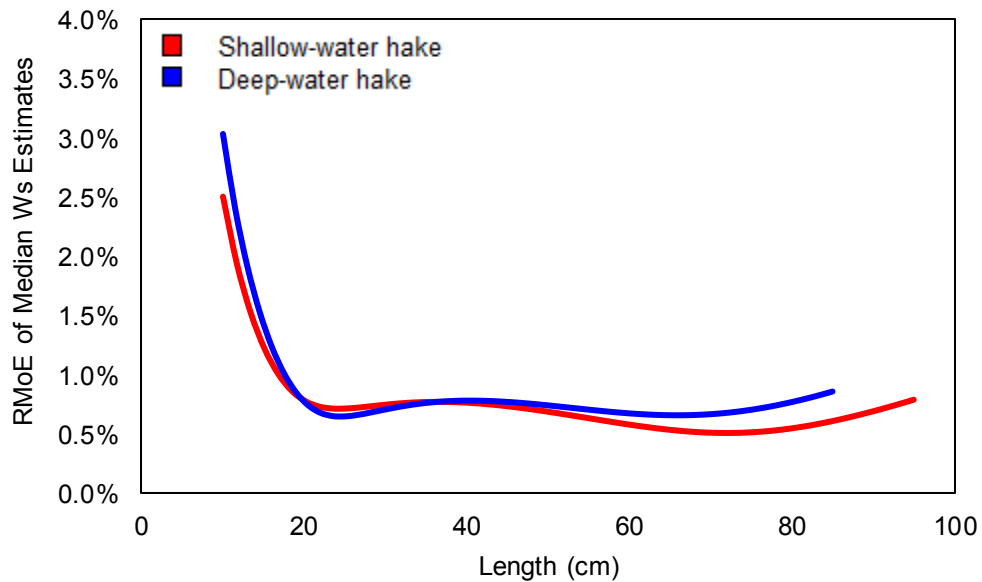


Figure 4: Relative margin of error (RMoE) showing confidence intervals from W_s equation precision test after 1000 bootstraps for shallow-water and deep-water hake along the South African coast.

Most fish (>60%) of both species had W_r values between 90 – 110% (Figure 5). Shallow-water hake across all sizes (Figure 5a) had good W_r values, with 61% of individuals having a W_r >100%. The best condition in shallow-water hake (200%) was in fish between 30 – 50 cm. Over 99% of shallow-water hake had W_r values between 50 – 150%, while those with poor W_r values (<50%) were more prevalent in small fish (<45 cm). Deep-water hake (Figure 5b) had 64% of individuals having a W_r >100%, relatively more than shallow-water hake. Several fish between 10 – 60 cm had good W_r values (>150%) and only two fish had W_r values >200%. Over 99% of deep-water hake had W_r values between 50 – 150%, while those with poor W_r values (<50%) were more prevalent in small fish (<20 cm). The W_r values for shallow-water hake showed greater variability than those for deep-water hake.

