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

Master of Science in Conservation Biology

FitzPatrick Institute of African Ornithology,

University of Cape Town

Sandra Hörbst

February 2019

University of Cape Town

Supervisors - Professor Coleen L. Moloney & Dr Els Vermeulen

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

University of Cape Town

Plagiarism declaration

I know that plagiarism is wrong. Plagiarism is using another's work and to pretend that it is one's own. Each contribution to, and quotation in, this thesis from the work or works of other people has been attributed and has been cited and referenced. I acknowledge that copying someone else's assignment or essay, or part of it, is wrong, and declare that this is my own work. This thesis is my own work. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

Signature: Signed by candidate

Date: 7th February 2019

Table of Contents

Acknowledgments

I am exceedingly grateful to my supervisors, Dr Els Vermeulen and Professor Coleen L. Moloney for their guidance and advice throughout the study. Particularly, I would like to thank Els for her endless encouragement, passion for southern right whales and inspiring me to accomplish this project. As well as sharing her office with me during the analysis and always being there to answer any question, giving quick feedback and corrections. I would like to specially thank Coleen for her valuable time, sharing statistical knowledge, answering related questions as well as her help with stylistic matters and corrections of the thesis. I truly appreciate both supervisors and could have not asked for better support. I would also like to thank the Mammal Research Institute Whale Unit, University of Pretoria for their long-term dataset and hard work during the field season collecting this valuable data on southern right whales. Additionally, I'd like to thank Dr Claire Charlton for a good cooperation establishing the methodology as well as her advice during analysis. Thanks to Toby Rogers for his time and feedback during write-up. Thanks to all the lecturers and the CB class 2018 for sharing their knowledge during the year. Lastly, I'd like to thank Monika Spielmann and Hennie Odendal for their endless support in difficult times and patience throughout the year.

Abstract

The long-term monitoring of the South African southern right whale population has revealed a decrease in sightings along the coast and an increase of calving intervals within the last few years, causing changes in the species´ demographics causing a decrease in annual population growth rate (6.5% y^{-1}). Because reproductive success is linked to body condition, the purpose of this study was to conduct a visual health assessment based on overhead photographs from the annual aerial southern right whale surveys and detect potential links between visual health condition of parous females and the increased calving intervals. Additionally, it was aimed to find relationships between visual health of parous females and environmental indices of the Southern Ocean, representing food availability. To allow global comparison of the results, the method used for the visual health assessment was developed in collaboration with international southern right whale researchers from Australia and South Africa. The health indices were adapted from a visual health assessment method developed for northern right whales and include body condition, skin condition, the presence of cyamids around the blowholes and rake marks on the skin. The results showed that these health variables derived from overhead photographs were sufficient to detect visual health changes over time. Within the study period (2005 – 2017), there were two years in which whales had a significant decreased visual health (i.e. increased health score) than average; 2008 and 2014. No direct link between the observed health condition and calving intervals could be found, possibly due to the lack of data on calving intervals post-2014 as well as the assessment of breeding females only (i.e. breeding females are in good enough conditions to reproduce). However, significant relationships were found between visual health and Southern Ocean productivity ($p < 0.001$) and climate indices ($p < 0.05$) with a 0-year lag. These results clearly indicate a link between southern right whale visual health condition and Southern Ocean food availability in one feeding ground, suggesting that this may be the primary feeding ground for parous females during pregnancy. Understanding the links between visual health, reproductive success and climate/food availability helps to understand changes in the population’s demographics and to predict the resilience of the species. Additionally, the standardization of the method allows for global comparison.

Keywords: Health assessment · Right whales · Reproduction · Body condition

Introduction

Southern right whales (*Eubalaena australis*) were severely hunted, especially during the first half of the 19th century, in at least 16 identified whaling grounds (IWC 2001). Estimates suggest that in 1920 only 60 adult females remained in the global population (Baker & Clapham 2004). Their common name "right whale" is thought to originate from whalers as they were considered the “right” whale to hunt globally, as they occur nearshore with predictable distributions, swim slowly and float when dead. Although southern right whale were protected in the 1930's Convention (D'Amato & Chopra, 1991; Kobayashi 2005) illegal catches from the Soviet Union continued until the 1970s (Tormosov et al. 1998) and may have delayed the species’ recovery by almost two decades (Baker & Clapham 2004). However, since the late 1970s, the South African population of southern right whales is increasing, and the most recent rate of increase has been estimated at 6.5% y^{-1} (Brandão et al. 2018). However, a decrease in sightings of unaccompanied adults (males and non-calving females) along the southern Cape coast has been noted since 2009 as well as a decrease of cow-calf pairs since 2015 (Findlay et al. 2016; Vermeulen et al. 2018; Figure 1).

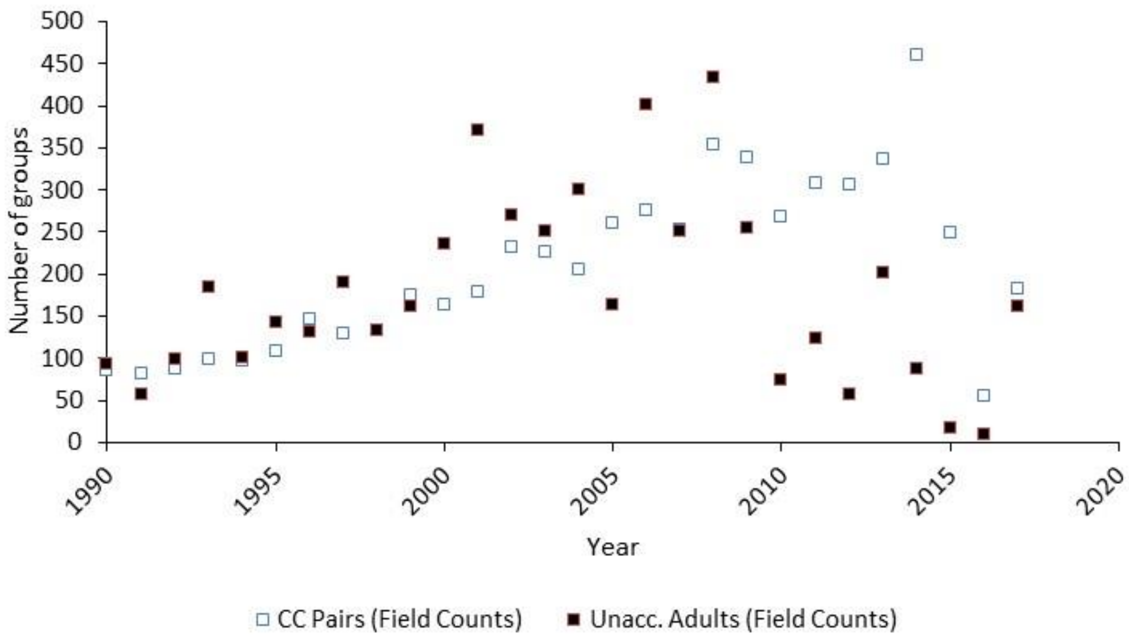


Figure 1: Number of unaccompanied adults and cow-calf pairs sighted in South Africa in annual aerial southern right whale surveys conducted in October each year. Graph from Vermeulen et al. 2018, p.16.

Moreover, the observed calving intervals have increased over the last few years (Figure 2), 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 were observed in the Australian southern right whale population (Charlton et al. 2018). This decrease in calving events (i.e. increase in calving intervals) will have negative impacts on the population demography of the species. Therefore, understanding variations in body condition among parous female southern right whales and how it impacts their calving success and potential demographic changes is important to predict resilience of the population to external stressors.

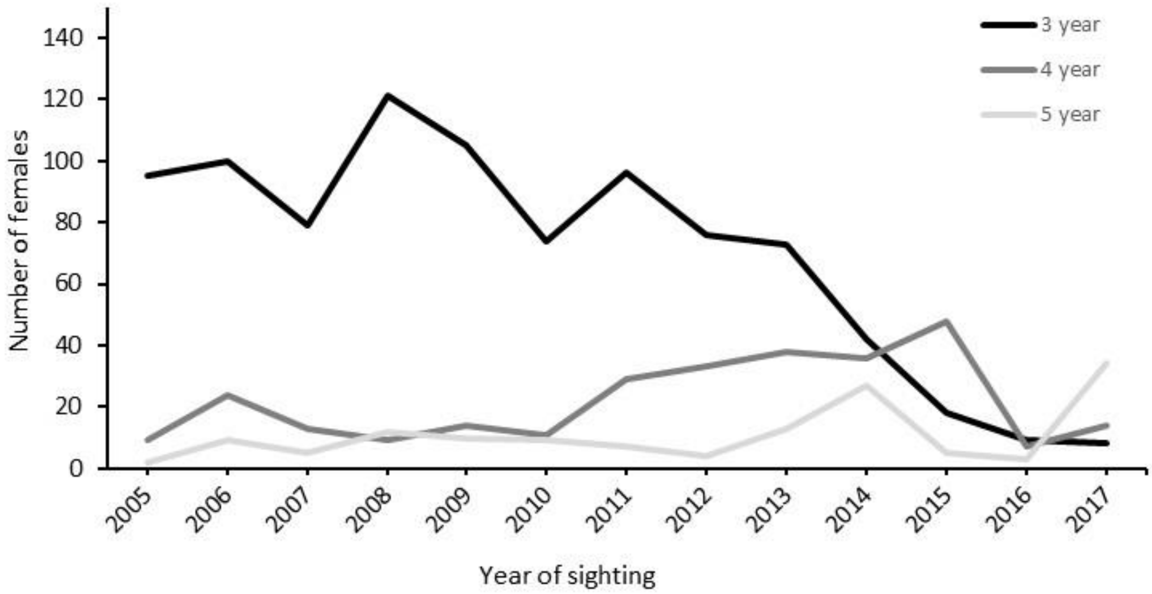


Figure 2: The number of female southern right whales (*Eubalaena australis*) off South Africa with three-, four- and five-year calving intervals to previous calving event, from 2005 to 2017.

Southern right whale reproduction

Female southern right whales usually give birth to their first calf at an age of eight years, thereafter normally giving birth every three years (Cooke et al. 2001; Brandão et al. 2011). Their three-year calving cycle includes one year of gestation, one year for nursing and raising the calf and one year of rest to recover and stock up fat reserves (Greene & Pershing 2004). However, reproduction is costly and females who are not able to accumulate enough fat because of decreased food availability are not likely to reproduce successfully (i.e. produce offsprings). In general, a minimum level of fat reserve is required in mammals for ovulation and successful reproduction (Frisch 1984; McEvoy & Robinson 2003). This relationship between body fat and ovulation has also been observed in baleen whales, such as fin whales

(*Balaenoptera physalus*) where fecundity (measured as ovulation rate) was correlated to body fat condition (Lockyer et al. 1986). Miller et al. (2011) showed showing that trends in blubber thickness correspond to the reproductive cycle of northern right whales and that right whales have the largest amount of body fat before the start of pregnancy.

Calving intervals of four- and five-years had been noted in a few instances, both in the northern and southern hemisphere (Knowlton et al. 1994; Cooke & Rowntree 2003; Best 2005; Kraus 2007), before the recent increase in the South African southern right whale population. These instances of increased calving interval were interpreted as calving failures (Knowlton et al. 1994, Burnell 2001). Four-year calving intervals can either result from failure to initiate pregnancy (and therefore the females will spend an extra year resting), or abortion of the foetus in early stages of gestation (and the female can shift immediately to resting) (Knowlton et al. 1994). A five-year calving interval is interpreted as a loss of the foetus in the late stages of gestation, resulting in the female resting until the next mating season (Knowlton et al. 1994). A five-year interval can also be interpreted as a death of the new-born calf, where the female will again rest until the next mating season (i.e. three-year interval plus a two-year interval; Knowlton et al. 1994). Two-year calving intervals of southern right whales are often not documented, especially in cases where the calf died before the annual survey of cow-calf pairs took place (Burnell 2001; Marón et al. 2015).

