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Southern right whale population connections, trophic ecology and health on their South Georgia (Islas Georgias del Sur, SG/GS) feeding ground

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Southern right whales (*Eubalaena australis*) are regularly observed during the austral summer on the South Georgia (Islas Georgias del Sur, SG/GS) feeding ground. Here we report new results on the population connections, trophic ecology and health status of right whales on this feeding ground, combining results from summer expeditions conducted in 2018 and 2020. Our findings add to the evidence for the connection of this ground with the southwest Atlantic calving grounds: a whale photographed in SG/GS in 2020 matched a female sighted off Brazil in 2002 (as a calf), 2005 and 2007 (with a calf). We have also matched a whale photographed in SG/GS with one from the Antarctic Peninsula (the first time a match has been made between

the two areas). Within the SG/GS photo-ID catalogue (77 identifications of whales from the left, right, both sides or overhead), 44 right whale images had sufficient coverage to be reviewed for kelp gull (*Larus dominicanus*) lesions (evidence of past visits to the Península Valdés calving ground in Argentina). Of these, eight whales (18%) had evidence of lesions and two had possible lesions. Visual assessments of whale health using vessel-based photographs primarily collected in 2017/18 and 2019/20 showed good levels of body fat, with all whales in good (55.7%) or medium (44.3%) body condition. Observed skin condition was poorer, with 46.2% of all assessable whales having poor skin condition, including the presence of lesions and sloughed skin. Quantitative measurements of body condition of five southern right whales in SG/GS in 2020, using drone photogrammetry, showed that both juveniles and adults were in similar condition to southern right whales measured on the Península Valdés calving ground in Argentina. Stable isotope analysis suggests the 6 females encountered at SG/GS in 2020 were likely feeding south of the Polar Front in the austral winter and early spring, while of the 3 males, two were feeding at lower latitudes and one south of the Polar Front. Overall southern right whales at SG/GS were in relatively good body condition in 2018 and 2020, with stable isotope patterns suggesting most of the whales encountered in 2020 had been feeding south of the polar front prior to visiting SG/GS.

Introduction

The Scotia Sea in the high latitudes of the South Atlantic contains some of the highest densities of Antarctic krill (*Euphausia superba*) in the Southern Ocean (Atkinson *et al.,* 2004; Atkinson *et al.,* 2008). This region was historically an important feeding ground for whales, with large catches during 20th century commercial whaling reflecting the great abundance of many baleen whale species (Moore *et al.,* 1999). Whaling severely depleted whale populations in the Scotia Sea, particularly at South Georgia (Islas Georgias del Sur, SG/GS) in the northern Scotia Arc, where over 173,000 whales were killed (IWC 2015). Whaling ceased in SG/GS in 1966, but whales were rarely sighted at SG/GS for the next three decades (Moore *et al.,* 1999). Since the 1990s, whale sightings have become more common (Richardson *et al.,* 2012; Jackson *et al.,* 2020), with southern right whales (*Eubalaena australis*) being the first species to be regularly encountered since whaling ended (Moore *et al.,* 1999; Richardson *et al.,* 2012).

Southern right whales are a migratory species of the balaenid whales and are distributed in genetically, demographically and geographically discrete wintering ground populations around the Southern Hemisphere. The species uses sheltered, mostly low-latitude coastal sites for calving, and feeds offshore at medium and high latitudes (40-60S, Harcourt *et al.,* 2019). In the South Atlantic, southern right whales at SG/GS have been linked primarily with calving grounds at Península Valdés in Argentina through photo-identification of individuals (Best *et al.,* 1993; Moore *et al.,* 1999; Nijs & Rowntree 2017). Genetic comparisons with calving grounds also show a stronger association between right whales feeding at SG/GS and calving grounds in the southwest Atlantic than with Chile-Peru or South Africa (Carroll *et al.,* 2020). Right whales are skim or suspension feeders, mostly feeding on slow swimming or sessile prey such as copepod crustaceans (Potvin & Werth 2017). In high latitude waters right whales feed mainly on Antarctic krill (Tormosov *et al.,* 1998) but they also feed on other crustacean species (mostly copepod crustaceans, e.g. Valenzuela *et al.,* 2018), primarily at mid-latitudes (Matthews 1938; Argüelles *et al.,* 2016; IWC 2016). Their prey at SG/GS are not known but are thought to comprise a mixture of copepods and krill (Jackson *et al.,* 2020).