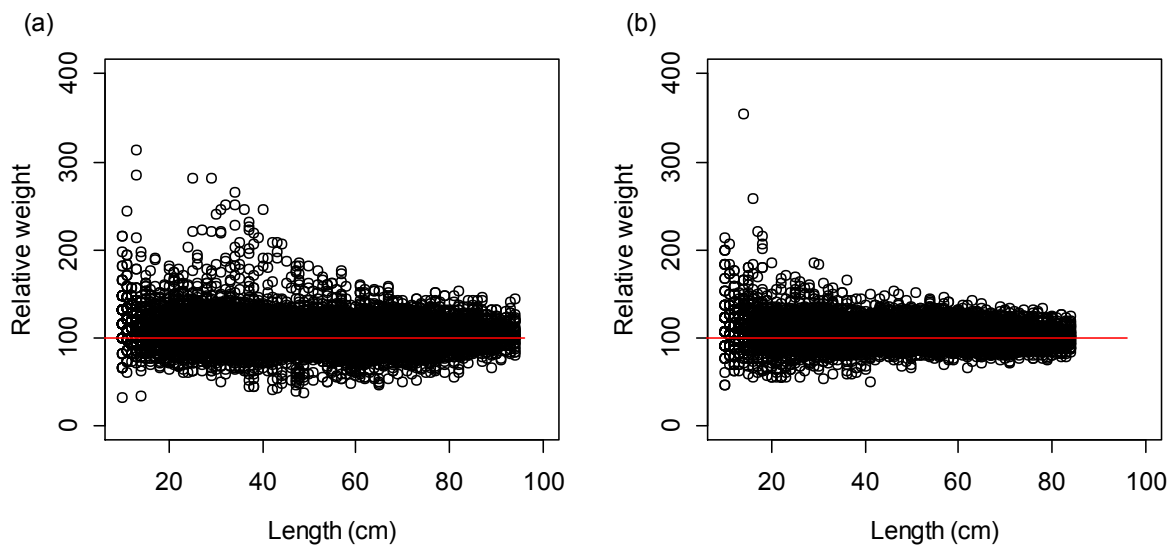


Figure 5: W_r of individual (a) shallow-water and (b) deep-water hakes as a function of total length (L).

Both species of hake displayed similar W_r frequency distributions (Figure 6). W_r values were grouped into bins with a width of 10%. All W_r values $\leq 50\%$ were grouped, as were all values $\geq 150\%$. These appear to be distributed normally, with the highest frequency of W_r values in the 100-110% bin.

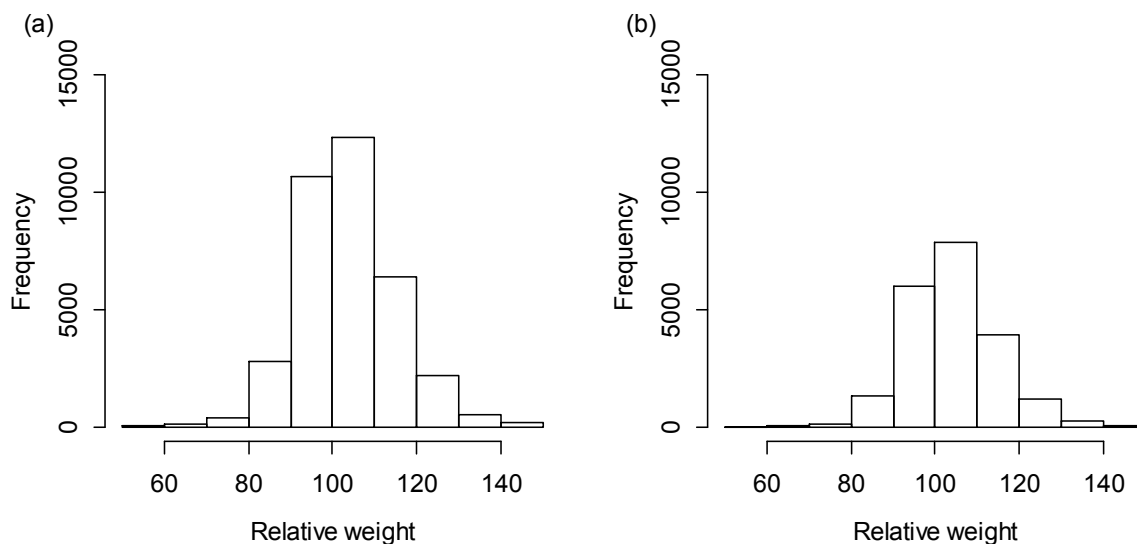


Figure 6: Frequency distributions of W_r for (a) shallow-water and (b) deep-water hake.

Annual mean W_r values (Figure 7a) range between 100% and 109% for both species. Shallow-water hake generally have poorer W_r values than deep-water hake. For both species, mean W_r values increase in the 1980s, remaining high until 2007, when they decrease to

100% until 2011. The results of single-factor analyses of variance (ANOVAs, Appendix: Table 4) of the annual mean W_r values for shallow-water hake showed no significant differences ($\alpha = 0.05$, $df_{res} = 36,118$, $p = 0.256$), however, for deep-water hake, there was a significant difference ($\alpha = 0.05$, $df_{res} = 21,158$, $p = 0.031$).

