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Visual health assessment of parous female southern right whales (Eubalaena australis) off the southern Cape coast, South Africa

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INTERNATIONAL WHALING COMMISSION

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This report is based on the MSc thesis "Visual health assessment of parous female southern right whales (*Eubalaena australis*) off the southern Cape coast, South Africa" by Sandra Hörbst (2019) with updated data including data of the 2018 annual aerial survey.

Abstract

Long-term monitoring of the South African southern right whale (*Eubalaena australis*) population has revealed a decrease in sightings along the coast and an increase of calving intervals within the last few years. As reproductive success is often linked to body condition, the purpose of this study was to conduct a visual health assessment of parous females (based on overhead photographs from the annual aerial southern right whale surveys) to detect potential links between their visual health condition and increased calving intervals as well as environmental indices of the Southern Ocean. The method used was adapted from a visual health assessment method developed for northern right whales (*Eubalaena glacialis*) by Pettis et al. (2004), adjusted in collaboration with southern right whale researchers from South Africa and Australia.

The main findings were:

- Health variables derived from overhead photographs were sufficient to detect visual health changes over time. Within the study period, two years (2008 and 2014) had a significant decreased visual health.
- No direct link between the visual health condition and calving intervals could be found, possibly due to the lack of data on calving intervals post-2014 as well as the fact that only calving females could be assessed with the given data.
- Significant relationships were found between visual health and Southern Ocean climate indices (SOI, $p<0.05$; ONI, $p<0.01$) as well as chlorophyll a concentrations in one proposed feeding ground ($p>0.001$), indicating a link between southern right whale visual health condition and Southern Ocean food availability.

The standardization of the methodology allows comparison of results on a global scale. Nonetheless, it is suggested that the survey methods also be standardized across populations to ensure even better

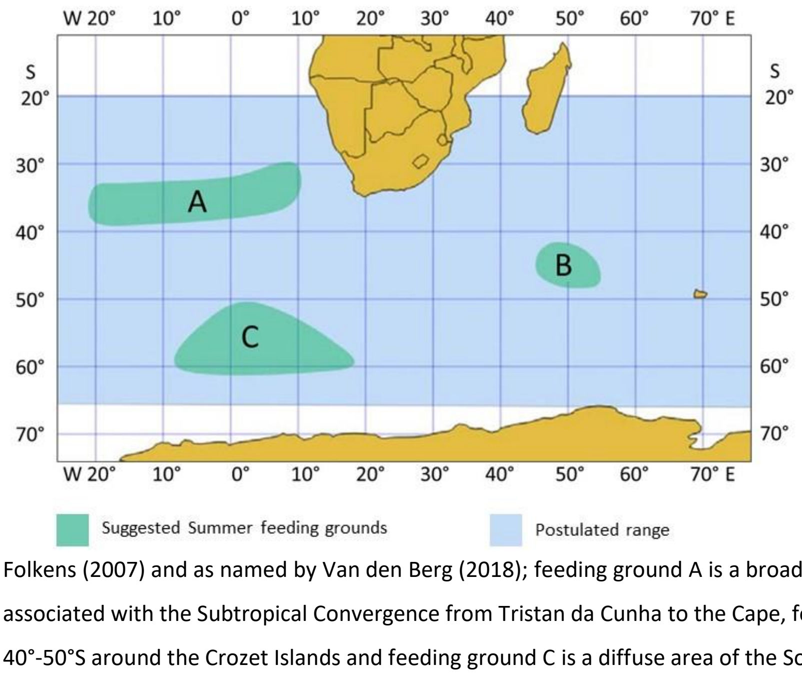
comparisons (including a quantitative assessment of the body condition of South Africa's southern right whales).

Introduction

After severe whaling, the South African population of southern right whales (*Eubalaena australis*) is recovering, with the most recent rate of increase estimated at 6.5% y^{-1} (Brandão et al. 2018). However, a decrease in sightings along the southern Cape coast of unaccompanied adults (males and non-calving females) has been noted since 2009 as well as a decrease in cow-calf pairs since 2015 (Findlay et al. 2017; Vermeulen et al. 2018). Moreover, the observed calving intervals started to increase from 2009, from a three-year to a four- and even five-year calving interval (Brandão et al. 2018; Vermeulen et al. 2018). Similar trends of increased calving intervals within the last few years have been observed in other populations of southern right whales (e.g. Charlton et al. 2018).

Body condition, and thus feeding success, has been shown to affect both survival and reproductive success of northern right whales (*Eubalaena glacialis*) (Pettis et al. 2004; Miller et al. 2011). In line with this, it is hypothesised that the increased calving intervals observed in recent years in the South African population could be caused by a decrease in body condition and overall health caused by poor feeding conditions. Little is known about the diet of southern right whales, but from historic whaling data southern right whales from the South African population are believed to feed in three main areas of the Southern Ocean (Townsend 1935; Tormosov et al. 1998; Figure 1). Additionally, some evidence suggests some feeding activity in a localised area of the South African west coast (Mate et al. 2011).

Figure 1: Southern right whale (*Eubalaena australis*) feeding grounds from the South African population. Graph from Best &



Folkens (2007) and as named by Van den Berg (2018); feeding ground A is a broad band of the south-eastern Atlantic Ocean associated with the Subtropical Convergence from Tristan da Cunha to the Cape, feeding ground B is a smaller area between 40°-50°S around the Crozet Islands and feeding ground C is a diffuse area of the Southern Ocean south of 52°S.