Because of their coastal distribution in winter, right whales were particularly vulnerable to whaling and were heavily hunted for three centuries in the Southern Hemisphere. A global review of right whale exploitation suggests 150,375 right whales were killed prior to 1850

(IWC 2001), but this is likely to be a significant underestimate, as many catch records have not survived (Baker & Clapham 2004) and whaling inefficiency meant that many more whales were killed but not landed (IWC 2001). In the South Atlantic, right whale hunts began in the early 17th century (Hart & Edmundson 2017) along the coast of Brazil and Argentina (de Morais *et al.,* 2017) and by the end of the 18th century it had moved offshore, including mid-latitude whaling grounds such as the Brazil Banks (Richards 1993, 2010; Smith *et al.,* 2012; Vighi *et al.,* 2020). In the 20th century the species was further exploited by illegal Soviet whaling; this hunt was particularly intense in the South Atlantic (Tormosov *et al.,* 1998). As a consequence, southern right whale populations have experienced a long period at low abundance, over which time there has been a significant reduction in their geographic range (Richards 2010).

Given the time elapsed since the main period of right whale whaling and observed population increases on several calving grounds (Best 1990; Cooke *et al.,* 2001; Groch *et al.,* 2005; Crespo *et al.,* 2019), southern right whales in the South Atlantic are now showing evidence of recovery and are classified as "Least Concern" on the Red List of the International Union for the Conservation of Nature (Cooke & Zerbini 2018). However, large numbers of calves died in the Península Valdés region between 2003 and 2013 (Rowntree *et al.,* 2013), indicating problems with the health status of this recovering population (IWC 2011, 2016). Calf death rates have been relatively low since 2014 (Sironi *et al.,* 2018; Moore *et al.,* 2021). One of the three hypotheses recommended by the IWC for further investigation was to understand right whale food availability and its effects on right whale body condition and health (IWC 2016). Since SG/GS has been commonly reported as a key feeding ground for southern right whales in the southwest Atlantic (Moore *et al.,* 1999; Richardson *et al.,* 2012). A positive correlation was found between the number of SRW calves in southern Brazil and krill densities near SG/GS, suggesting that reproductive success may be directly influenced by food availability in this region during the early months of gestation (Seyboth *et al.,* 2016). In order to investigate the health, body condition and dynamics of southern right whales on this feeding ground, we conducted two summer expeditions in 2018 and 2020 (Jackson *et al.,* 2020; Kennedy *et al.,* 2020). Here we report our overall findings on southern right whale population health and foraging ecology and suggest further research needed to understand the dynamics and importance of SG/GS as a feeding site for this recovering population.

Methods

Our study area spanned the SG/GS marine ecosystem, including the coastal and shelf waters around SG/GS and the shelf waters of Shag Rocks to the west of the island (33.5 − 43°W, 53 − 56°S). Both datasets were collected during dedicated British Antarctic Surveys expeditions conducted in SG/GS waters in 2018 and 2020 (Jackson *et al.,* 2020; Kennedy *et al.,* 2020).