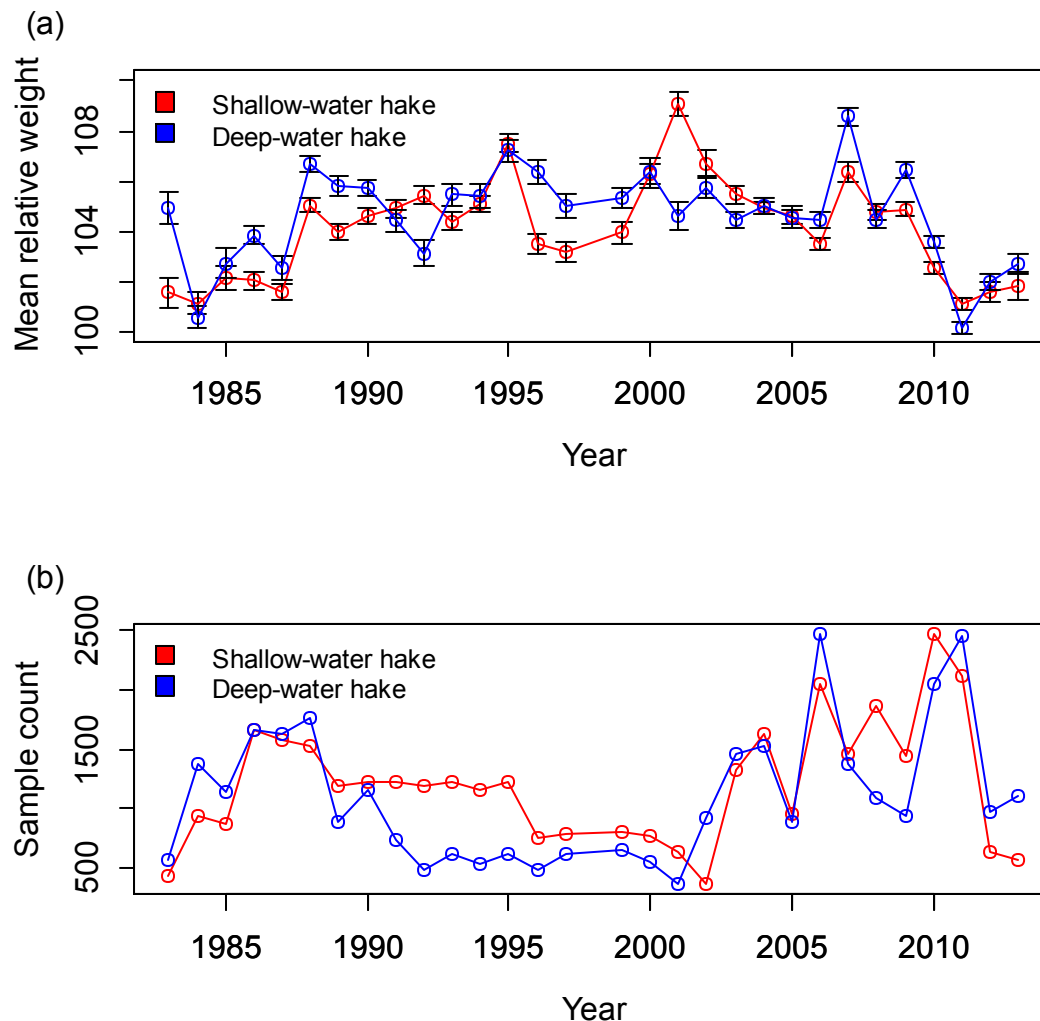


Figure 7: Comparison between shallow-water (red) and deep-water (blue) hake along the South African coast, from 1983 to 2013, for (a) annual mean W_r values \pm se and (b) number of samples.