Southern right whale migration

Southern right whales usually occur between 60° S and 20° S, spending austral winter and spring at the low latitude breeding grounds and summer and fall at the high latitude feeding grounds (Cummings 1985; Reeves & Kenney 2003). Mate et al. (2011) have shown that southern right whales off the South African coast migrate to locations between 37°-45°S and some south of 52°S, possibly associated with the Sub Tropical Convergence and Arctic Polar Front. In the austral winter, reproducing females migrate to shallow coastal regions for calving, with the major breeding grounds found in Argentina, Australia, South Africa, New Zealand, Chile and Peru (Reilly et al. 2013; Galetti et al. 2014). Female southern right whales show strong site fidelity (Best 2000, Burnell 2001; Charlton et al. 2018), causing genetic differentiation between these four major breeding grounds (Patenaude et al. 2007; Valenzuela et al. 2008). Southern right whales also show a clear preference for sheltered shallow bays with a narrow temperature range at their breeding area (Elwen & Best 2004; Keller et al. 2006; Pirzl 2008). In spring southern right whales start returning to their feeding grounds in colder regions with high productivity (Tulloch et al. 2018) to stock up their fat reserves after fasting at their breeding grounds for up to four months (Burnell 2001; Charlton 2017).

Body condition, affected by feeding success, has been shown to affect both survival and reproductive success of northern right whales (*Eubalaena glacialis*) (Pettis et al. 2004). Sub-Antarctic waters (southern right whale feeding grounds) with higher Sea Surface Temperatures (SSTs) than normal cause a decline in krill density (Trathan et al. 2006). Such shortage of food availability has been shown to affect blubber thickness (i.e. energy reserve) of right whales, affecting their energy balance and reproduction (Miller et al. 2011). In line with this, it is hypothesised that the increased calving intervals observed in the South African population in recent years (2009-2017, Figure 1) could be caused by a decrease in body condition and overall health.

Visual health assessments

Health is defined by Stedman (2005 p.641) as "*the state of the organism when it functions optimally without evidence of disease or abnormality*". To assess the health of wildlife, methods such as tracking population abundance, reproduction and mortality have been used to date (Fowler & Siniff 1992). Visual health assessment methodologies are repeatable and have been conducted for terrestrial and marine mammals (Lowman et al. 1976; Bradford et al. 2008; Joblon et al. 2014; Morfeld et al. 2014). Body fat or body condition measurements have been used to indicate reproductive success and survivorship in terrestrial and marine mammals (Guinet et al. 1998; Schulte-Hostedde et al. 2001). Body condition scoring for mammals was first developed for ewes by Jeffries (1961) using a 0 to 5 scale, where higher scores indicate better health (i.e. fatter sheep). This method was adapted for dairy cows by Lowman et al. (1976) and used across the globe. The visual health assessment method was further developed by defining the condition scores using photographs and a short text description (Earle 1976; Grainger & McGowan 1982).

Assessing the health of free ranging whales is difficult because of limited visibility of the entire body (Pettis et al. 2004). However, body condition changes have been detected using aerial photographs in gray whales (*Eschrichtius robustus*) (Perryman & Lynn 2002), humpback whales (*Megaptera novaeangliae*) (Christiansen et al. 2016) and southern right whales (Miller et al. 2012; Christiansen et al. 2018). A 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. The results of Pettis et al. (2004) suggested that changes in body condition and overall health can be detected visually from photographs and can be related to reproductive success.

Southern right whale diet and breeding success

Little is known about the diet of southern right whales, but from historic data it is suggested that they feed mainly on krill south of the polar front and on copepods north of 50°S (Tormosov et al. 1998). This latitudinal difference in diet can be explained by the distribution of Antarctic krill (*Euphausia superba*), which occur at high latitudes between the Polar Front and the Antarctic Shelf (Atkinson et al. 2004). Based on data from illegal Soviet whaling, southern right whales from the South African population are historically known to feed in three main areas of the Southern Ocean (Tormosov et al. 1998; Figure 3).

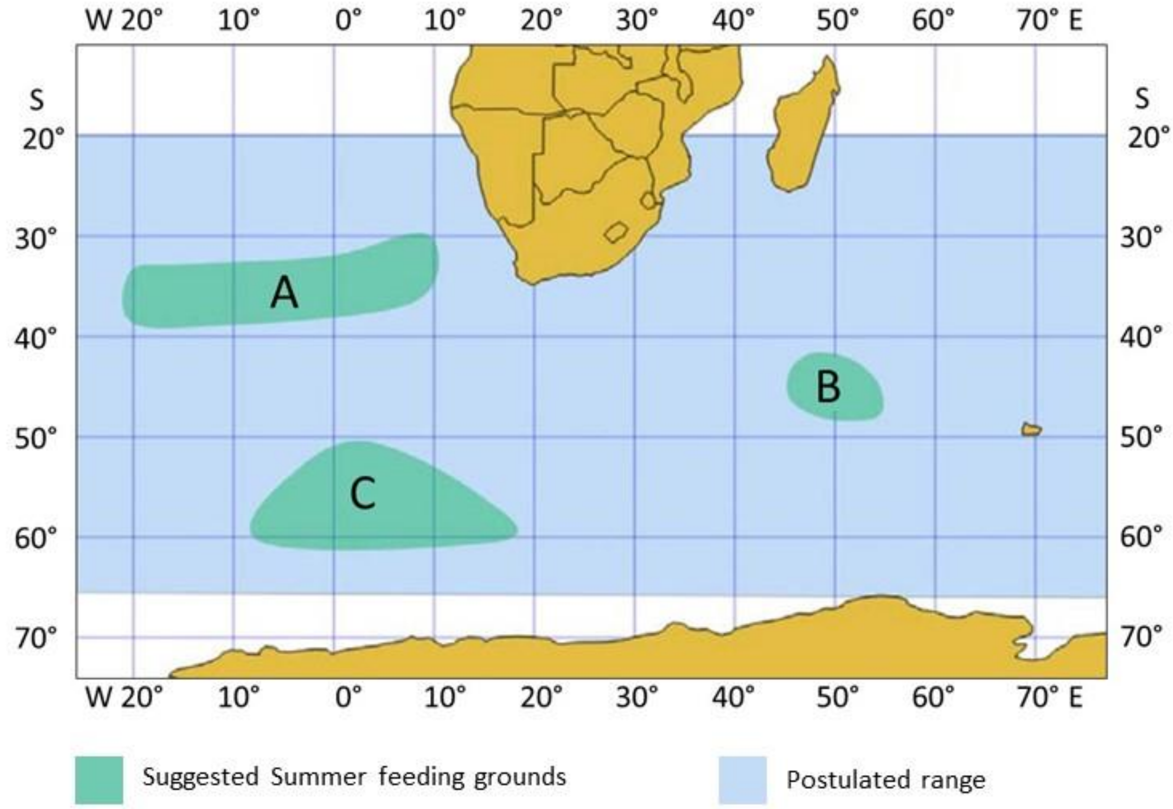


Figure 3: Southern right whale (*Eubalaena australis*) feeding grounds from the South African population. Figure from Best & Folkens (2007) and as named by Van den Berg (2018); Feeding ground A is a broad band of the south-eastern Atlantic Ocean associated with the Subtropical Convergence from Tristan da Cunha to the Cape, feeding ground B is a smaller area between40°-50°S around the Crozet Islands and feeding ground C is a diffuse area of the Southern Ocean south of 52°S (Tormosov et al, 1998).

Although data collection on krill exists (Atkinson et al. 2004), the methods used are not always consistent (Leaper et al. 2006). Nevertheless, a relationship has been detected between krill abundance and physical environmental factors (Murphy et al. 1998; Trathan et al. 2003). This implies that environmental variables such as chlorophyll a concentrations or SSTs can be used to show the relationships between food availability and reproductive success with various lag times. A study conducted in South Georgia showed a relationship between SST anomalies and the breeding success of land-based predators relying on krill (Forcada et al. 2005; Trathan et al. 2006) as well as southern right whales in Argentina (Leaper et al. 2006).

A recent study in South Africa showed correlations of El Niño/Southern Oscillation (measured through the following climate indices: Oceanic Niño Index, Antarctic Oscillation and Southern Oscillation index), Sea Ice extent (September Antarctic sea ice extent) and chlorophyll a concentrations, with the abundance of southern right whale cow-calf pairs sighted along the South African coast (Van den Berg 2018). In Brazil, a positive correlation was found between the number of southern right whale calves at the breeding grounds and prey availability at their feeding grounds at a 0-year lag (Seyboth et al. 2016), suggesting that the reproductive success of southern right whales is influenced by food availability during early months of gestation (Seyboth et al. 2016). Additionally, an increase in calving intervals to five-years was found to correlate with El Niño events in the Argentinean southern right whale population off Península Valdés (Leaper et al. 2006). Increased calving intervals during the 1990s, seen in North Atlantic right whales, have also been linked to possible food limitations (Kraus 2007).

Aims and objectives of the study

The aim of this study is to measure health condition of parous female southern right whales based on the method described in Pettis et al. (2004) to identify variations in visual health condition over time and assess the relationship between external health indicators and reproductive success (measured through calving intervals). Further, the intention is to assess the relationship between observed health and environmental variables in the Southern Ocean.

More specifically, the objectives of this study are to:

- Conduct a qualitative visual assessment of external health condition of parous female southern right whales using overhead photographs.
- Test the hypothesis that changes in visual health condition over time are related to changes in reproductive success.
- Test whether there are relationships between visual health condition and climate/biological indices representing food availability.
- Standardise the methodology for measuring visual health condition in southern right whales to facilitate comparability of results on a global scale.

Methods

Photo Identification data

A 13-year dataset (2005-2017) of aerial overhead identification (ID) photographs of parous female southern right whale was obtained from a 39-year long database from the Mammal Research Institute Whale Unit, University of Pretoria (Best 1990). These photographs were taken during the annual aerial southern right whale survey, conducted every year at the beginning of October. The survey has been carried out since 1979 to date and occurs between Nature's Valley (33°59'49"S 23°33'40" E) and Muizenberg (34°07'29"S 18°29'09"E). The main purpose of this aerial survey is to obtain photographs of the callosity patterns on the heads of females with calves as well as unaccompanied adults with brindle or partial grey coloration, for subsequent ID. The photographs were taken from a helicopter hovering between 90-150 meters above the whales, using a Canon DSLR camera from 2005 onwards. The helicopter typically spent 2-5 minutes with each cow-calf pair to obtain accurate images. Depending on wind conditions, the operating hours of the survey ranged from 08h00 to 16h00 to make use of optimal light conditions.

The callosities are areas of raised epithelium covered with cyamids ("whale lice") and barnacles. Callosity patterns on the head as well as unique dorsal coloration patterns are used to identify individual whales according to Payne et al. (1983) and Kraus et al. (1986). All ID photographs are processed using an identification software (Hiby-Lovell system) to enable automatic comparison of newly photographed individuals to a catalogue of previously identified individuals. For this study, photographs obtained between 2005 and 2017 were used for analysis. The range of years used ensures coverage of whales in years with “normal” calving intervals (2005-2008) and years just before and during increases in modelled calving intervals (2009-2017 according to Brandão et al. 2018). The year 2005 was chosen as a cut off year as it was the first year where digital photographs were obtained, leading to an increased number of photographs per whale.

Health assessment variables

The visual health scoring criteria for northern right whales from Pettis et al. (2004) were adapted and modified in consultation with southern right whale specialists from South Africa and Australia. The scoring criteria that were developed for southern right whales include five visual health indices. All five health indices were scored on a numerical scale, with low scores indicating better health than high scores (Table 1). Because the main purpose of the photographs was to capture the whale´s callosity and dorsal colouration pattern for ID purposes, and not for visual health assessment, the photographs are mainly focussed on the head and the back of the whale, and do not necessarily provide an image of the entire body.

For this reason, a quantitative body assessment was not carried out in this study. Photographs for the visual health assessment were further evaluated on the percentage of whales' body length seen above water (guided by figure 2 of Christiansen et al. 2018).