Understanding variations in body condition among parous females and how this impacts their calving success, and causes potential demographic changes, is important to predict resilience of the southern right whale population to external stressors. Visual health assessments are repeatable methods and have been conducted for terrestrial and marine mammals (e.g. Lowman et al. 1976; Bradford et al. 2008; Joblon et al. 2014; Morfeld et al. 2014). The visual health assessment method for northern right whales was established by Pettis et al. (2004) using selected physical variables from archived photographs, showing changes in body condition of females in calving and non-calving years. This suggests that changes in body condition and overall health can be detected visually from photographs and can be related to reproductive success.

Methods

A 14-year dataset of digital aerial overhead identification (ID) photographs of parous female southern right whales was chosen from a 39-year long database from the Mammal Research Institute Whale Unit, University of Pretoria. These photographs were taken during the annual southern right whale aerial surveys, conducted every year at the beginning of October along the southern Cape coast (for details of the methodology see Best 1990, Best et al. 2001, and document SC/68A/SH/01). In total, 75,886 digital photographs obtained between 2005 and 2018 were used for analyses. The year 2005 was chosen as the cut-off year because digital photographs were obtained for the first time, maximising the number of photographs per whale and image quality. This range of years ensured coverage of whales in years with "normal" calving intervals (2005-2008) and years with increased modelled and observed calving intervals (2009-2018 according to Brandão et al. 2018 and SC/68A/SH/01 respectively).

Health assessment variables

The visual health scoring criteria for northern right whales from Pettis et al. (2004) were adapted and adjusted in consultation with southern right whale specialists from South Africa (E. Vermeulen) and Australia (C. Charlton and F. Christiansen). The scoring criteria that were developed for southern right whales include five visual health indices and were scored on a numerical scale from 0-1, with low scores indicating better health than high scores (Table 1). Because the main purpose of the annual southern right whale aerial surveys was to capture the whale´s callosity and dorsal colouration pattern for identification purposes, the photographs do not necessarily provide an image of the entire body, necessary for a visual health assessment. Therefore, a quantitative body assessment could not be done for the South African population. The other four visual health indices used in this assessment were (Table 1):

1. Body condition – qualitative

   The score for body condition was based on the estimation of the relative amount of subcutaneous fat (Pettis et al. 2004). The numerical score of the visual assessment of body fat condition was categorised as follow: "excellent", "good", "medium" and "poor" (Table 1). The “excellent” body condition is an additional score (not used by Pettis et al. 2004) and was assigned to whales whose area posterior to the blowholes showed severe convexity and no differentiation of the neck roll and posterior area (C. Charlton unpublished data).

2. Skin condition

   The skin condition score was evaluated generally (i.e. creating one numerical score) considering the number and severity of a) epidermal lesions from i) gull strikes, ii) ship strikes, iii) entanglement or iv) other lesions, as well as b) sloughing skin, and c) cyamids on the whale's body. Subsequently, based on the numerical score, the skin condition was split up in three categories: "good", "medium" and "poor" (Table 1).

3. Cyamids around blowholes

   The incidence of cyamids around the blowholes was evaluated on presence/absence and quantity of cyamids and fell into one of the following two categories: "absent/few" or "present" (Table 1).

4. Rake marks

   The definition of rake marks used for the visual health assessment of southern right whales is not consistent with that of Pettis et al. (2004); here, rake marks are predatory in origin, as described by George et al. (1994), representing bites or tooth rake marks. The visual assessment was based on presence-absence, number, brightness, depth of the rake marks and area affected. The created score was evaluated generally (i.e. creating one numerical score) from a combination of a) rake marks post blow hole b) rake marks pectoral fin c) rake marks fluke d) bite pectoral fin e) bite fluke. Scored rake marks fell into one of the following three categories: "good", "medium" and "poor" (Table 1).

Table 1: Five health indices and their scoring categories for visual health assessment of southern right whales (*Eubalaena australis*), adapted from Pettis et al. (2004) in collaboration with E. Vermeulen, C. Charlton and F. Christiansen.

	Health index	Detail	Excellent	Good	Medium	Poor
1	Body condition - quantitative	Photogrammetry width to length	Top 10th percentile	Above average	Average	Below average
			0	**0.1 – 0.2**	**0.3 – 0.4 – 0.5 – 0.6**	**0.7 – 0.8 – 0.9 – 1**
2	Body condition – qualitative	Deposited fat reserve post blow hole (convex/ concave body shape)	Severe convexity, no differentiation between neck roll and posterior area	Flat or rounded neck roll, convexity	Slight to moderate convexity	Concavity, dip posterior neck area
				0 – 0.1 – 0.2	**0.3 – 0.4 – 0.5 – 0.6**	**0.7 – 0.8 – 0.9 – 1**
3	Skin condition	a) Epidermal lesions i) Gull strike		Black skin with no lesions	Approximately >5cm lesions	Approximatly >50 cm lesions
		ii) Ship strike		As above	As above	As above
		iii) Entanglement		As above	As above	As above
		iv) Other		As above	As above ns	As above
		b) Skin sloughing (peeling)		Black skin with no sloughing	Approximatly >5cm sloughing	Approximatly >50 cm sloughing
		c) Orange cyamids on body		No cyamids	Approximatly >5 cm cyamids	Approximatly >50 cm cyamids
				0 – 0.1 – 0.2	**0.3 – 0.4 – 0.5 – 0.6**	**0.7 – 0.8 – 0.9 – 1**
4	Rake marks or bite (predation event)	a) Rake marks post blow hole (scraping)		No rake marks present	Evidence of rake marks	Rake marks approximatly >50cm
		b) Rake marks pectoral fin (scraping)		No rake marks present	Evidence of rake marks	Rake marks approximatly >50cm
		c) Rake marks fluke (scraping)		No rake marks present	Evidence of rake marks	Rake marks approximatly >50cm
		d) Bite pectoral fin		No bite scars present	Evidence of bite scars	Bite marks approximatly >50cm
		e) Bite fluke		No bite scars present	Evidence of bite scars	Bite marks approximatly >50cm
				1 – Absent/Few	**2 - Present**	
5	Cyamids around blowholes			**0 – 0.1 – 0.2 – 0.3 – 0.4**	**0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1**	
				Absent or very few	Present	