Monthly mean W_r values were calculated for January to October, as there was no sampling in November or December. Both species of hake showed elevated W_r values through autumn and winter (March to August, Figure 8a). However, these patterns must be considered in relation to the monthly sampling effort shown in Figure 8b. Shallow-water hake (red) have higher W_r values in the sampling peaks of February and September. Deep-water hake (blue) have higher W_r values for the most intense sampling period, January, as well as its

subsequent sampling peak in April. Deep-water hake shows very high W_r values in September, yet experienced much less sampling in this month than shallow-water hake. The results of single-factor ANOVAs (Appendix: Table 5) of the monthly mean W_r values showed highly significant differences for shallow-water hake ($\alpha = 0.05$, $df_{res} = 36,118$, $p < 0.001$) and deep-water hake ($\alpha = 0.05$, $df_{res} = 21,158$, $p < 0.001$).

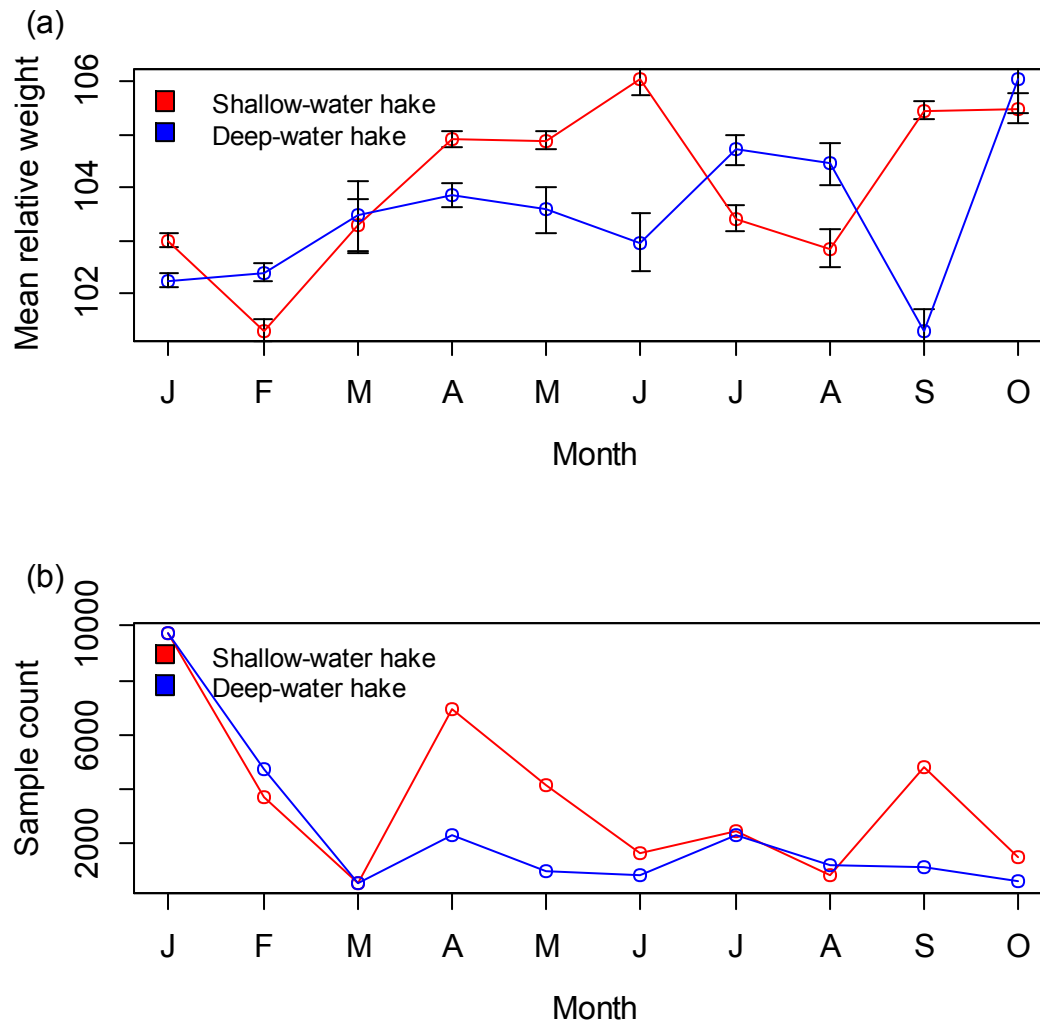


Figure 8: Comparison between shallow-water and deep-water hake along the South African coast for monthly (a) mean W_r values \pm se and (b) number of samples, from January to October (averaged over the period of 1983 to 2013).