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). This was done by examining the prominence of accumulated fat in the neck area ("neck roll") posterior to the blowholes, as described by Rowntree (1999). The same area was evaluated during body condition scoring for delphinids (Joblon et al. 2014). The score is based on dorsal convexity or concavity just posterior to the blowholes. When viewed laterally, right whales in good conditions have a flat or slightly rounded convex shape or fat roll posterior to the blowholes. Whales considered to be in poor body condition show concavity in the same area posterior to the blowholes. Right whales in extremely poor condition can have "humps" posterior to the blowholes and even show a dip behind this hump (Pettis et al. 2004). The visual assessment of body fat condition was scored on a scale of 0-1, with scores falling into one of the following four categories (Table 1): "excellent" "good", "medium" and "poor" (C. Charlton unpublished data; Figure 4). The "excellent" body condition is an additional score (not used by Pettis et al. 2004) and is assigned to whales whose area posterior to the blowholes showed severe convexity and no differentiation of the neck roll (C. Charlton unpublished data).

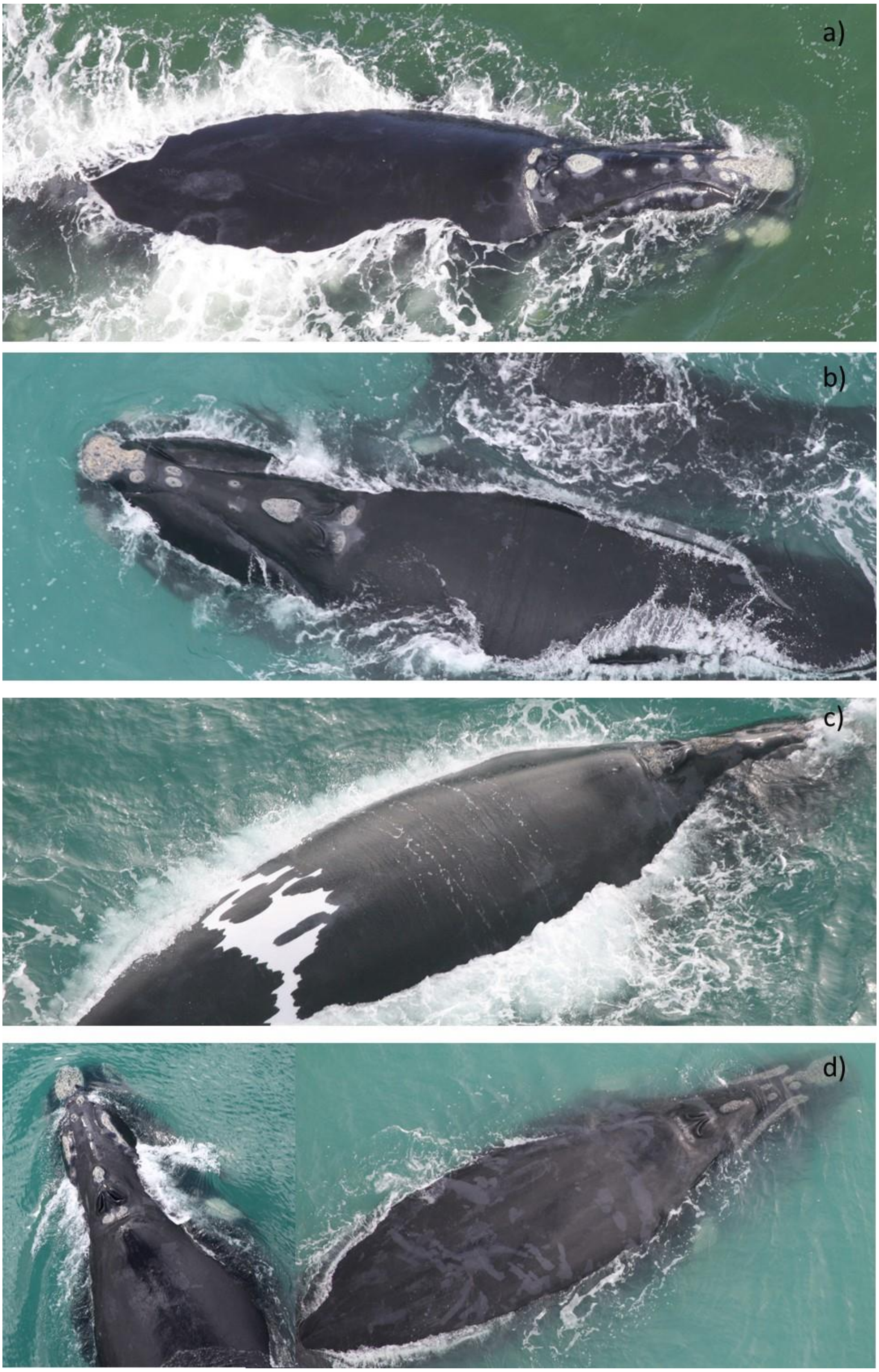


Figure 4: Body condition scores for southern right whales (*Eubalaena australis*) using overhead photographs and based on the prominence of the fat roll posterior to the blowholes: **a)** 'excellent', showing no differentiation in the fat roll, **b)** 'good', showing a flat area behind the blowholes, **c)** 'medium', showing a slight concavity, and **d)** 'poor', body condition showing concavity or a dip posterior to the blowholes.

2. Skin condition

   The skin condition score was evaluated by considering the number and severity of the following three factors a) epidermal lesions from gull strikes, ship strikes, entanglement or other, b) sloughing skin, and c) cyamids on the body (possibly *Cyamus ovalis*, as this species is often found to colonize wounds or areas where skin is severely damaged). Lesions can appear as white or greyish plaque-like patches with indistinct edges or they may appear as blisters resulting in crater-like patches (Pettis et al. 2004). Sloughing skin refers to areas of peeling skin where layers of the epidermis are falling off naturally or being shed through the whale's behaviour (breaching, lobtailing, etc.). Cyamids, also known as 'whale-lice', are present on the whale's body when the skin condition is poor or is considered unhealthy (Pettis et al. 2004; Rowntree 1996). Two cyamid species found on right whales (*Cyamus erraticus* and *Cyamus ovalis*) were described by Iwasa (1934). The skin condition was scored on scale of 0-1, with scores falling into one of the following three categories: "good", "medium" and "poor" (Table 1 & Figure 5).

Figure 5: Skin condition scores of southern right whales (*Eubalaena australis*) based on presence and severity of lesions, skin sloughing and cyamid coverage on the whale's body: **a)** 'good', showing black skin with no lesions, sloughing or cyamids, **b)** 'medium', showing some lesions, sloughing or cyamids, and **c)** 'poor', showing severe lesions, sloughing or cyamids.

3. Cyamids around blowholes

The incidence of cyamids around the blowholes was evaluated on a two-point scale for presence and number of cyamids. Whale-lice are known to occur around the blowhole region of cetaceans when the whale is injured or affected by other stressors like entanglement (Osmond and Kaufman 1998). Cyamids around blowholes were scored on scale of 0-1, with scores falling into one of the following two categories: "absent" or "present" (Table 1 & Figure 6).

Figure 6: Scores for cyamids around the blowholes of southern right whales (*Eubalaena australis*) based on incidence, number and size of patches. **a)** 'absent', with no or few cyamids around the blowholes and **b)** 'present', with cyamids around the blowholes

4. Rake marks

The definition of rake marks in this study is not consistent with that of Pettis et al. (2004), which defines rake marks as parallel lines in the skin occurring only anterior to the blowholes of the whale and often seen on whales chronically entangled. However, in this study 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. Rake marks were scored on scale of 0-1, with scores falling into one of the following three categories: "good", "medium" and "poor" (Table 1 & Figure 7).

Figure 7: Rake mark scores of predatory origin in southern right whales (*Eubalaena australis*) based on presence-absence, number, brightness, depth and area around blowholes. **a)** 'good' condition, no rake marks are visible, **b)** 'medium', a few rake or bite marks are visible, and **c)** 'poor' many rake marks are present.

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 C. Charlton, E. Vermeulen and F. Christiansen. The closer to one the score is, the worse the condition of the whale.

	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 of neck roll	Flat or rounded neck roll, convexity	Slight to moderate convexity	Concavity, dip
				0 – 0.1 – 0.2	**0.3 – 0.4 – 0.5 – 0.6**	**0.7 – 0.8 – 0.9 – 1**
3	Skin condition	i) Epidermal lesions – Gull strike		Black skin with no lesions	>5cm lesions	>50 cm lesions
		ii) Epidermal lesions – Ship strike		As above	>5cm lesions	>50 cm lesions
		iii) Epidermal lesions – Entanglement		As above	>5cm lesions	>50 cm lesions
		iv) Epidermal lesions – Other		As above	>5cm lesions	>50 cm lesions
		Skin sloughing (peeling)		Black skin with no sloughing	>5cm sloughing	>50 cm sloughing
		Cyamids on body		No cyamids	>5 cm cyamids	>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)	Rake marks post blow hole (scraping)		No rake marks present	Evidence of rake mark	Rake mark >50cm
		Rake marks pectoral fin (scraping)		No rake marks present	Evidence of rake mark	Rake mark >50cm
		Rake marks fluke (scraping)		No rake marks present	Evidence of rake mark	Rake mark >50cm
		Bite pectoral fin		No bite scars present	Evidence of bite	Bite mark >50cm
		Bite fluke		No bite scars present	Evidence of bite	Bite mark >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 analysis

For this study, 61,913 digital images were examined of 1,450 uniquely identified female southern right whales from 2005 to 2017. The year 2005 was chosen as the cut-off year due to the introduction of digital photography; females photographed before 2005 were ignored even if they were sighted during the study period. Photographs in which the female is 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 of body visibility, "not applicable" was assigned and that particular sighting of the female was removed from the data set. To evaluate the quality of the photographs, the image quality and the visibility of the water was assessed for all photographs (combined) available for a female in a given year (Table 2).

Table 2: Scores (1-3) assigned to quality of photographs and visibility of the water used in visual health assessment of southern right whales (*Eubalaena australis*).

	Scores		
Image quality	**1**	**2**	**3**
	Sharp photographs the features to be scored clearly visible	Some pictures were blurry and the 'to be scored features' partially visible	Most/all photographs were of bad quality and blurry and the features were difficult or not visible
Visibility of water	**1**	**2**	**3**
	Water was clear and features (e.g. sloughing skin, injuries) could be seen through the water	Water was slightly murky and the 'to be scored features' were not clearly visible	Water was murky and impossible to see anything of the 'to be scored features' or the whale

Based on the four health assessment 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. This weighting differs from the average weighing used in the study by Pettis et al. (2004). The weighting was subjective but based on prior knowledge from the literature. Subcutaneous fat was identified as the most important contributor to TS and is based on the findings from Miller et al. (2011) showing that trends in blubber thickness correspond to the reproductive cycle of northern right whales. Therefore, body condition was given the most weight calculating TS. Skin condition was considered a slightly less important indicator of health, as sloughing skin (partially or full) can 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 known to indicate stress or bad health (Knowlton and Kraus 2001) but might not necessarily affect the accumulation of subcutaneous fat. 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 (predatory of origin, as defined in this study) were given the least importance, because although they can affect reproduction, they do not necessarily affect long-term feeding behaviour to restore fat reserves.

In addition to the subjective weighting, a principal component analysis (PCA) was conducted to visualize the relation among principal components of the four health score variables. Should PC 1 explain most of the variability in the data, the results would be used to create an alternative total score. The mean TSs for each year were compared using an ANOVA to detect whether there was a difference in health between the various years during the study period. To check for consistency in scoring, a randomised controlled trial (double-blind approach) was carried out. Two experienced southern right whale researchers additionally scored the four health variables of 10 females randomly selected using a routine in R (Core version 3.5.1; RStudio Team 2018) from the data set of photographs from 2005 to 2017. Inter-researcher consistency among all three researchers for the four health score variables was compared using Fleiss' Kappa test for agreement (Conger 1980; Fleiss 1971; Fleiss et al. 2003).