Scoring and consistency analyses

Only photographs in which the female was clearly visible were used to score the four health variables. If a reliable score could not be assigned, because of bad image quality or low percentage (< 30%) of body visibility, "not applicable" was assigned and that particular sighting was removed from the data set. Based on the assessed health variables, a Total Score (TS) of external body condition was calculated for each female, using weighted values of the different health variables: 45% for body condition, 27.5% for skin condition, 17.5% for cyamids around blowholes and 10% for rake marks. Although, the weighting was subjective, it was based on literature: subcutaneous fat was identified as the most important contributor, based on the findings of Miller et al. (2011) who showed that trends in blubber thickness correspond to the reproductive cycle of northern right whales. Skin condition was considered a slightly less important indicator of health, as sloughing skin (partially or fully) can also be periodic and a natural way to replace old skin (Reeb et al. 2007), or can be caused by the whales' behaviour (Fortune et al. 2017). Cyamids around the blowholes are also known to indicate stress or bad health (Knowlton and Kraus 2001) but might not necessarily affect the accumulation of subcutaneous fat. However, orange cyamids on the body of adults have been used previously as indicators of poor health (e.g., Knowlton and Kraus, 2001), and epidermal lesions may affect the overall health of the individual. Therefore, it was assumed that this factor made only a small contribution to the whale's reproductive ability and the contribution of this variable was weighted less than 20%. Lastly, rake marks were given the least importance, as they do not necessarily affect long-term feeding behaviour to restore fat reserves.

The TS of each female for each year was compared using an ANOVA to detect whether there was an annual variation in visual health condition over the study period. A Tukey posthoc test was conducted to show which years were significantly different from each other. Additionally, a principal component analysis (PCA) was conducted to visualize the relation among principal components of the four health score variables.

To check for consistency in scoring, a randomised controlled trial (double-blind approach) was carried out. Inter-researcher consistency analysis was conducted among three researchers for the four health score variables of 10 randomly selected (using a routine in R (Core version 3.5.1; RStudio Team 2018)) females (from 2005 - 2017 data). The scoring of the three researchers were compared using Fleiss' Kappa test for agreement (Conger 1980; Fleiss 1971; Fleiss et al. 2003).

Statistical analysis of health assessment scores in relation to environmental indicators and reproductive success

Generalized additive models (GAMs) were used to test if the health scores of females could be explained by environmental indicators. Four climate indices were used to represent the state of the ecosystem: Oceanic Niño Index (ONI), Antarctic Oscillation (AAO), Southern Oscillation Index (SOI) and September Antarctic sea ice extent (SASIE) obtained from Van den Berg (2018, Table 1), as suggested by NOAA Climate Predictor Centre database (http://www.cpc.ncep.noaa.gov/) and National Snow & Ice Data Centre (https://nsidc.org/data/seaice_index/). In addition, mean January chlorophyll a concentrations (mg/m3) were obtained from Van den Berg (2018, Table 1) (through https://www.oceancolour.org/) for the three proposed feeding grounds. Relationships between climate indices and visual health condition of female southern right whales were estimated using a 0-year lag only (except SASIE, which was estimated using a 1-year lag, as it is measured in September when calving females are present in their breeding ground).

To test whether individual health scores could be used as a predictor of reproductive success (measured through the length of calving interval) the health scores were related to each female's previous and next calving interval using General Additive Models (GAMs). A Kruskal Wallis test was used to detect possible changes in calving interval with changes in health scores over the study period.

Results

Scoring and consistency analyses

In total, 48,678 photographs were used for the visual health assessment, based on the visibility of the whale's body in the photograph (i.e. whale breaking the surface and visibility of the water). After evaluation of the different health variables and image quality, 182 non-unique females were excluded from further analyses due to missing values (NAs) in any of the four health variables. This selection procedure lead to 2,916 non-unique females (of which 2,034 were multiparous and 882 primiparous) or 1,570 uniquely identified females over various sightings being used for analyses. Comparing females' total health scores (TS) among the years using an ANOVA showed a significant annual fluctuation in the mean TS ($F= 20.07$, $df1 = 13$, $df2 = 2902$ $p <0.001$). A Tukey posthoc test showed significant differences between 2014 and the other years as well as a significant difference between 2008 and most years (Figure 2; Appendix 1).