Comparisons between the west and south coasts of South Africa (Table 2) show that the south coast has statistically higher mean W_r values, according to a two-way ANOVA, where species was also a significant factor ($\alpha = 0.05$, $df_{res} = 57,154$, $p = 0.02$) and single-factor ANOVAs (Appendix: Tables 6 and 7) for shallow-water hake ($\alpha = 0.05$, $df_{res} = 36,025$, p

<0.001) and deep-water hake ($\alpha = 0.05$, $df_{res} = 21,128$, $p = 0.01$). This difference in condition between the two coasts is more marked in shallow-water than deep-water hake, with south coast shallow-water hake having, on average, 3% higher mean W_r values over the sampling period. The difference in the mean W_r values of deep-water hake is much less, only 0.55%. The south coast sample is also much smaller than the west coast sample for deep-water hake.

Table 2: Mean W_r values and number of samples for west and south coast hake.

	Mean W_r value (%)	Number of samples n	Standard error s
(a) Shallow-water hake			
West coast	102.586	17089	0.099
South coast	105.275	18938	0.096
(b) Deep-water hake			
West coast	104.150	16972	0.091
South coast	104.695	4158	0.166

More females were sampled than males for both species. Female shallow-water hake (Table 3a) have higher mean W_r values, by $\sim 0.50\%$, than the males. Deep-water hake (Table 3b) have more similar mean W_r values between the sexes, with the mean for males being 0.028% higher. A two-way ANOVA (Appendix: Table 8) with species ($\alpha = 0.05$, $df_{res} = 53,762$, $p = 0.03$) and sex ($\alpha = 0.05$, $df_{res} = 53,762$, $p = 0.04$) showed that males and females had significantly different mean W_r values.

Table 3: Mean W_r values and number of samples for male and female hake.

	Mean W_r value (%)	Number of samples n	Standard error s
(a) Shallow-water hake			
Males	103.909	14272	0.100
Females	103.522	19423	0.087
(b) Deep-water hake			
Males	103.921	8457	0.113
Females	103.942	11720	0.095

Discussion

W_s equations were successfully developed for both species of hake. These equations provide a fixed length-weight baseline for all shallow-water hake 10 - 95 cm and deep-water hake 10 - 85 cm. These baselines should be less susceptible to differences between the decades and the shifting baseline syndrome (Pauly 1995), since they span over 30 years. The median W_s equations were used to calculate W_r indices of fish condition. The median is considered more desirable as it's less influenced by outlying values. This follows international convention and can be used as a fixed baseline for future work on these species. The W_r indices showed temporal (annual and monthly) variability, however the mean W_r values remained >100%, indicating good fish condition. Shallow-water hake from the south coast also had significantly higher mean W_r values than west coast shallow-water hake and deep-water hake.

Shallow-water hake were heavier than deep-water hake across most lengths. However, this result does not allow for conclusions to be drawn about the quality of the fish, in terms of commercial preference. While it is considered true that the entire range of possible shallow-water hake conditions were sampled, there may be deep-water hake conditions that have never been sampled due to logistical difficulties sampling areas deeper than 800 m. Recent focus on discovering more about the ocean with projects such as the Census of Marine Life may result in the development of new deep-sea technology that could address this issue (Costello *et al.* 2010).

The RMoE had very small confidence intervals, indicating good precision of the W_s equations, especially for fish >20 cm. Despite truncating the dataset for fish <10 cm, the smaller fish are still the most unpredictable, since taking precise measurements on-board a moving vessel increases the chance of erroneous values. For small fish these imprecise measurements have larger margin of error than for large fish. Further information on various bootstrapping methods that generate confidence intervals which cover the true value of the estimates, with a probability matching the claimed confidence level, is provided by Elvarsson *et al.* (2014).