Parity

Parity is the state of a female in relation to having given birth to a viable offspring. It is known to affect the body condition scores in other mammals; multiparous (i.e. have given birth to more than one offspring over time) females have better body condition than primiparous (i.e. have given birth to an offspring for the first time) females, as these latter females still invest some energy towards the growing process (Gallo et al. 1996). Females scored in a certain year that were seen before with a calf were assumed to be multiparous whereas females seen for the first time with a calf were assumed to be primiparous. The weighted total health score of primiparous and multiparous females over the study period was compared using a t-test.

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 female southern right whales can be explained by climatic and biological 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). The El Niño/Southern Oscillation indices were obtained from Van den Berg (2018) Table 1 (Appendix 1) as suggested by the NOAA Climate Predictor Centre database (http://www.cpc.ncep.noaa.gov/). SASIE values were derived from Van den Berg (2018) Table 1 as suggested by the National Snow & Ice Data Centre (https://nsidc.org/data/seaice_index/). In addition, mean January chlorophyll a concentrations (mg/m^3) over one year were obtained from Van den Berg's (2018) Table 1 (through https://www.oceancolour.org/) for the three known feeding grounds (Figure 2).

To test whether individual health scores can be used as a predictor of reproductive success, measured through the length of the calving interval, the health scores were related to each female´s calving interval using GAMs. First, the health scores were compared to the previous calving interval (i.e. years between current and previous calf). Additionally, the health scores were compared to the next calving interval (i.e. years between the current calf and next calf). Changes in health scores over the course of the study period were investigated to identify if the health scoring assessment can detect a change in calving interval using a Kruskal Wallis test. All statistical analyses were carried out in R Core version 3.5.1 (RStudio Team, 2018). For analyses and visualisation, the following packages in R Core v 3.5.1 were used: 'nlme' version 3.1-137 (Pinheiro et al. 2018), 'mgcv' version 1.8-26 (Wood et al. 2016), 'ggplot2' version 3.1.0 (Wickham, 2016) and 'irr' version 0.84 (Gamer et al. 2012), 'stats' version 3.6.0 (Miller, 1981; Yandell, 1997).

Results

Parameter scoring

In total, 41,215 photographs out of a total of 61,913 were utilized for the visual health assessment based on the visibility of the whale's body in the photograph (i.e. whale breaking the surface). These images resembled 1,450 uniquely identified females over various sightings or 2,674 non-unique females (i.e. representing the number of encounters that were available for health assessment). After evaluation of the different health variables, 118 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 40,438 images of 2,556 non-unique females (1,777 multiparous females and 779 primiparous females) used for further analyses. The body condition and cyamids around blowholes (especially when closed) were particularly difficult to observe in aerial photographs. This resulted in NA's being assigned to body condition (n = 66) and cyamids around blowholes (n = 73) more often than rake marks (n = 9) and skin condition (n = 5).

The average body length visible of females used for the analysis (n=2,556) on each photograph was 69.44% (SD ± 12.16) which ranged from 10% to 100% during the study period (Figure 8a). The average clarity score (scored 1 – 3) of all used images was 1.18 (SD ± 0.39) out of a maximum score of 3 (Figure 8b) and the average visibility (scored 1 – 3) of the water was 2.16 (SD ± 0.48) out of a maximum score of 3 (Figure 8c). In total, 4% of females were sighted four times during the study period, 20% were observed on three occasions and 28% twice between 2005-2017. This means that almost half (47%) of females were sighted only once in this study period.

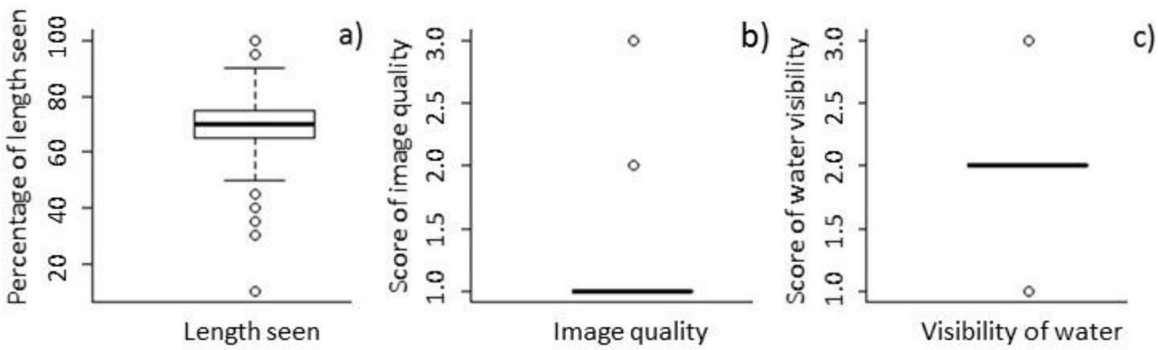


Figure 8: Boxplot diagram of a) length seen of the whale above water, b) image quality, and c) visibility of the water. The thick line is the median and the dots are outliers

Overall, a change in body condition, skin condition and cyamids around the blowholes was seen over the years, with an apparent decrease in body condition in 2008 and 2014 (Figure 9). Comparing the average total health (TS) among the years using an ANOVA shows that the mean TSs are significantly different among years ($F= 21.77$, $df_1 = 12$, $df_2 = 2543$ $p< 0.001$) with a significant decrease in health in 2008 and 2014 (Figure 10). A Tukey posthoc test showed significant differences between 2014 and the other years as well as significant difference between 2008 and most years (Appendix 2).

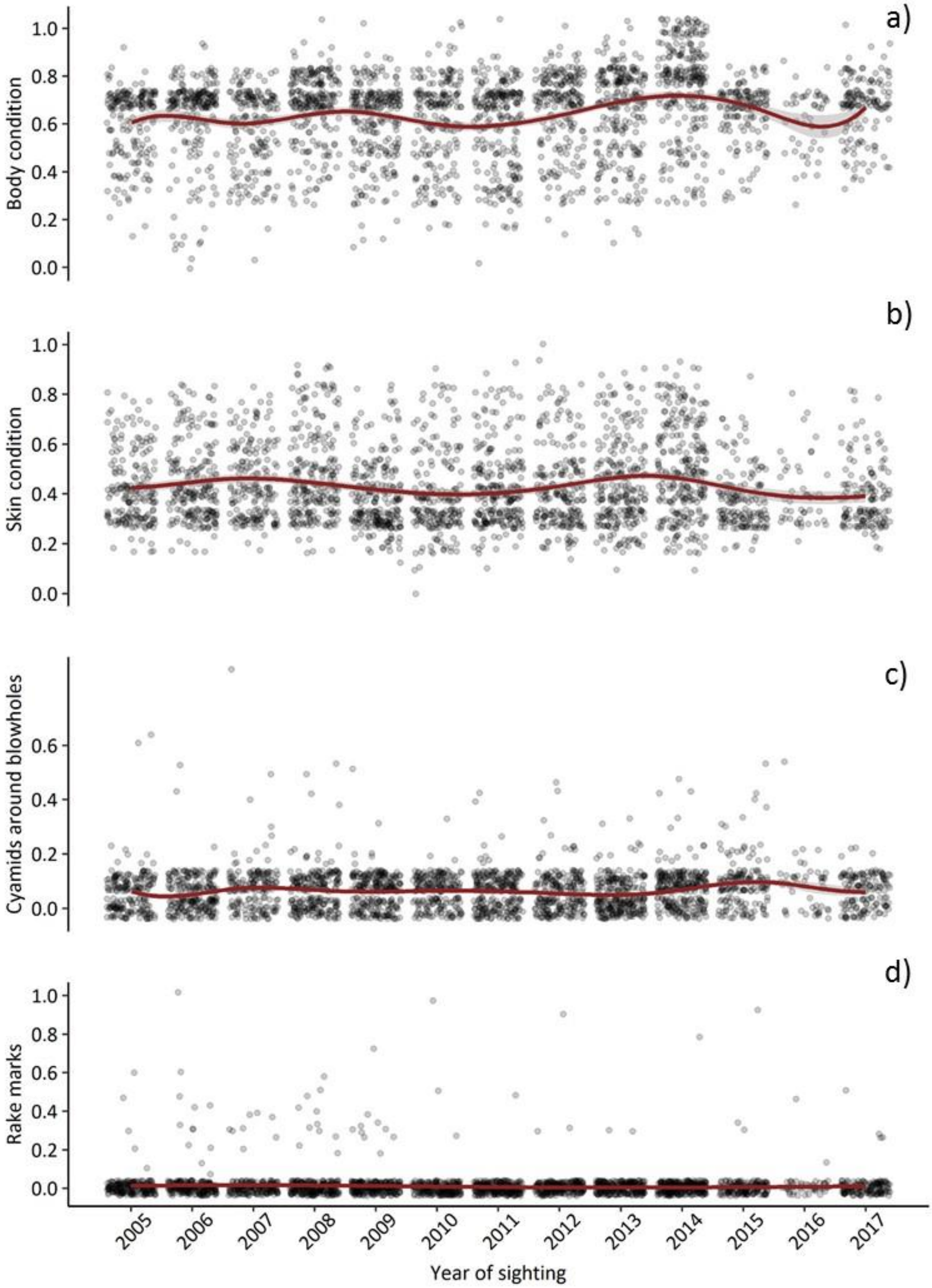


Figure 9: Scatter plot showing health condition variables for parous female southern right whales (*Eubalaena australis*) over the study **a)** Body condition evaluated from 2005-2017, **b)** skin condition evaluated from 2005-2017. **c)** incidence of cyamids around blowholes evaluated from 2005-2017, and **d)** presence of rake marks evaluated from 2005-2017. Red line indicates smooth regression line (formula = y ~ s (x, bs = "ps") with standard error displayed in grey.

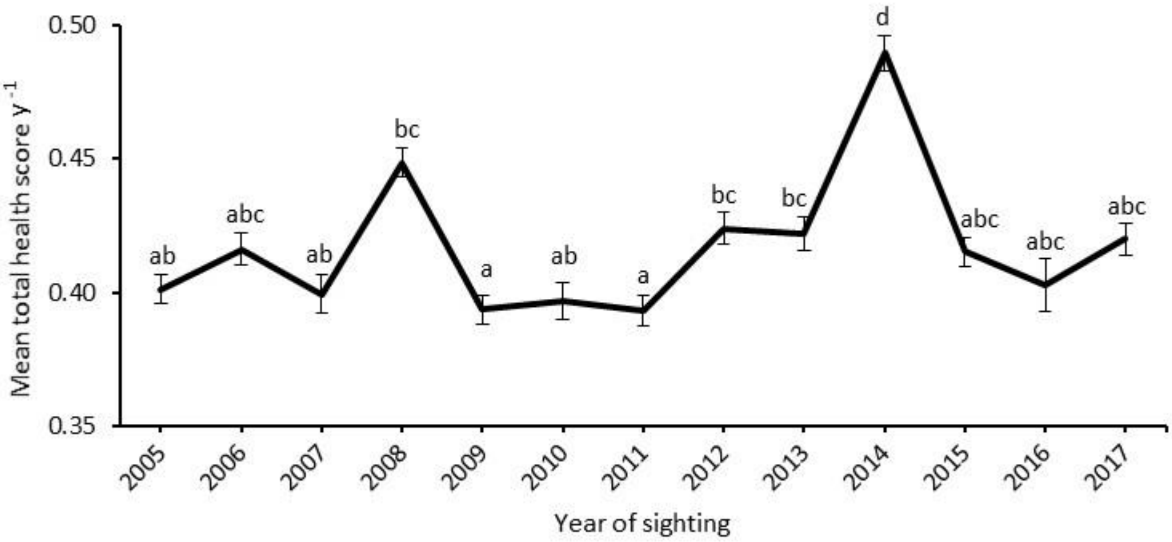


Figure 10: Mean total health scores (± SE) for parous female southern right whales (*Eubalaena australis*), indicating decreased health (i.e. increased score) in 2008 and 2014. The letters a, b, c, d above the line indicate which statistical population(s) the years fall into and are a result of the Tukey posthoc test.