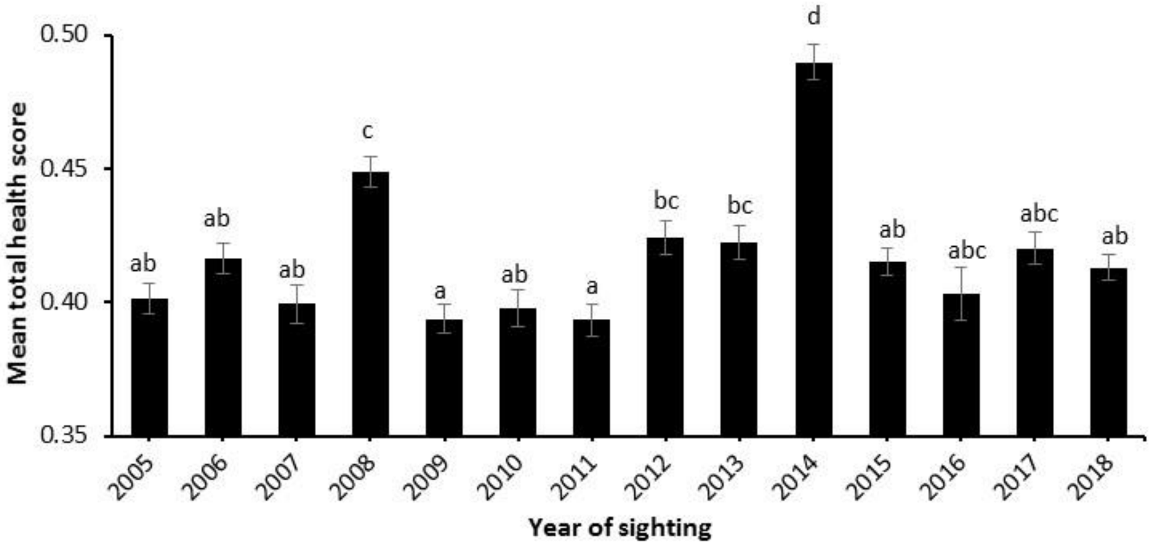


Figure 2: Mean total health scores (± SE) for parous female southern right whales (*Eubalaena australis*), indicating decreased health (i.e. increased score) in 2008 and 2014. The letters a, b, c, d above the line indicate which statistical population(s) the years fall into and are a result of the Tukey posthoc test.

The PCA analysis showed that body condition, skin condition and cyamids around the blowholes contribute almost equally to PC 1 and only rake marks are not well covered (Table 2). This indicates that the suggested calculation of TS by the author, in which rake marks are given least weight, is similar to the results of the PCA.

Table 2: Contribution of the four health score variables to principal components.

Contribution	Dim.1 (PC 1)	Dim.2 (PC 2)	Dim.3 (PC 3)	Dim.4 (PC 3)
Body condition	26.51	5.22	60.84	7.42
Skin condition	39.22	2.20	3.95	54.63
Cyamids around blowholes	33.43	4.69	27.39	34.48
Rake marks	0.83	87.89	7.82	33.47

The results of the Fleiss' Kappa test for inter-rater agreement ($K_w = 0.57$, $z = 10.60$, $p < 0.001$) suggested moderate agreement (Landis & Koch, 1977) among the three researchers for all four health scores combined (based on 10 individuals).

Analysis of health assessment scores in relation to environmental indicators and reproductive success

Results of the GAM relating TS to environmental indicators on a 0-year lag showed that ONI, SOI and chlorophyll a concentration in one feeding ground (feeding ground A) were significantly related to visual health of reproducing female southern right whales (Table 3).

Table 3: Results of the generalized additive model relating health score of female southern right whales (*Eubalaena australis*) off the South African coast, to year and various climate and biological indices of the Southern Ocean. Significant values are displayed in bold. * p < 0.05, ** p < 0.01 and *** p< 0.001.

Response variable	Explanatory variable	edf	R-sq. (adj)	Deviance expl.	p-value	
TS	ONI (Oceanic Niño Index)	3.240			**0.005**	**
	AAO (Antarctic Oscillation)	1.821			0.247	
	SOI (Southern Oscillation Index)	1.007			**0.032**	*
	SASIE lag 1 (Sept. Antarctic sea ice extent)	1.964	0.079	8.23%	0.112	
	Chlorophyll a (feeding ground A)	1.882			**<0.001**	***
	Chlorophyll a (feeding ground B)	1.000			0.211	
	Chlorophyll a (feeding ground C)	1.003			0.796	

Comparing the four health score variables to previous calving intervals (excluding primiparous females) and to next calving interval (excluding 1,504 non-unique females with no next calving interval), only rake marks and year had a significant effect (Table 4).

Table 4: Results of the generalized additive model comparing calving intervals to the four health score parameters. Significant-values are displayed in bold. * p < 0.05, ** p < 0.01 and *** p < 0.001.

Response variable	Explanatory variable	edf	R-sq. (adj)	Deviance expl.	p-value	
Previous calving interval	Body condition	1.002			0.123	
	Skin condition	1.005			0.141	
	Cyamids around blowholes	1.001	0.038	4.20%	0.066	
	Rake marks	2.817			**<0.001**	***
	Year	5.081			**<0.001**	***
Next calving interval	Body condition	2.171			0.207	
	Skin condition	1.001			0.638	
	Cyamids around blowholes	2.079	0.047	5.51%	0.051	
	Rake marks	1.360			**0.043**	*
	Year	5.342			**<0.001**	***

Calving intervals (to previous or to next calf) did not seem to vary with a decrease in health (i.e. increased score) for each of the health score variables (Appendix 2 and 3) and the statistical comparisons (Kruskal-Wallis tests) were not significant (Table 5).

Table 5: Results of Kruskal-Wallis tests comparing calving intervals among scores for four health score variables.