The W_r values seem to be organised around the baseline of 100% (Figures 5 and 6), for both species, however, the spread is more prominent and widely distributed for shallow-water hake. The wider dispersal of shallow-water hake is likely due to differences in habitat and ecology (Punt and Leslie 1991, Pillar and Barange 1997). More than 50% of the calculated W_r values are greater than 100%, for both species. This trend is likely a result of the EmP method that reduces length bias, since the W_s equations are not heavily influenced by recurring weight-at-length measurements. This is appropriate for hake since the trawl gear used during the surveys may be more efficient at catching fish in the medium and large length classes (the survey gear is described in greater detail in Yemane *et al.*'s (2008) methods).

Fluctuations in mean annual W_r values depicted changes in body condition throughout the sampling period. The lower condition in the 1980s could be due to density dependence and intraspecific and interspecific competition for resources. This competition could have resulted from a sudden increase in population size after a marked reduction in fishing pressure after 1977 (Payne 1989). A sudden dip in condition of both species after 1995 was possibly due to the 1995 Benguela Niño (Cury and Shannon 2004). It took three years for the hake stock to recover to pre-Benguela Niño condition (Cury and Shannon 2004). The decline in fish condition of both species from 2007 to 2011 was compared to prey mean annual W_r values sardine (Ndjaula *et al.* 2013). Whilst the mean annual W_r values for sardine from the study by Ndjaula *et al.* (2013) show low values in this period (2007 – 2011), they also show a long-term decline in mean annual condition from 1992, which does not match the trends in hake W_r values for most of the period of analysis.

Not many marine species have used the EmP method to calculate W_r values, perhaps since it is a relatively new method. Harikishun (2013) has used this method to calculate W_r values for yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. His W_r values for individual fish ranged from 92 – 110%, while annual and monthly mean W_r values ranged from 99 – 101% and 99.9 – 100.5%, respectively. When compared to both sardine and yellowfin tuna, hake have higher W_r values, which can indicate better fish condition.

Mean monthly W_r values show a clear trend of higher condition in austral autumn and winter and lower condition in summer. This relates to the biological life history of hake, as they spawn in spring and summer (Punt and Leslie 1991). Spawning carries a high energy

demand, especially for females producing eggs. Therefore, once spawning is completed hake require time to recover and build up their energy reserves, which reach their peak in winter. Sudden inconsistencies may be observed between adjacent months, as evidenced by the sudden drop in the mean monthly W_r values in September (Figure 8). This is likely a result of sampling design, as research cruises often target specific seasons or events, which may lead to unequal numbers of sampling days in each month. Mean monthly W_r values were found to be statistically different from one another, however, this is most likely a consequence of the large sample sizes. When the sample size is very large, as is the overall case here, ANOVAs are able to detect small significant differences which may be too small to have biological or ecological significance (McDonald 2009). The W_r values still provide a description of variability within monthly hake condition.

The spatial analysis of mean W_r values shows significant variation between coasts for both species, however this difference is only highly significant ($p < 0.001$) for shallow-water hake. The Agulhas Bank on the south coast is suggested, by Hutchings *et al.* (2009), to be a favoured spawning location for shallow-water hake because it has desirable environmental and ecological conditions. Payne (1989) claimed it was widely considered that hake have to spawn in mid-water. Therefore the Agulhas Bank would be too shallow for deep-water hake to spawn. Sundby *et al.* (2001) discussed the spawning behaviour of hake on the west coast. Hake caught prior to spawning have much a high body weight than shortly after spawning. This is seen in a sudden drop in monthly W_r values and has been incorporated in the W_s equations through comprehensive sampling efforts.

The W_s baselines for hake can be useful to the agencies managing hake stocks. The W_r values are conceptually straight-forward indices and easily applicable. Hake fishery stakeholders might also appreciate such information since these baselines relate to the current form of the fishery, with respect to TACs and little foreign fishing pressure. The mean annual W_r values could be qualitatively related to certain prominent environmental and ecological events (Cury and Shannon 2004). The W_s equations used data from periods spanning a wide range of environmental conditions, so that future changes in any direction should already be incorporated. These W_s equations can be beneficial as baselines against which to measure long term changes, and to compare W_r values of fish condition.