The PCA on the four health score variables of parous females showed that principal component one (PC 1) accounted for 46.2 %, principal component two (PC 2) for 38.8% and collectively describe 85 % of the variability in the data, whereas principal components three (PC 3) and four (PC 4) explained only 7.9 % and 7.1 % respectively. Body condition, skin condition and cyamids around the blowholes are equally contributing to PC 1 and only rake marks are not well covered (Table 3). Additionally, it was revealed that the total health score is similar to the results of the PCA analysis showing that rake marks are essentially excluded from PC 1. The mean PC 1 scores averaged across the study period show similar trends of decreased health in 2008 and 2014 (Figure 11). However, as PC 1 could only explain less than 50% of the variability in the data, no alternative score was created.

Table 3: 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	27.69	6.05	65.48	0.78
Skin condition	36.31	3.82	14.27	45.60
Cyamids around blowholes	34.95	6.79	14.25	44.00
Rake marks	1.04	83.33	6.00	9.62

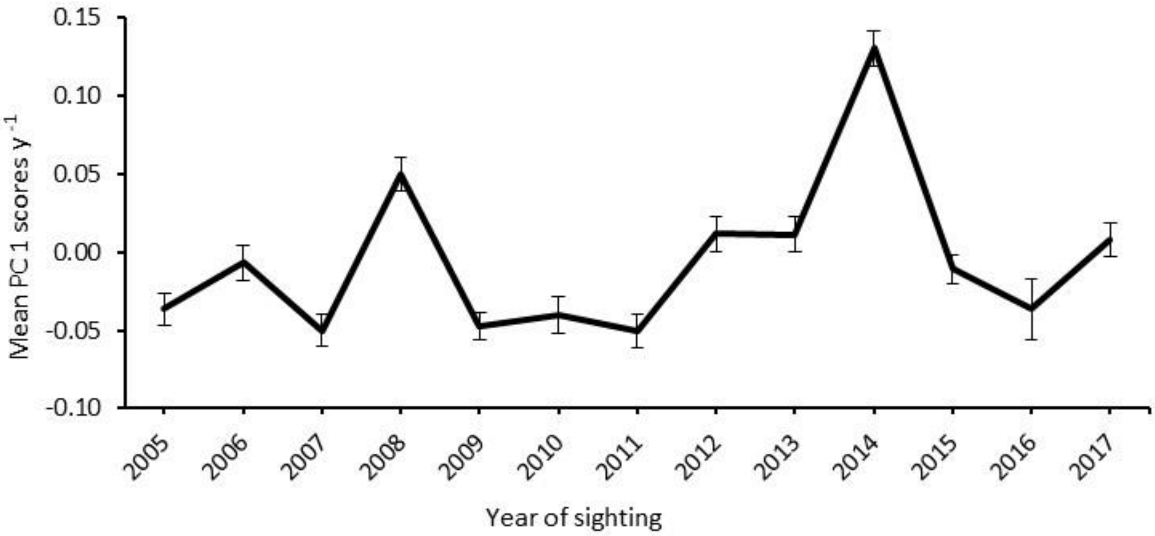


Figure 11: Mean PC 1 score (± SE) for parous female southern right whales (*Eubalaena australis*), indicating decreased health (i.e. increased score) in 2008 and 2014.

The results of Fleiss' Kappa test, which compared agreement among the scores assigned by three researchers for all four health scores of 10 individuals (K_w = 0.57, z = 10.60, p <0.001), suggested moderate agreement (Landis & Koch,1977). Comparing the different health score variables among the researchers, there is poor agreement for body condition (K_w = -0.195, z = -1.26, p= 0.208) and skin condition (K_w = -0.027, z = -0.20, p = 0. 842) but 100% agreement for cyamids around the blowholes and rake marks (K_w = 0/0, z = 0/0, p = 0/0).

Parity

Comparison of parity using the TS displayed no significant difference between primiparous and multiparous female southern right whales over the study period (t= 0.086, df= 1431.2, p= 0.932). Therefore, further analyses were conducted using both primiparous and multiparous females combined.

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

Results of the GAM relating TS to environmental indicators showed that ONI, SOI, AAO, SASIE, 'year' and chlorophyll a in feeding ground A (Appendix 3) were significantly related to total health of reproducing female southern right whales with a 0-year lag (Table 4). Additionally, a GAM was run with body condition, skin condition, cyamids around blowholes and rake marks as separate response variables. Results indicated a link between the various health indicators (Appendix 4).

Table 4: Results of the generalized additive model relating TS to year and data for various climate and biological indices potentially influencing the health score of female southern right whales (*Eubalaena australis*) off the South African coast. Significant values are displayed in bold. * p < 0.05, ** p < 0.01 and *** p< 0.001.

Response variable	Explanatory variable	edf (empirical distribution function)	R-sq. (adj)	Deviance expl.	p-value	
TS	ONI (Oceanic Niño Index)	2.269	0.089	9.31%	**0.011**	*
	AAO (Antarctic Oscillation)	1.000			**0.016**	*
	SOI (Southern Oscillation Index)	2.166			**< 0.001**	***
	SASIE (Sept. Antarctic sea ice extent)	1.003			**< 0.001**	***
	Year	1.000			**< 0.001**	***
	Chlorophyll a (feeding ground A)	1.000			**< 0.001**	***
	Chlorophyll a (feeding ground B)	1.000			0.435	
	Chlorophyll a (feeding ground C)	1.000			0.860	.

Comparing the four health score variables to previous calving intervals (excluding primiparous females), only rake marks and year had a significant effect (Table 5). Median calving intervals increased with a decreased health (i.e. increased score for body condition, cyamids around blowholes & rake marks; Figure 12) but the results were not significant (Table 6). Comparing the four health score variables to next calving event (including primiparous and multiparous females but excluding 1,424 non-unique females which had no next calving interval within the study period) showed no significant influence, except for rake marks (Table 5). Similar to the results in Figure 12, there was some variability in calving intervals across scores for the different health variables, but the results were not statistically significant (Figure 13 & Table 6).

Table 5: 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	1.00			0.923	
	Skin condition	1.01			0.506	
	Cyamids around blowholes	2.74	0.07	7.07%	0.476	
	Rake marks	2.38			**< 0.001**	***
	Year	1.00			**< 0.001**	***
Next calving interval	Body condition	1.00			0.624	
	Skin condition	1.34			0.726	
	Cyamids around blowholes	1.00	0.01	1.65%	0.214	
	Rake marks	1.00			**< 0.001**	***
	Year	1.00			0.400	

Table 6: 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	13.81	10	0.182
	Skin condition	7.49	10	0.678
	Cyamids around blowholes	3.21	6	0.783
	Rake marks	13.59	10	0.193
Next	Body condition	6.34	10	0.786
	Skin condition	8.68	9	0.467
	Cyamids around blowholes	8.75	6	0.188
	Rake marks	12.5	8	0.130

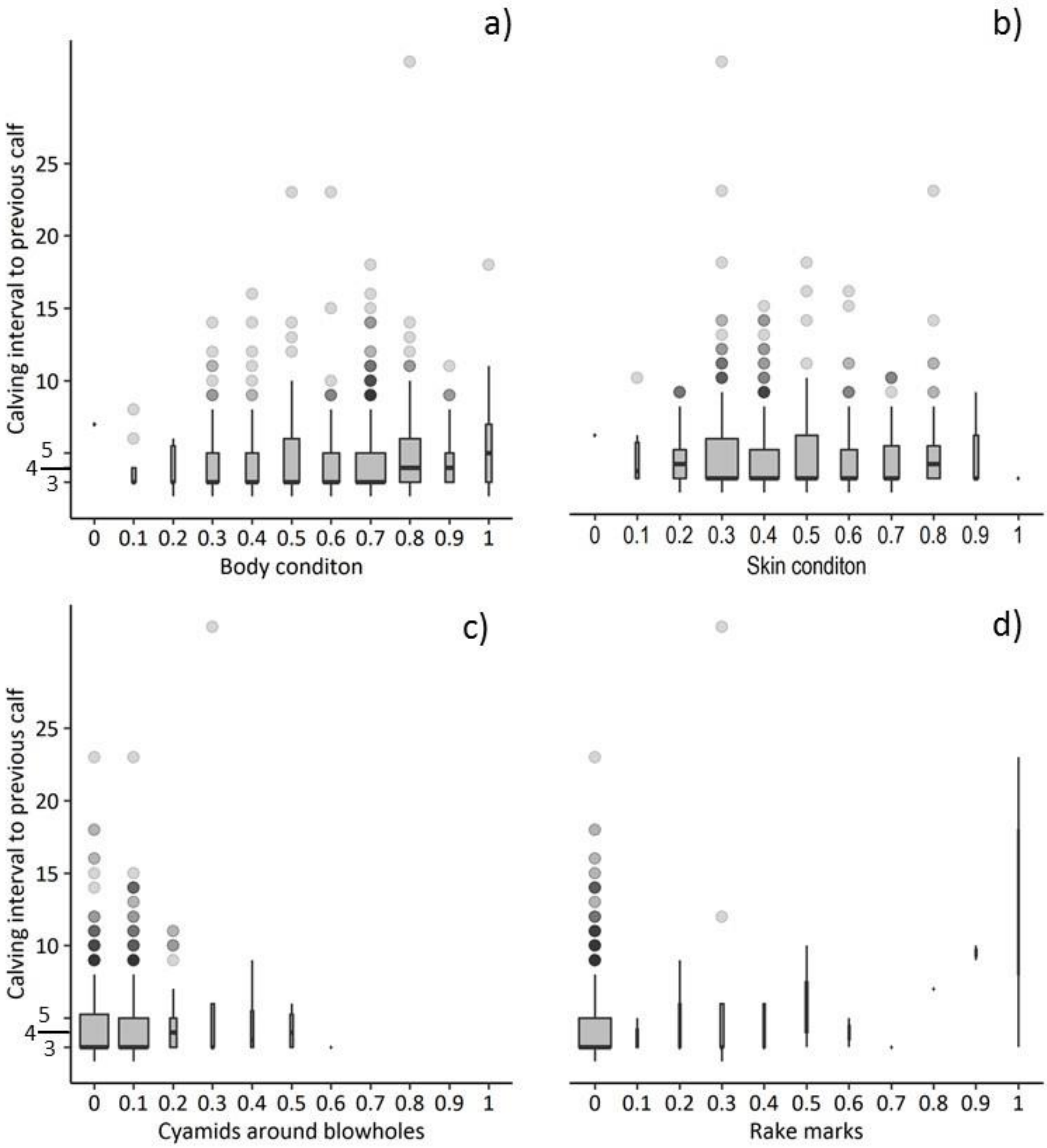


Figure 12: The calving interval from previous calf in relation to health scores for parous female southern right whales (*Eubalaena australis*). The boxes indicate interquartile ranges, the thick line is the median and the dots are outliers **a)** Body condition **b)** Skin condition **c)** Cyamids around blowholes **d)** Rake marks.