Calving interval	Health score parameter	χ^2	df	p-value
Previous	Body condition	14.366	10	0.157
	Skin condition	9.2853	10	0.505
	Cyamids around blowholes	8.2104	6	0.223
	Rake marks	13.471	10	0.199
Next	Body condition	15.986	10	0.100
	Skin condition	10.991	9	0.276
	Cyamids around blowholes	11.707	7	0.111
	Rake marks	11.045	10	0.354

Discussion

Scoring and consistency analysis

Results of this study clearly indicated annual fluctuations of visual health condition of parous female southern right whales during their stay at breeding grounds off the southern Cape coast. A significant reduction in visual health could be detected in 2008 and 2014. After the first year of decreased visual health (i.e. increased health score) (2008), calving intervals started to increase, indicating that an increased number of females started to take an extra year's rest. At the same time, the number of unaccompanied adults along the South African coast dropped. After the second year of a significantly decreased visual health of calving females (2014), the number of cow-calf pairs has dropped significantly along the South African coast and the occurrence of four- to five-year calving intervals peaked (Brandão et al. 2018 and SC/68A/SH/01). Although no clear links could be established between visual health condition and calving interval, this timing is not believed to be a coincidence.

Comparison of inter-rater reliability between the researchers showed overall only moderate agreement. This could arguably be a result of the different experience of each researcher in scoring. At the same time, only a small sample size was used for the inter-rater reliability test due to time constraints, which might affect the overall result. However, Pettis et al. (2004) have shown sufficient objectivity of visual health assessment methods conducted on northern right whales. Comparing the results to other studies, one still needs to be careful and account for the difference in scoring. Nevertheless, when using the method within the same study (conducted by one researcher) it is believed to be objective enough to detect changes of visual health among individuals and years.

Analysis of visual health scores in relation to environmental indicators and reproductive success

Results showed that visual health condition of parous female southern right whales was related to climatic variables. This confirms the findings of Van den Berg (2018) (document SC/68A/SH/xx) who revealed that the number of southern right whale calves in South Africa is linked with ocean productivity and Southern Ocean climate conditions. Chlorophyll a concentrations in one feeding ground were found to have a significant relationship with visual health condition of parous females. However, possible lagged effects of environmental variables on females' health condition need to be investigated further.

According to the GAM analysis, only rake marks and year were indicated as possible predictors of the female's previous and next calving interval. However, the number of rake marks observed was very low; in fact, rake marks have the lowest contribution to explain the health of female southern right whales as suggested by the PCA results, so this result needs to be interpreted with care. Further analysis did not indicate a clear relationship between the visual health condition of parous female southern right whales and their calving intervals. However, this could be caused by the data collection procedure; only females with calves (i.e. in a good enough condition to reproduce) were photographed on the annual aerial surveys so non-calving females could not be assessed. It could also be caused by the small number of females that calved post-2014 (when visual health condition significantly decreased and four- and five-year calving intervals peaked), leading to a much smaller sample size for analyses.

The results presented in this study could only be obtained because of the length of the dataset that was used. Long-term datasets are important to find relationships between baleen whale health and associated demographics as well as climate indices. Therefore, the continuation of the southern right whale monitoring program is of vital importance in times of environmental change.

Limitations

The visual health assessment analyses were limited by several factors, including the image quality and angle, as the photographs were taken for identification purposes. Additionally, the study was limited by only showing some form of association, but no causation of the apparent annual fluctuation in visual health. It is also important to mention that this study focuses on breeding females only and does not assess the entire population. In summary, the main limitations of this study were:

- Prominence of accumulated fat in the neck area was not always clearly visible from aerial photographs.

- Inter-rater consistency was only moderate, likely due to the small number of females scored by all researchers.
- Only calving females were assessed, due to the data collection procedure.
- Females' stage of lactation was not accounted for. Miller et al. (2011) showed a decrease in blubber thickness between the second and fourth month of lactation.

Future research & ways forward

- Global standardization of methodology is recommended to allow better comparison of data between breeding grounds.
- Re-evaluation of inter-rater consistency needs to be conducted with a larger sample size to validate the methodology.
- Relationship between visual health and climatic indices and chlorophyll a concentrations need further and more detailed assessment using a variety of time lags and accounting for individual whales. Right whale feeding success is complex and influenced by several biological and environmental processes (Hilsta et al. 2009) and therefore should not be simplified and misinterpreted.

References

Best PB. 1990. Natural markings and their use in determining calving intervals in right whales off South Africa. African Zoology **25**:114-123.

Best PB, Brandão A, Butterworth DS. 2001. Demographic parameters of southern right whales off South Africa. Journal of Cetacean Research and Management **2**: 161-169.

Best PB, Folkens PA. 2007. Whales and dolphins of the southern African subregion. Cambridge University Press, Cambridge.

Bradford AL, Weller DW, Ivashchenko YV, Burdin AM, Brownell Jr RL. 2008. Seasonal and annual variation in body condition of western gray whales off northeastern Sakhalin Island, Russia. Publications, Agencies and Staff of the U.S. Department of Commerce 129.

Brandão A, Vermeulen E, Ross-Gillespie A, Findlay K, Butterworth DS. 2018. Updated application of a photo-identification based assessment model to southern right whales in South African waters, focussing on inferences to be drawn from a series of appreciably lower counts of calving females over 2015 to 2017. Unpublished report (SC/67B/SH/22) presented to the 67Bth IWC scientific committee (Southern Hemisphere Subcommittee), Bled, Slovenia 2018.

Charlton C, Bannister J, McCauley RD, Brownell Jr RL, Ward R, Salgado-Kent C, Burnell S. 2018. Demographic parameters of southern right whales (*Eubalaena australis*) off Australia. Unpublished report (SC/67B/INFO/22 Rev1) presented to the 67Bth IWC scientific committee (Southern Hemisphere Subcommittee), Bled, Slovenia 2018.

Conger AJ. 1980. Integration and generalisation of Kappas for multiple raters. Psychological Bulletin **88**: 322-328.

Fleiss JL. 1971. Measuring nominal scale agreement among many raters. Psychological Bulletin **76**: 378-382.