References

- Blackwell, B.G., Brown, M.L., Willis, D.W. 2000. Relative weight (W_r) status and current use in fisheries assessment and management. *Rev. Fish. Sci.* **8** (1), 1–44.
- Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., Miloslavich, P. 2010. A census of marine biodiversity knowledge, resources, and future challenges. *PLoS one.* **5** (8) e12110, 1-15.
- Cury, P., Shannon, L. 2004. Regime shifts in upwelling ecosystems: observed changes and possible mechanisms in the northern and southern Benguela. *Prog. Oceanog.* **60** (2), 223-243.
- Elvarsson, B.P., Taylor, L., Trenkel, V.M., Kupca, V., Stefansson, G. 2014. A bootstrap method for estimating bias and variance in statistical fisheries modelling frameworks using highly disparate datasets. *Afr. J. Mar. Sci.* **36** (1), 99-110.
- Fulton, E.A., Smith, A.D.M., Punt, A.E. 2005. Which ecological indicators can robustly detect effects of fishing? *ICES J. Mar. Sci.* **62** (3), 540–551.
- Gerow, K.G., Hubert, W.A., Anderson-Sprecher, R. 2004. An alternative approach to detection of length-related biases in standard-weight equations. *N. Am. J. Fish. Manage.* **24** (3), 903–910.
- Gerow, K.G., Anderson-Sprecher, R.C., Hubert, W.A. 2005. A new method to compute standard-weight equations that reduces length-related bias. *N. Am. J. Fish. Manage.* **25** (4), 1288–1300.
- Harikishun, A. 2013. *Establishing a weight-length baseline for evaluating changes in yellowfin tuna (Thunnus albacores) body condition in the Western Indian Ocean.* Bachelor of Science (Honours) thesis, University of Cape Town.
- Hutchings, L., Augustyn, C.J., Cockcroft, A., Van der Lingen, C., Coetzee, J., Leslie, R.W., Mayekiso, M. 2009. Marine fisheries monitoring programmes in South Africa. *S. Afr. J. Mar. Sci.* **105** (5-6), 182-192.
- Large, S.I., Fay, G., Friedland, K.D., Link, J.S. 2013. Defining trends and thresholds in responses of ecological indicators to fishing and environmental pressures. *ICES J. Mar. Sci.* **70** (4), 755-767.

- Link, J.S., Yemane, D., Shannon, L.J., Coll, M., Shin, Y.J., Hill, L., Borges, M.F. 2010. Relating marine ecosystem indicators to fishing and environmental drivers: an elucidation of contrasting responses. *ICES J. Mar. Sci.* **67** (4), 787–795.
- McDonald, J.H. 2009. *Handbook of biological statistics*. Baltimore, MD: Sparky House Publishing. **2**, 173-181.s
- Murphy, B.R., Brown, M.L., Springer, T.A. 1990. Evaluation of the relative weight (Wr) index, with new applications to walleye. *N. Am. J. Fish. Manage.* **10** (1), 85–97.
- Murphy, B.R., Willis, D.W., Springer, T.A. 1991. The relative weight index in fisheries management: status and needs. *Fish. (Bethesda)*. **16** (2), 30–38.
- Ndjaula, H.O.N., Gerow, K.G., van der Lingen, C.D., Moloney, C.L., Jarre, A. 2013. Establishing a baseline for evaluating changes in body condition and population dynamics of sardine (*Sardinops sagax*) in the southern Benguela ecosystem. *Fish. Res.* **147**, 253-263.
- Nelson, G., Hutchings, L. 1983. The Benguela upwelling area. *Prog. Oceanog.* **12** (3), 333-356.
- Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends. Ecol. Evol.* **10**, 430.
- Payne, A.I.L. 1989. Cape hakes. In Payne, A.I.L. and Crawford, R.J.M (ed.). *Oceans of Life off Southern Africa*. Vlaeberg, Cape Town. **14**, 136-147.
- Pillar, S.C., Barange, M. 1997. Diel variability in bottom trawl catches and feeding activity of the Cape hakes off the west coast of South Africa. *ICES J. Mar. Sci.* **54** (3), 485-499.
- Punt, A.E., Leslie, R.W. 1991. Estimates of some biological parameters for the Cape hakes off the South African west coast. *S. Afr. J. Mar. Sci.* **10** (1), 271-284.
- Punt, A.E. 1992. Selecting management methodologies for marine resources, with an illustration for southern African hake. *S. Afr. J. Mar. Sci.* **12** (1), 943-958.
- Punt, A.E. 1994. Assessments of the stocks of Cape hakes *Merluccius* species off South Africa. *S. Afr. J. Mar. Sci.* **14** (1), 159-186.
- Punt, A.E., Butterworth, D.S., Martin, J. 1995. The effects of errors in the placement of the boundary between the West and South Coast hake *Merluccius* species stocks on the