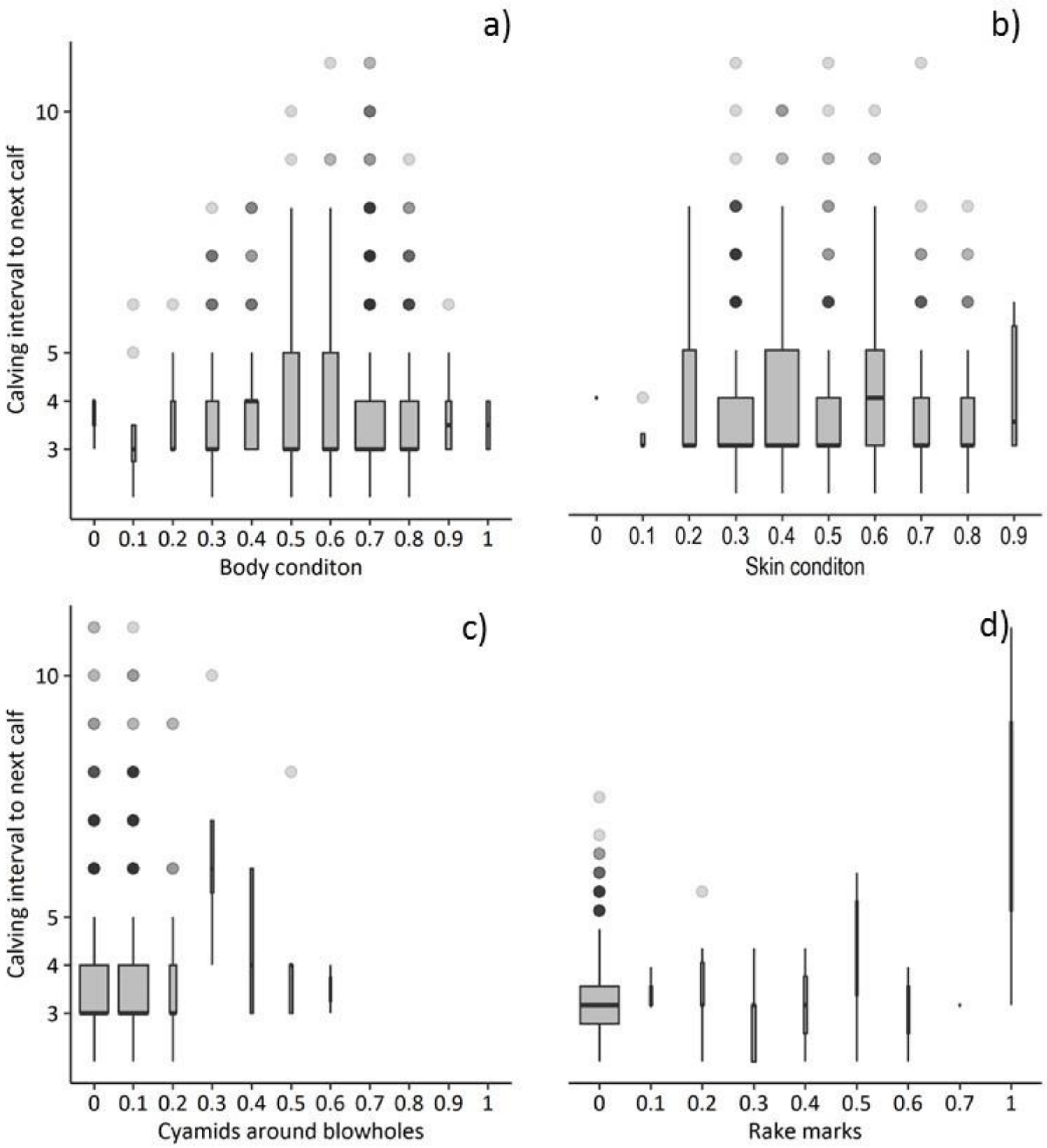


Figure 13: The calving interval to next calf in relation to health scores for parous female southern right whales (*Eubalaena australis*). The boxes indicate interquartile ranges, the thick line is the median and the dots are outliers **a)** Body condition **b)** Skin condition **c)** Cyamids around blowholes **d)** Rake marks.

Discussion

Health variables

Although images for this study were obtained from a 39-year database, only those collected from 2005 onwards were used due to the introduction of digitalised photography, which provided better image quality for the assessment. Conducting a visual health assessment using overhead photographs is more subjective than a semi-quantitative measurement, but the use of a 12-year dataset of overhead photographs provides a much larger dataset and allows for retrospective analyses. The analysed photographs were initially taken for ID purposes, but this study showed that they also can be used for a visual health assessment. Results of this study clearly indicated annual fluctuations of visual health of parous female southern right whales during their stay at breeding grounds off the southern Cape coast. More specifically, a significant reduction in health could be detected in 2008 and 2014. Using weighted scores in this study differ from the average score used in the study by Pettis et al. and make a comparison of the health between southern- and northern right whales difficult. However, the subjective weighting of the total score has been supported by the PCA results, indicating that rake marks are the least important contributor to indicate health of female southern right whales.

Results of this study further showed that there was no significant difference in visual health of multiparous and primiparous females. This suggests that both multiparous and primiparous females are influenced by the same phenomena (possibly food shortage in their feeding grounds) causing a similar decrease in health. Additionally, it may suggest that multiparous females evaluated in the study are not in ideal breeding condition and therefore do not show a significant difference to primiparous females, as it is known through other studies that primiparous mammals still invest energy and nutrients towards growing (Gallo et al. 1996).

Comparison of inter-rater reliability between the researchers showed overall moderate agreement (Landis & Koch,1977). While there was 100% agreement for cyamids around blowholes and rake marks, there was reduced agreement on body condition and skin condition scores, which is concerning because the condition scores have high weightings in calculating the total health score. This difference could arguably be a result of the different experience of each researcher in scoring, or the difficulty of seeing body condition in some overhead photographs. At the same time, only a small sample size was used for the inter-rater reliability test, which might affect the overall result. The guidelines for Fleiss' K_w scale are not commonly accepted and may be more harmful than useful (Gwet 2010) when interpreting the inter-rater reliability results. However, the use of archived data increases the effectiveness of this method for retrospective analysis. Pettis et al. (2004) has shown sufficient objectivity of visual health assessment method conducted on northern right whales. Comparing results to other studies, care is still required to account for the difference in scoring. However, when using the method within the same study (health assessment conducted by one researcher) it is a consistent method to detect changes of health among individuals and years.

Health assessment in relation to environmental indicators and reproductive success

Results also showed that visible health of parous female southern right whales was related to climatic variables on a 0-year lag. This confirms the findings of Van den Berg (2018) who revealed that the abundance of southern right whales in South Africa is correlated with ocean productivity and Southern Ocean climate conditions at different lag times. More specifically, Van den Berg (2018) indicated that strong El Niño conditions in 2015-2016 seemed to be correlated with the decrease in sightings of cow-calf pairs off the South African coast with a 0-year lag. Relations between global climate indices and whale breeding success were also found by Leaper et al. (2006) at Península Valdés, Argentina. However, the relationship of visual health and climatic index SASIE needs to be interpreted carefully at a 0-year lag, as SASIE is measured in September when the female southern right whales are at their breeding grounds. Therefore, SASIE will affect food availability for the next feeding season only. However, previous studies have shown that krill density is linked to sea ice extent (Loeb et al. 1997; Atkinson et al. 2004), which affects food availability and therefore southern right whale breeding success (Leaper et al. 2006). Therefore, further analysis of the link between SASIE and visual health condition, at various time lags, should be considered for future research.

Additionally, chlorophyll a concentrations in feeding ground A (as named by Van den Berg, 2018) were found to have a significant negative relation with visual health of parous female southern right whales. This suggests that only one feeding ground would immediately affect females' visual health and ultimately reproductive success. This is in accordance with the findings of Van den Berg (2018) who indicated positive correlations at a 2-year time lag between chlorophyll a concentrations at feeding ground A and abundance of southern right whale calves off the southern Cape coast. Although no other feeding ground seemed to immediately affect visual health of female southern right whales, Van den Berg (2018) did find correlations between calf abundance and chlorophyll a concentrations in feeding ground C at two different time-lags. However, correlations between climate indices and visual health conditions on various time-lags could not be investigated in this study and need further examination.

The study by Seyboth et al. (2016) also showed that the reproduction of southern right whales is directly influenced by food availability. Right whale feeding success is complex and influenced by several biological and environmental processes (Hilsta et al. 2009) and therefore should not be simplified by ignoring potential lagged effects and misinterpreted. Relations of climate indices and health of female southern right whales were compared with a 0-year lag in this study. However, the mean chlorophyll a concentrations were measured in January and reflect a 10-month lag, as the assessed whales were photographed during the annual aerial survey conducted in October. This 10-month lag therefore could influence health condition seen at the breeding grounds when parous females calve. The decreased visual health in 2008 and 2014 can be assumed to be a result of poor food availability in the feeding season during pregnancy. Successful reproduction (ovulation, sustaining pregnancy, etc.) requires a minimum body condition, which is attained through fat storage over several consecutive years (Seyboth et al. 2016), suggesting that not only the year of pregnancy is linked to visible bad health condition. Therefore, further investigation of relationships between visual health and chlorophyll a concentrations (at the three feeding grounds) at different time-lags is needed to fully understand the links between food availability and visual health condition in parous female southern right whales.

Relating females' visual health variables to previous calving interval indicated only level of rake marks as a predictor. Similar results were found when relating visual health variables to the next calving intervals. However, the number of rake marks observed was very low in this study. In fact, rake marks have the lowest contribution to explain the health of female southern right whales as suggested by the PCA results.

The visual health assessment did not show a relationship between the visual health condition of parous female southern right whales and calving intervals. However, this could be because all females assessed were in a good enough condition to breed (i.e. females who were not able to breed were not photographed and therefore not assessed in this study). The lack of a clear relationship between health condition and calving intervals could also be caused by a small number of females which 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 analysis of health in relation to next calving interval. Nevertheless, in 2008 the visual health of the female right whales was observed to decrease (i.e. increased health score) and afterwards calving intervals have started to increase, indicating that females take an extra year of rest after visually bad health and only manage to breed in subsequent years. Similar trends occurred in 2014, when visual health of females decreased (i.e. increased health score) and the frequency of four- and five-year calving intervals increased. Further analyses are required in a few years' time, when more data on calving intervals post-2014 will be available, as body condition in northern right whales is positively correlated to calving intervals, suggesting recovery of subcutaneous fat reserve during the time between calves (Miller et al. 2011). However, this study supports the hypothesis formulated by Van den Berg (2018) that continuous years of low food availability may have had accumulating effects on the female southern right whales' health (at least for the period of 2011-2014, when health reached a minimum), affecting their reproductive success and associated demographics.

Relevance of the study

Understanding the relationship of health condition of parous female southern right whales and how it relates back to reproductive success and climate is important to predict population trends and the resilience of the species to a fast-changing environment. Body condition is tightly connected to reproductive success in right whales (Miller et al. 2011; Leaper et al. 2006) and other marine mammals (Atkinson & Ramsey 1995). Therefore, in addition to calf reproduction, understanding variations in health and body condition of parous females in relation to the state of the environment can be useful for making informed management decisions. The southern right whale´s three-year breeding cycle consists of one year of gestation, one year for nursing and another year to rest and recover (Greene & Pershing 2004). If a female southern right whale is not able to stock up on subcutaneous fat in her year of rest, she is likely to not reproduce successfully. However, females might still reproduce if the fat storage is not fully saturated. This would be seen visually and potentially leads to poor overall health and can be detected through visual assessments. Pettis et al. (2004) have demonstrated that a visual health assessment is a viable tool that can be applied to right whales using photographs, showing differences in body condition of reproducing and resting females. While studies have examined marine mammal reproductive success by analysing reproductive output in relation to effects of climate and food availability (Lockyer 1986; Leaper et al. 2006; Miller et al. 2011; Seyboth et al 2016; Van den Berg, 2018), this study related attempted to use visual measures visual measures of health condition and link these to reproductive success and climatic indices. Although the results are not conclusive, there are indications that there might be links between health condition and reproductive success of female southern right whales.

Limitations of the study

The visual health assessment analyses were limited by several factors, including the photograph quality and angle. The study relied on visibility of the animal in the photographs (i.e. above water). Photographs of bad quality and visibility were unsuitable for the visual assessment and resulted in exclusion from the analyses or NAs being assigned. Due to the nature of the photographs and their collection, a quantitative analysis (i.e. photogrammetry) of the southern right whale females could not be conducted for the South African population. Additionally, the prominence of accumulated fat in the neck area is not always clearly visible from aerial photographs. Also, this study did not account for the females' stage of lactation when photographed during the annual survey, assuming that all births occurred at a similar time. Miller et al. (2011) showed a decrease in blubber thickness between the second and fourth month of lactation for southern right whale females, showing a seasonal change of body condition in lactating females. Another study by Miller et al. (2012) showed that lactating females became thinner between the sampling at the beginning of the calving season and at the end. Further, the study is limited by only showing association, but no causation of the increased calving interval. It is also important to mention that this study focuses on breeding females and does not assess the entire population.