Fleiss JL, Levin B, Paik MC. 2003. Statistical methods for rates and proportions, 3rd Edition. John Wiley & Sons, New York.

Findlay K, Thornton M, Wilkinson C, Vermeulen E, Hoerbst S. 2017. Report on the 2016 Mammal Research Institute Whale Unit Southern Right Whale Survey , Nature's Valley to Lambert's, South Africa. Unpublished report (SC/67A/SH/05 Rev1) presented at the 67Ath IWC scientific committee, Bled, Slovenia 2017.

Fortune SM, Koski WR, Higdon JW, Trites AW, Baumgartner MF, Ferguson SH. 2017. Evidence of molting and the function of "rock-nosing" behavior in bowhead whales in the eastern Canadian Arctic. PLoS One **12**: e0186156.

George JC, Philo LM, Hazard K, Withrow D, Carroll GM, Suydam R. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort seas stock. Arctic **1994**: 247-255.

Hlista BL, Sosik HM, Traykovski LVM, Kenney RD, Moore MJ. 2009. Seasonal and interannual correlations between right-whale distribution and calving success and chlorophyll concentrations in the Gulf of Maine, USA. Marine Ecology Progress Series **394**: 289-302

Hörbst, S. 2019. Visual helath assessment of parous female southern right whales (*Eubalaena australis*) off the southern Cape coast, South Africa. MSc Thesis, Universisty of Cape Town, Cape Town, South Africa.

Joblon MJ, Pokras MA, Morse B, Harry CT, Rose KS, Sharp SM, Niemeyer ME, Patchett KM, Sharp WB, Moore MJ. 2014. Body condition scoring system for delphinids based on Short-beaked common dolphins (*Delphinus delphis*). Journal of Marine Animals and their Ecology **7**: 5-13.

Knowlton AR, Kraus SD. 2001. Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. Journal of Cetacean Research and Management (special issue) **2**: 193-208.

Landis JR, Koch GG. 1977. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. Biometrics: 363-374.

Lowman BG, Scott NE, Somerville SH. 1976. Condition scoring of cattle. East of Scotland College of Agriculture. Animal Production, Advisory and Development Department. Edinburgh School of Agriculture.

Mate BR, Best PB, Lagerquist BA, Winsor MH. 2011. Coastal, offshore, and migratory movements of South African right whales revealed by satellite telemetry. Marine Mammal Science **27**:455–476

Miller CA, Reeb D, Best PB, Knowlton AR, Brown MW, Moore MJ. 2011. Blubber thickness in right whales Eubalaena glacialis and Eubalaena australis related with reproduction, life history status and prey abundance. Marine Ecology Progress Series **438**: 267-283.

Morfeld KA, Lehnhardt J, Alligood C, Bolling J, Brown JL. 2014. Development of a body condition scoring index for female African elephants validated by ultrasound measurements of subcutaneous fat. PLoS One **9**: e93802.

National Snow & Ice Data Center. 2018. Sea Ice Index. Available at: https://nsidc.org/data/seaice_index/.

NOAA. 2018. Climate Predictor Centre. Available at: http://www.cpc.ncep.noaa.gov/.

Ocean Color - CCI. 2018. Available at: https://nsidc.org/data/seaice_index/.

Pettis HM, Rolland RM, Hamilton PK, Brault S, Knowlton AR, Kraus SD. 2004. Visual health assessment of North Atlantic right whales (*Eubalaena glacialis*) using photographs. Canadian Journal of Zoology **82**: 8-19.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reeb D, Best PB, Kidson SH. 2007. Structure of the integument of southern right whales, Eubalaena australis. The Anatomical Record **290**: 596-613.

Tormosov DD, Mikhaliev YA, Best PB, Zemsky VA, Sekiguchi K, Brownell Jr RL. 1998. Soviet catches of southern right whales (*Eubalaena australis*), 1951–1971. Biological data and conservation implications. Biological Conservation **86**: 185-197.

Townsend CH. 1935. The distribution of certain whales as shown by logbook records of American whaleships. Zoologica **19**: 1-50

Van den Berg, G. 2018. Linking climate and ocean productivity to the prevalence of southern right whales (*Eubalaena australis*) in South African waters. Honours Thesis, Universisty of Stellenbosh, Stellenbosh, South Africa. 33p.

Vermeulen E, Wilkinson C, Thornton M, Peters IT, Findlay K. 2018. Report on the 2017 Mammal Research Institute Whale Unit Southern Right Whale Survey, Nature’s Valley to Lamberts Bay, South Africa. Unpublished report (SC/67B/SH/01) presented to the 67Bth IWC scientific committee (Southern Hemisphere Subcommittee), Bled, Slovenia 2018.