- performance of the current hake management procedure. *S. Afr. J. Mar. Sci.* **15** (1), 83-98.
- Shannon, L.J., Cury, P.M., Nel, D., Van der Lingen, C.D., Leslie, R.W., Brouwer, S.L., Hutchings, L. 2006. How can science contribute to an ecosystem approach to pelagic, demersal and rock lobster fisheries in South Africa? *Afr. J. Mar. Sci.* **28** (1), 115-157.
- Sundby, S., Boyd, A.J., Hutchings, L., O'Toole, M.J., Thorisson, K., Thorsen, A. 2001. Interaction between Cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. *S. Afr. J. Mar. Sci.* **23** (1), 317-336.
- Yemane, D., Field, J.G., Leslie, R.W. 2008. Indicators of change in the size structure of fish communities: a case study from the south coast of South Africa. *Fish. Res.* **93** (1), 163-172.

Appendix

Differences in mean W_r values were tested with analyses of variances (ANOVA) tables. Single factor ANOVAs were used to test the differences between annual (Table 4) and monthly mean W_r values (Table 5). A two-way ANOVA was used to test the differences between the mean W_r values for species and South African west and south coasts (Tables 6). There appeared to be a statistically significant difference between the west and south coast and so individual single-factor ANOVAs were produced with each species individually and both coasts (Table 7). A two-way ANOVA was also used to test the differences between species and male and female hake. The only significant difference in mean W_r values was found between south and west coast shallow-water hake.

Table 4: Single factor ANOVAs to test for differences between annual mean W_r values for both species of hake.

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
(a) Shallow-water hake					
Year	225	1	224.9	1.291	0.256
Residuals	6289208	36118	174.1		
(b) Deep-water hake					
Year	634	1	634.2	4.643	0.031
Residuals	2889990	21158	136.6		

Table 5: Single factor ANOVAs to test for differences between monthly mean W_r values for both species of hake.

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
(a) Shallow-water hake					
Month	31554	1	31554	182.100	<0.001
Residuals	6257879	36118	173		
(b) Deep-water hake					
Month	7320	1	7320	53.710	<0.001
Residuals	2883305	21158	136		

Table 6: Two-way ANOVA table to test for differences between the mean W_r values for species and South African west and south coasts.

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Species	879	1	879	5.524	0.02
Coast	54731	1	54731	344.073	<0.001
Residuals	9091345	57154	159		

Table 7: Single factor ANOVAs to test for differences between the mean W_r values of South Africa's west and south coast hake, for both species separately.

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
(a) Shallow-water hake					
Coast	64912	1	64912	377.10	<0.001
Residuals	6201730	36025	172		
(b) Deep-water hake					
Coast	994	1	994	7.30	0.01
Residuals	2878440	21128	136		

Table 8: Two-way ANOVA table to test for differences between the mean W_r values for species and sex (males and females).

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Species	668	1	668.4	4.476	0.03
Sex	611	1	611.3	4.094	0.04
Residuals	8027312	53762	149.3		