Implications and future research

Decreasing health of female southern right whales along the South African coast will impact demographics and decrease sightings along the Southern Cape coast further. Marón et al (2015) showed that an increase in calving interval will lead to a decrease of population growth. Therefore, a decreased health of parous female southern right whales could lead to a further decrease in sightings, especially of cow-calf pairs. A notable decrease in unaccompanied adults has also been detected since 2009 (Findlay et al. 2016). This decreased presence of southern right whales at their breeding ground may not only have biological implications for the species, but also economic impacts for South Africa as a nation. South Africa is a world-famous destination for boat- and land-based whale watching, especially the Western Cape Province (O'Connor et al. 2009). Boat-based whale-watching relies entirely on unaccompanied southern right whales during the austral winter months, due to the regulations of this activity (it is prohibited to approach cow-calf pairs). On the other hand, land-based whale watching is almost exclusively focused on southern right whale cow-calf pairs (O'Connor et al. 2009), which prefer the nearshore areas and are easy to spot from land along the Western Cape coast. Therefore, the decreased presence of this species along the South African coast can severely impact this multimillion-dollar industry.

The results presented in this study could only be obtained due to the long-term nature of the utilised data series. It is clear that long term-datasets are important to find relations between baleen whale health and associated demographics as well as climate changes. Therefore, the continuation of the southern right whale monitoring program is of vital importance in times of environmental change. Also, a global standardization of the methodology is recommended to allow better comparison of data between breeding grounds. Additionally, the relationships between health and climatic and biological indicators of food availability need further and more detailed assessment.

Conclusion

A visual health assessment on parous female southern right whales was conducted using a 13-year dataset of overhead photographs. Results showed significant temporal changes of visual health within the study period. Although no direct links could be detected with increased calving intervals, results indicate a relationship with Southern Ocean environmental indices. The negative relationship with chlorophyll a concentrations at feeding ground A suggests that this might be the primary feeding ground utilized by pregnant females, but the links between food availability and climate indices are complex and need further investigations. The standardization of methodology with Australian and South African researchers allows comparison of results on a global scale. Nonetheless, it is suggested that the survey methods across populations also should be standardized to ensure even better comparison (including the quantitative assessment of the South African population). Further, a reassessment in a few years' time is highly recommended, once more data are available of calving intervals post-2014, to fully understand the links between health and reproductive success of southern right whales from the South African population.

References

Atkinson SN, Ramsay MA. 1995. The effects of prolonged fasting of the body composition and reproductive success of female polar bears (*Ursus maritimus*). Functional Ecology **9**: 559-567.

Atkinson A, Siegel V, Pakhomov E, Rothery P. 2004 Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature **432**: 100-103.

Best PB. 2000. Coastal distribution, movements and site fidelity of right whales (*Eubalaena australis*) off South Africa, 1969–1998. South African Journal of Marine Science **22**: 43-55.

Best PB. 1990. Natural markings and their use in determining calving intervals in right whales off South Africa. South African Journal of Zoology **25**: 114-23

Best PB. 2005. Trends in the southern right whale population wintering in South African waters, 1971-2003. Journal of Cetacean Research and Management. IWC document SC/56/SH5.

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

Baker CS, Clapham PJ. 2004. Modelling the past and future of whales and whaling. Trends in Ecology and Evolution **19**: 365-371.

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, Best PB, Butterworth D. 2011. Monitoring the recovery of the southern right whale in South African waters. IWC document SC/S11/RW18.

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.

Burnell SR. 2001. Aspects of the reproductive biology, movements and site fidelity of right whales off Australia, Journal of Cetacean Research and Management (Special Issue) **2**: 89–102.

Charlton CM. 2017. Population demographics of Southern Right Whales (*Eubalaena australis*) in Southern Australia. Doctor of Philosophy Thesis. Curtin University, Western Australia.

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.

Christiansen F, Dujon AM, Sprogis KR, Arnould JP, Bejder L. 2016. Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. Ecosphere **7**: e01468.10.1002/ecs2.1468.

Christiansen F, Vivier F, Charlton C, Ward R, Amerson A, Burnell S, Bejder L. 2018. Maternal body size and condition determine calf growth rates in southern right whales. Marine Ecology Progress Series **592**: 267-281.

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

Cooke J, Rowntree V. 2003. Analysis of inter-annual variation in reproductive success of South Atlantic right whales (*Eubalaena australis*) from photo-identifications of calving females observed off Península Valdés , Argentina , during 1971–2000. Unpublished report (SC/55/O) presented to the IWC scientific committee, Berlin, Germany 2003.

Cooke JG, Rowntree V, Payne R. 2001. Estimates of demographic parameters for southern right whales (*Eubalaena australis*) observed off Península Valdés, Argentina. Journal of Cetacean Research and Management (Special Issue) **2**: 125−132

Cummings WC. 1985. Right whales, *Eubalaena glacialis* (Muller, 1776) and *Eubalaena australis* (Desmoulins, 1822) Ridgway SH, Harrison R, (Eds.). Handbook of Marine Mammals, vol. 3, The Sirenians and Baleen Whales. Academic Press, London.

D'amato A, Chopra SK. 1991. Whales: their emerging right to life. American Journal of International Law **85**: 21-62.

Earle DF. 1976. A guide to scoring dairy cow condition. Journal of the Department of Agriculture, Victoria **74**: 228.

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.

Elwen SH, Best BP. 2004. Environmental factors influencing the distribution of southern right whales (*Eubalaena australis*) on the south coast of South Africa II: Within bay distribution. Marine Mammal Science **20**: 583-601.

European Space Agency, Plymouth Marine Labaratory. 2018. Ocean Colour-CCI. Available at: https://www.oceancolour.org/browser/.

Findlay K, Thornton M, Wilkinson C, Vermeulen E, Hoerbst S. 2016. 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.

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.

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.

Frisch RE. 1984. Body fat, puberty and fertility. Biological Reviews **59**: 161-188.

Forcada J, Trathan PN, Reid K, Murphy EJ. 2005. The effects of global climate variability in pup production of Antarctic fur seals. Ecology **86**: 2408-2417.

Fowler CW, Siniff DB. 1992. Determining population status and the use of biological indices in the management of marine mammals. McCollough DR, Barrett (Eds.) In Wildlife 2001: Populations. Springer, Dordrecht. 1025-1037.

Galletti Vernazzani B, Cabrera E, Brownell R L Jr. 2014. Eastern South Pacific southern right whale photo-identification catalog reveals behavior and habitat use patterns. Marine Mammal Science **30**: 389–398.

Gallo L, Carnier P, Cassandro M, Mantovani R, Bailoni L, Contiero B, Bittante G. 1996. Change in body condition score of Holstein cows as affected by parity and mature equivalent milk yield. Journal of Dairy Science **79**: 1009-1015.

Gamer M, Lemon J, Fellows I, Puspendra S. 2012. irr: Various coefficients of interrater reliability and agreement. R package version 0.84.

Grainger C, McGowan AA. 1982. The significance of pre-calving nutrition of the dairy cow. Occasional Publication, New Zealand Society of Animal Production, New Zealand.

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.

Greene CH, Pershing AJ. 2004. Climate and the conservation biology of North Atlantic right whales: the right whale at the wrong time? Frontiers in Ecology and the Environment **2**: 29-34.

Guinet C, Roux JP, Bonnet M, Mison V. 1998. Effect of body size , body mass , and body condition on reproduction of female South African fur seals (*Arctocephalus pusillus*) in Namibia. Canadian Journal of Zoology **76**: 1418-1424.

Gwet KL. 2010. Handbook of inter-rater reliability: the definitive guide to measuring the extent of agreement among multiple raters. Advanced Analytics, Gaithersburg MD, 208pp.

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

Iwasa M. 1934. Instructions for use two species of whale lice (*Amphipoda, Cyamidae*) parasitic on right whales. Journal of the Faculty of Science Hokkaido Zoology **3**: 33-39.

IWC (International Whaling Commission). 2001. Report of the workshop on the comprehensive assessment of right whales: a worldwide comparison. Journal Cetacean Research and Management **2**: 1-60.

Jefferies BC. 1961. Body condition scoring and its use in management. Tasmanian Journal of Agriculture **32**: 19-21.

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.

Keller CA, Ward-Geiger LI, Brooks WB, Slay CK, Taylor CR, Zoodsma BJ. 2006. North Atlantic right whale distribution in relation to sea-surface temperature in the southeastern United States calving grounds. Marine Mammal Science **22**: 426-445.

Knowlton AR, Kraus SD, Kenney RD. 1994. Reproduction in North Atlantic right whales (*Eubalaena glacialis*). Canadian Journal of Zoology **72**: 1297-1305.

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.

Kobayashi L.. 2005. Lifting the International Whaling Commission's moratorium on commercial whaling as the most effective global regulation of whaling. Environs: Environmental Law and Policy Journal **29**: 177.

Kraus SD, Moore KE, Price CA, Crone MJ, Watkins WA, Win, HE, Prescott JH. 1986. The use of photographs to identify individual North Atlantic right whales (*Eubalaena glacialis*). Report international Whaling Commision **10**: 145-51.

Kraus SD. 2007. High investment, low return: the strange case of reproduction in *Eubalaena glacialis*. In Kraus SD, Rolland R, Rolland SSRM, (Eds.). The urban whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge. 172-199.

Leaper R, Cooke J, Trathan P, Reid K, Rowntree V, Payne R. 2006. Global climate drives southern right whale (*Eubalaena australis*) population dynamics. Biology Letters **2**: 289-292.

Lockyer C. 1986. Body fat condition in Northeast Atlantic fin whales, *Balaenoptera physalus*, and its relationship with reproduction and food resource. Canadian Journal of Fisheries and Aquatic Sciences **43**: 142-147.

Loeb V, Siegel V, Holm-Hansen O, Hewitt R, Fraser W, Trivelpiece W, Trivelpiece S. 1997. Effects of sea-ice extent and krill or salp dominance on the Antarctic food web. Nature **387**: 897.

Marón CF, Rowntree VJ, Sironi M, Uhart M, Payne RS, Adler FR, Seger J. 2015. Estimating population consequences of increased calf mortality in the southern right whales off Argentina. Unpublished report (SC/66A/BRG/1) presented to the IWC scientific committee, San Diego, United States 2015.

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.

McEvoy TG, Robinson JJ. 2003. Nutrition and its interaction with reproductive processes. In: Holt WV, Pickard AR, Rodger JC, Wildt DE (Eds.) Reproductive science and integrated conservation. Cambridge University Press, Cambridge. 42-56.

Miller RG. 1981. Simultaneous statistical inference (Second edition). Springer, New York. 299pp.

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.

Miller CA, Best PB, Perryman WL, Baumgartner MF, Moore MJ. 2012. Body shape changes associated with reproductive status, nutritive condition and growth in right whales *Eubalaena glacialis* and *Eubalaena australis*. Marine Ecology Progress Series **459**: 135-156.

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.

Murphy EJ, Watkins JL, Reid K, Trathan PN, Everson I, Croxall JP, Priddle J, Brandon MA, Brierley AS, Hofmann E. 1998. Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill. Fisheries Oceanography **7**: 381-390.

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

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

O'Connor S, Campbell R, Cortez H, Knowles T. 2009. Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits, a special report from the International Fund for Animal Welfare. Yarmouth MA, United States, prepared by Economists at Large. 73-77

Osmond MG, Kaufman GD. 1998. A heavily parasitized humpback whale (*Megaptera novaeangliae*). Marine Mammal Science **14**: 146-149.

Patenaude NJ, Portway VA, Schaeff CM, Bannister JL, Best PB, Payne RS, Rowntree VJ, Rivarola M, Baker CS. 2007. Mitochondrial DNA diversity and population structure among southern right whales (*Eubalaena australis*). Journal of Heredity **98**: 147-157.