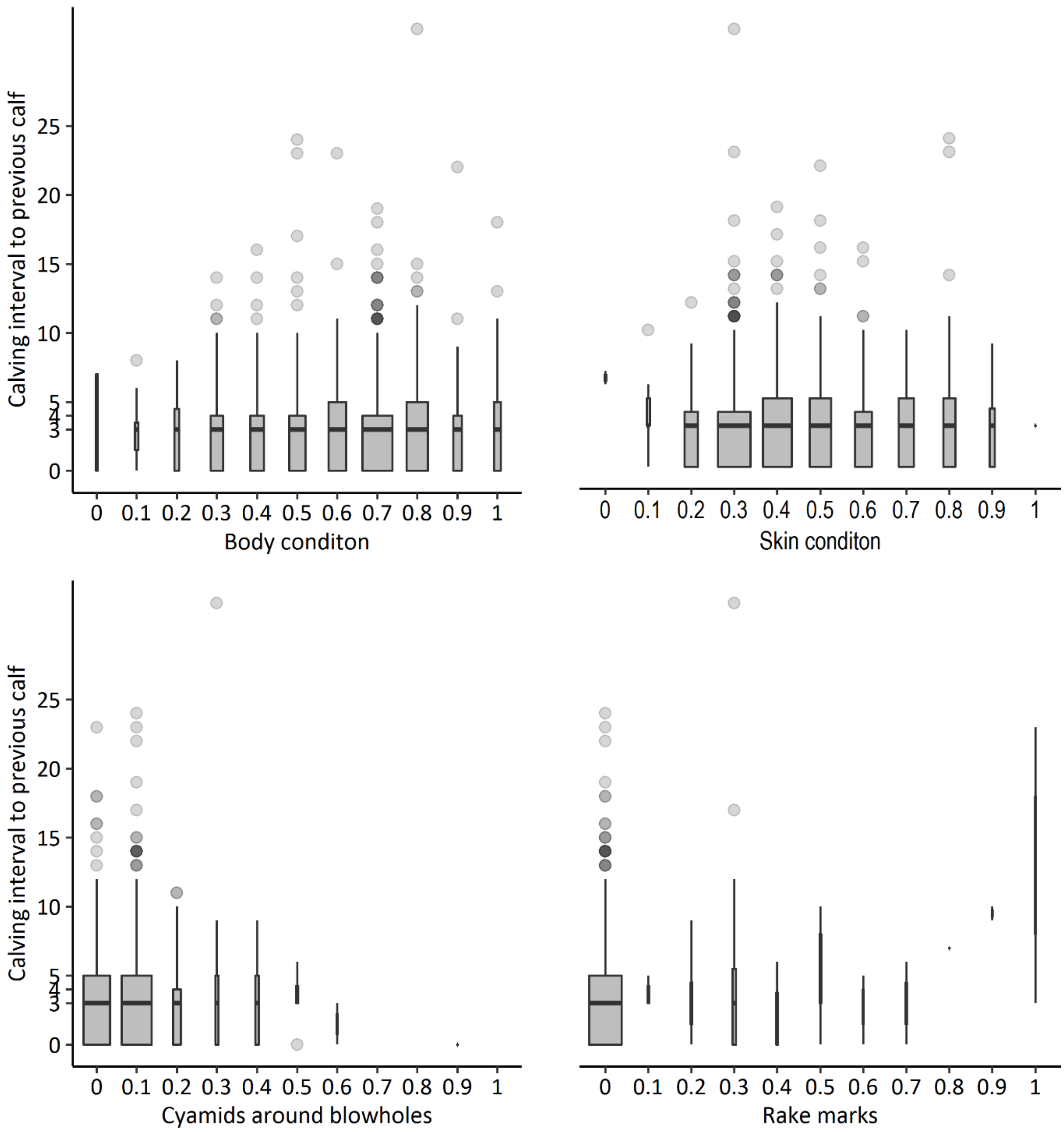
Appendices

Appendix 1

Year	Difference	p adj.	Year	Difference	p adj.	Year	Difference	p adj.	Year	Difference	p adj.
2006-2005	0.015	0.921	2017-2006	0.004	1.000	2010-2009	0.004	1.000	2018-2011	0.020	0.322
2007-2005	-0.002	1.000	2018-2006	-0.003	1.000	2011-2009	0.000	1.000	2013-2012	-0.002	1.000
2008-2005	0.047	**<0.001**	2008-2007	0.049	**<0.001**	2012-2009	0.031	**0.020**	2014-2012	0.066	**<0.001**
2009-2005	-0.008	1.000	2009-2007	-0.006	1.000	2013-2009	0.029	**0.028**	2015-2012	-0.009	1.000
2010-2005	-0.004	1.000	2010-2007	-0.002	1.000	2014-2009	0.096	**<0.001**	2016-2012	-0.021	0.973
2011-2005	-0.008	1.000	2011-2007	-0.006	1.000	2015-2009	0.022	0.521	2017-2012	-0.004	1.000
2012-2005	0.023	0.368	2012-2007	0.025	0.268	2016-2009	0.009	1.000	2018-2012	-0.011	0.977
2013-2005	0.021	0.464	2013-2007	0.023	0.347	2017-2009	0.027	0.214	2014-2013	0.067	**<0.001**
2014-2005	0.088	**<0.001**	2014-2007	0.090	**<0.001**	2018-2009	0.019	0.334	2015-2013	-0.007	1.000
2015-2005	0.014	0.979	2015-2007	0.016	0.947	2011-2010	-0.004	1.000	2016-2013	-0.019	0.986
2016-2005	0.002	1.000	2016-2007	0.004	1.000	2012-2010	0.026	0.138	2017-2013	-0.002	1.000
2017-2005	0.019	0.823	2017-2007	0.021	0.724	2013-2010	0.024	0.187	2018-2013	-0.009	0.994
2018-2005	0.012	0.975	2018-2007	0.014	0.931	2014-2010	0.092	**<0.001**	2015-2014	-0.075	**<0.001**
2007-2006	-0.017	0.846	2009-2008	-0.055	**<0.001**	2015-2010	0.017	0.867	2016-2014	-0.087	**<0.001**
2008-2006	0.032	**0.010**	2010-2008	-0.051	**<0.001**	2016-2010	0.005	1.000	2017-2014	-0.069	**<0.001**
2009-2006	-0.023	0.271	2011-2008	-0.055	**<0.001**	2017-2010	0.022	0.558	2018-2014	-0.077	**<0.001**
2010-2006	-0.019	0.688	2012-2008	-0.025	0.173	2018-2010	0.015	0.806	2016-2015	-0.012	1.000
2011-2006	-0.023	0.261	2013-2008	-0.027	0.072	2012-2011	0.031	**0.019**	2017-2015	0.005	1.000
2012-2006	0.008	1.000	2014-2008	0.041	**<0.001**	2013-2011	0.029	**0.026**	2018-2015	-0.002	1.000
2013-2006	0.006	1.000	2015-2008	-0.034	**0.020**	2014-2011	0.096	**<0.001**	2017-2016	0.017	0.997
2014-2006	0.073	**<0.001**	2016-2008	-0.046	0.078	2015-2011	0.022	0.508	2018-2016	0.010	1.000
2015-2006	-0.001	1.000	2017-2008	-0.029	0.135	2016-2011	0.010	1.000	2018-2017	-0.007	1.000
2016-2006	-0.013	1.000	2018-2008	-0.036	**<0.001**	2017-2011	0.027	0.206			

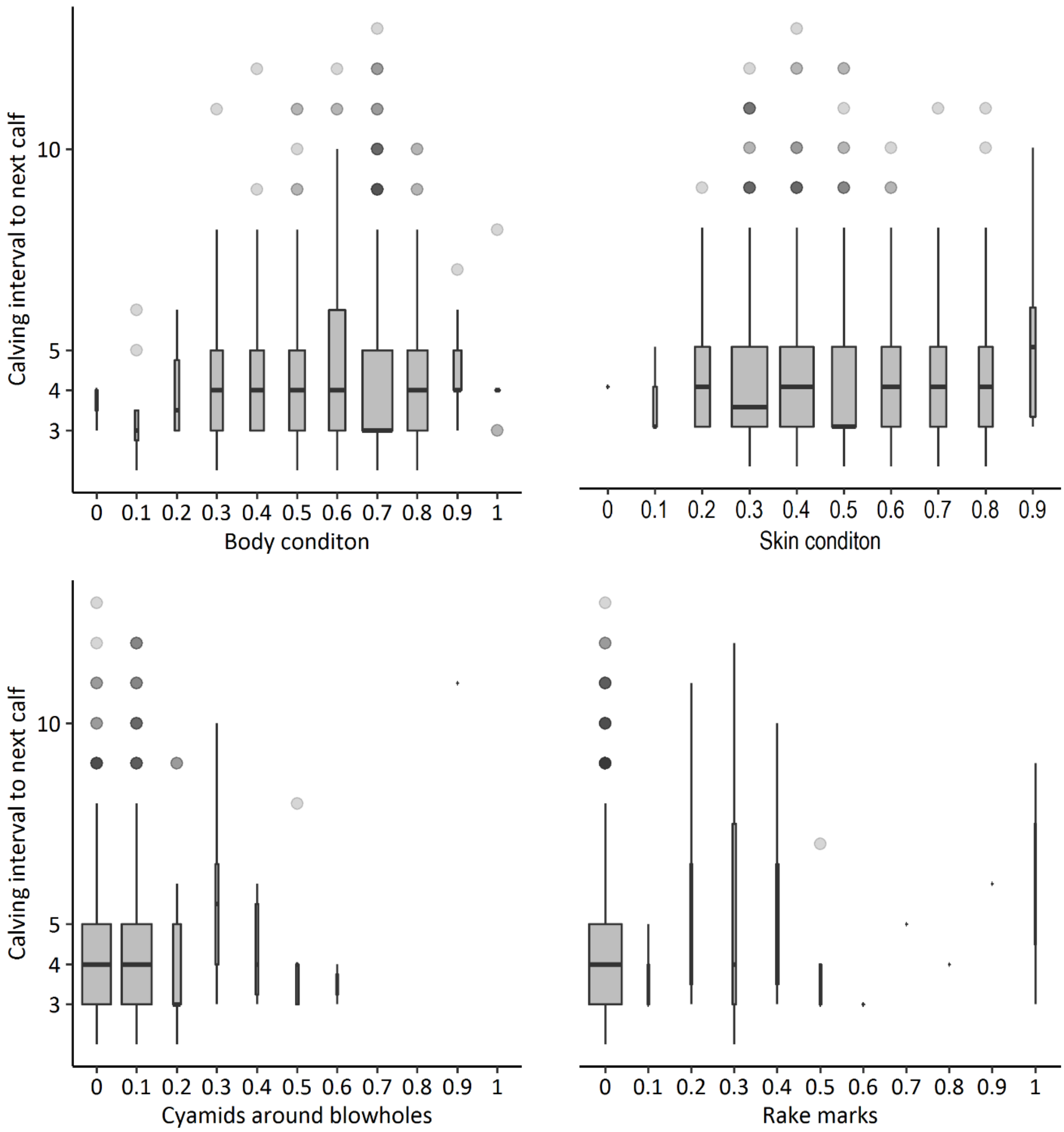
Results from the Tukey posthoc test for TS, showing the difference and significance of total health score between the various years over the study period. Significant values are displayed in bold.

Appendix 2



The calving interval to previous calf in relation to health scores for parous female southern right whales (*Eubalaena australis*). The boxes indicate interquartile ranges, the thick line is the median and the dots are outliers **a)** Body condition **b)** Skin condition **c)** Cyamids around blowholes **d)** Rake marks.

Appendix 3



The calving interval to next calf in relation to health scores for parous female southern right whales (*Eubalaena australis*). The boxes indicate interquartile ranges, the thick line is the median and the dots are outliers **a)** Body condition **b)** Skin condition **c)** Cyamids around blowholes **d)** Rake marks.