Payne R, Brazier O, Dorsey EM, Perkins JS, Rowntree VJ, Titus A. 1983. External features in southern right whales (*Eubalaena australis*) and their use in identifying individuals. Communication and behavior of whales. Westview Press, Boulder, Colorado. 371-445.

Perryman WL, Lynn MS. 2002. Evaluation of nutritive condition and reproductive status of migrating gray whales (Eschrichtius robustus) based on analysis of photogrammetric data. Journal of Cetacean Research and Management **4**: 155-164.

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.

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team. 2018. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-137.

Pirzl R. 2008. Spatial ecology of Eubalaena australis: habitat selection at multiple scales Ph.D. thesis, School of Life and Environmental Sciences, Deakin University, Melbourne.

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.

Reeves RR, Kenney RD. 2003. Baleen whales: Right whales and allies. Wild Mammals of North America: Biology, Management and Conservation, 2nd Edition. Feldhamer GA, Thompson BC, Chapman JA, (Eds.). Johns Hopkins University Press, Baltimore, Maryland. 425-463.

Reilly SB, Bannister JL, Best PB, Brown M, Brownell Jr RL, Butterworth D, Clapham PJ, Cooke J, Donovan GP, Urbán J, Zerbini AN. 2013. *Eubalaena australis*, southern right whale view. IUCN Red List Threat Species.

Rowntree VJ. 1996. Feeding, distribution, and reproductive behavior of cyamids (*Crustacea: Amphipoda*) living on humpback and right whales. Canadian Journal of Zoology **74**: 103-109.

Rowntree VJ. 1999. Does the size of a female right whale's neck roll predict the condition of her calf? In Abstracts in the proceedings of the 13th Biennial Conference on the Biology of Marine Mammals: 163. Maui, Hawaii, 27 November–3 December 1999.

Schulte-Hostedde AJ, Millar JS, Hickling GJ. 2001. Evaluating body condition in small mammals. Canadian Journal of Zoology **79**: 1021-1029.

Seyboth E, Groch KR, Dalla Rosa L, Reid K, Flores PAC, Secchi ER. 2016. Southern right whale (*Eubalaena australis*) reproductive success is influenced by krill (*Euphausia superba*) density and climate. Scientific Reports **6**: 1-8.

Stedman TL. 2005. Stedman's medical dictionary. 27th ed. Lippincott Williams and Wilkins, Baltimore, Maryland.

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.

Trathan PN, Brierley AS, Brandon MA, Bone DG, Goss C, Grant SA, Murphy EJ, Watkins JL. 2003 Oceanographic variability and changes in Antarctic krill (*Euphausia superba*) abundance at South Georgia. Fisheries Oceanography **12**: 569-583.

Trathan PN, Murphy EJ, Forcada J, Croxall JP, Reid K, Thorpe S. 2006. Physical foraging in the southwest Atlantic: ecosystem controll. In Top predators in marine ecosystems. Boyd IL, Wanless S, Camphuysen CK, (Eds.). Cambridge University Press, Cambridge. 28-45.

Tulloch VJ, Plagányi ÉE, Matear R, Brown CJ, Richardson AJ. 2018. Ecosystem modelling to quantify the impact of historical whaling on Southern Hemisphere baleen whales. Fish and Fisheries **19**: 117-137.

Valenzuela LO, Sironi M, Rowntree VJ, La Sala L, Pozzi L, Mohamed N, Musmeci L, Andrejuk J, Uhart M, Chirife A, Maron C. 2008. Population genetic structure of living and dead southern right whales (*Eubalaena australis*) off Península Valdés, Argentina. Journal of Cetacean Researchand Management **62**: 1-12.

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, University of Stellenbosh, Stellenbosh, South Africa.

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.

Wood SN, Pya N, Saefken B. 2016. Smoothing parameter and model selection for general smooth models. Journal of the American Statistical Association **111**: 1548-1563.

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer, New York.

Yandell BS. 1997. Practical Data Analysis for Designed Experiments. Chapman & Hall, London.

Appendices

Appendix 1

Year	ONI	AAO	SOI	SASIE	Chlorophyll a feeding ground A	Chlorophyll a feeding ground B	Chlorophyll a feeding ground C
2005	0.54	0.24	-0.62	18.8	0.13	0.22	0.41
2006	-0.35	-0.13	0.49	19.09	0.15	0.25	0.57
2007	0.33	-0.11	-0.4	18.86	0.15	0.21	0.25
2008	-1.1	-0.15	0.88	18.15	0.13	0.23	0.17
2009	-0.44	0.65	0.93	18.96	0.15	0.2	0.35
2010	0.83	-0.3	-0.28	18.8	0.15	0.19	0.44
2011	-1.17	0.89	1.83	18.74	0.12	0.23	0.39
2012	-0.68	0.04	0.75	19.21	0.17	0.24	0.56
2013	-0.03	0.19	0.15	19.39	0.16	0.22	0.3
2014	-0.23	-0.21	0.43	19.76	0.13	0.2	0.36
2015	0.48	0.4	-0.46	18.44	0.15	0.19	0.44
2016	1.83	0.76	-1.05	18.07	0.15	0.25	0.52
2017	-0.27	0.25	0.33	17.83	0.15	0.23	0.41

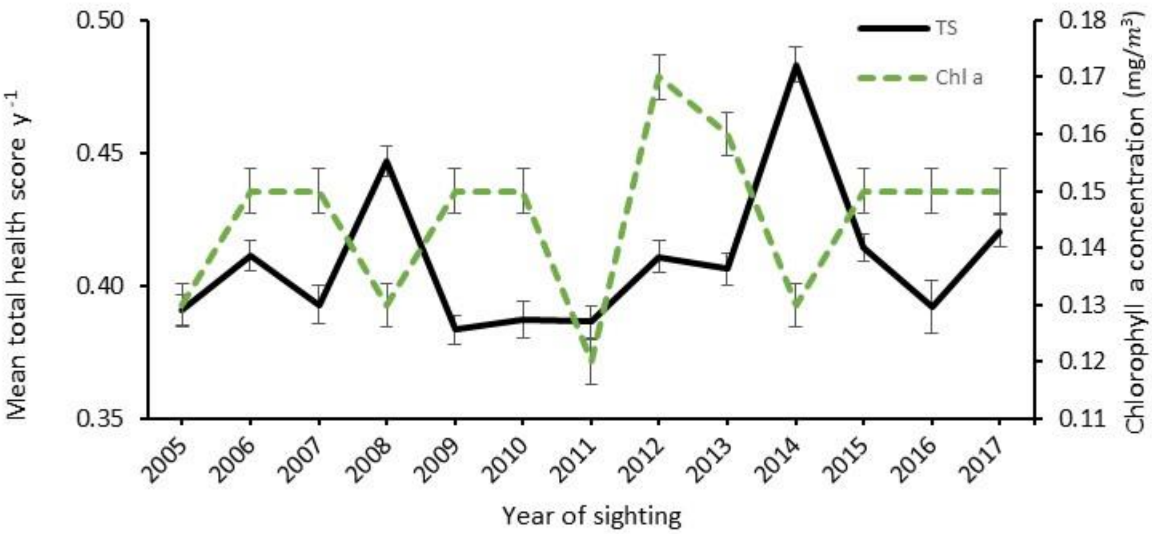
Data for environmental indices potentially influencing the health condition of southern right whale (*Eubalaena australis*) along the South African coast. ONI = Oceanic Niño Index, AAO = Antarctic Oscillation, SOI = Southern Oscillation Index, SASIE = September Antarctic sea ice extent, Chlorophyll a = Mean January chlorophyll a concentration (mg/m^3) for feeding grounds A, B and C respectively.

Appendix 2

Year	Difference	p adj.	Year	Difference	p adj.	Year	Difference	p adj.	Year	Difference	p adj.
2006-2005	0.015	0.898	2015-2006	-0.001	1.000	2016-2008	-0.046	0.067	2015-2011	0.022	0.458
2007-2005	-0.002	1.000	2016-2006	-0.013	0.999	2017-2008	-0.029	0.118	2016-2011	0.010	1.000
2008-2005	0.047	**<0.001**	2017-2006	0.004	1.000	2010-2009	0.003	1.000	2017-2011	0.027	0.180
2009-2005	-0.008	1.000	2008-2007	0.049	**<0.001**	2011-2009	0.000	1.000	2013-2012	-0.002	1.000
2010-2005	-0.004	1.000	2009-2007	-0.006	1.000	2012-2009	0.031	**0.016**	2014-2012	0.065	**<0.001**
2011-2005	-0.008	0.999	2010-2007	-0.002	1.000	2013-2009	0.029	**0.023**	2015-2012	-0.009	0.999
2012-2005	0.023	0.330	2011-2007	-0.006	1.000	2014-2009	0.096	**<0.001**	2016-2012	-0.021	0.961
2013-2005	0.021	0.421	2012-2007	0.025	0.237	2015-2009	0.022	0.471	2017-2012	-0.004	1.000
2014-2005	0.088	**<0.001**	2013-2007	0.023	0.311	2016-2009	0.009	1.000	2014-2013	0.067	**<0.001**
2015-2005	0.014	0.968	2014-2007	0.090	**<0.001**	2017-2009	0.027	0.188	2015-2013	-0.007	1.000
2016-2005	0.002	1.000	2015-2007	0.016	0.926	2011-2010	-0.004	1.000	2016-2013	-0.019	0.979
2017-2005	0.019	0.787	2016-2007	0.004	1.000	2012-2010	0.027	0.096	2017-2013	-0.002	1.000
2007-2006	-0.017	0.812	2017-2007	0.021	0.682	2013-2010	0.025	0.133	2015-2014	-0.074	**<0.001**
2008-2006	0.032	**0.008**	2009-2008	-0.055	**<0.001**	2014-2010	0.092	**<0.001**	2016-2014	-0.086	**<0.001**
2009-2006	-0.023	0.240	2010-2008	-0.052	**<0.001**	2015-2010	0.018	0.791	2017-2014	-0.069	**<0.001**
2010-2006	-0.019	0.587	2011-2008	-0.055	**<0.001**	2016-2010	0.006	1.000	2016-2015	-0.012	1.000
2011-2006	-0.023	0.230	2012-2008	-0.025	0.153	2017-2010	0.023	0.463	2017-2015	0.005	1.000
2012-2006	0.008	1.000	2013-2008	-0.027	0.062	2012-2011	0.031	**0.015**	2017-2016	0.017	0.995
2013-2006	0.006	1.000	2014-2008	0.041	**<0.001**	2013-2011	0.029	**0.022**			
2014-2006	0.073	**<0.001**	2015-2008	-0.034	**0.018**	2014-2011	0.096	**<0.001**			

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 3



Graph displaying the mean health score for parous female southern right whales (+SE) over the study period and the mean chlorophyll a concentrations of feeding ground A in January over the same period of time.

Appendix 4

Response variable	Explanatory variable	edf	R-sq. (adj)	Deviance expl.	p-value	
Body condition	Skin condition	1.96	0.06	6.72%	**0.048**	*
	Cyamids around blowholes	1.00			**0.022**	*
	Rake marks	1.00			0.891	
	Year	7.83			**< 0.001**	***
Skin condition	Body condition	1.00	0.04	4.88%	0.056	.
	Cyamids around blowholes	1.32			**< 0.001**	***
	Rake marks	1.54			0.473	
	Year	7.65			**< 0.001**	***
Cyamids around blowholes	Body condition	1.00	0.04	4.49%	**0.029**	*
	Skin condition	3.63			**< 0.001**	***
	Rake marks	3.54			**< 0.001**	***
	Year	6.52			**< 0.001**	***
Rake marks	Body condition	1.57	0.01	0.97%	0.521	
	Skin condition	1.00			0.559	
	Cyamids around blowholes	3.38			**0.059**	*
	Year	1.57			**0.030**	*

Results of the generalized additive model relating the four health variables with each other and with the year of sighting. Significant-values are displayed in bold. * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.