Photo-identification catalogue and matching

Individual adult southern right whales can be identified by their unique patterns of head callosities and skin pigmentation. Photographs for individual identification (photo-ID) purposes (Payne *et al.,* 1983; Kraus *et al.,* 1986; Patenaude & Baker 2001) were compiled from right whales during dedicated surveys in 2018 and 2020 (Jackson *et al.,* 2020; Kennedy *et al.,* 2020) and from opportunistic sources, including images submitted to Happywhale (www.happywhale.com) and images contributed directly to the SG/GS right whale project (Jackson *et al.,* 2020). All SG/GS southern right whale photographs obtained in this study were evaluated for image suitability and were assigned a quality rating from 0 (lowest quality) to 3 (highest quality), following the approach taken by Wade *et al.* (2011). The ratings were based on the following criteria (listed in order of importance): oblique angle, focus, amount of visible

callosity pattern and exposure. Only images of quality 2 or 3 were used for individual identification purposes, but all images were analysed and retained for health assessment and future photo-ID comparisons. All new photographs were compared to the BAS SG/GS photo-ID catalogue by an experienced matcher. If the head callosity pattern did not match with any other photo-identified whale, this photograph was added to the catalogue as a unique individual. This catalogue is available from the International Whaling Commission archive on request.

The 2020 SG/GS photo-ID catalogue was compared to wintering ground catalogues from (1) the Península Valdés overhead and boat-based catalogues (1971 - 2017, 4007 unique individuals); (2) Uruguay overhead catalogue (2001 - 2009, 194 unique individuals, Costa *et al.,* 2007; Jorge *et al.,* 2011); (3) Brazil overhead catalogue (1987 - 2020, 1024 unique individuals, Groch 2018); and; (4) South Africa overhead catalogue (1979 - 2020, 2321 individuals, Best 1990). The Península Valdés catalogue matching was predominantly conducted using the software package BigFish (Skadia) with assistance from the Hiby-Lovell software system; Uruguay catalogue matching was also conducted with BigFish and Discovery software (version 1.2) (Gailey & Karczmarski 2012), while the Brazilian and South African catalogues used the Hiby-Lovell software system to assist with matching. Cross-catalogue matching was complicated because photographs from wintering grounds were collected from aerial platforms and those from SG/GS were obtained from boats, with the BigFish and Hiby-Lovell systems requiring different amounts of photographic coverage of the head. Consequently, from the SG/GS photo-ID catalogue, 41 individuals could be compared with the Península Valdés catalogues, 65 individuals with the Uruguayan catalogue, 17 individuals with the Brazilian catalogue and 15 with the South African catalogue.

Assessment of right whale health and body condition

A visual health assessment was conducted using all photo-IDs from the SG/GS southern right whale catalogue, following the approach of Pettis et al. (2004). All southern right whale photographs were scored for the following four parameters: body fat condition, skin condition, rake marks forward of the blowhole (two or more parallel lines in the epidermis that sometimes occur anterior to the blowholes) and cyamids around the blowhole (Pettis *et al.,* 2004). This assessment was conducted by a single researcher with substantial past experience analyzing southern right whale photographs for photo-ID and body condition. A visual assessment for evidence of kelp gull lesions was also carried out by a researcher experienced in lesion identification and any lesions were confirmed in review with a second experienced researcher. Healed or healing lesions usually look like rounded white patches of rugged skin with irregular edges and can vary substantially in size; identification of these is described in more detail in Marón et al. (2015).

To quantitatively assess the body condition of southern right whales in SG/GS, aerial photographs were taken above surfacing right whales in 2020 using a DJI Inspire 1 Pro multi-rotor unmanned aerial vehicle (UAV), at heights of 23-77 m (mean 52m). During each drone telemetry flight, the UAV was flown over a known size target at the same altitude at which the whale imagery was collected, in order to calibrate the imagery for corrected whale body measurements. Comparing several images taken on a flat calm day, the GPS data from 10 images was within 0.6 m of accuracy for altitude, the average was 0.27m. From the aerial photographs, the body length and widths (at 5% increments along the body of the whale) were measured using the approach of Christiansen *et al.,* (2016). For each width measurement, the corresponding height (dorso-ventral distance) was calculated using the known height-width ratio of southern right whales from Península Valdés (Christiansen *et al.,* 2019). The body

volume (BV) of each whale was then estimated by modelling the body shape of the whales as a series of infinitesimal ellipses (Christiansen *et al.,* 2019). A body condition index (BCI) was then calculated for each whale using a modified formula of Christiansen *et al.,* (2020):

$$BCI = \frac{BV_{Obs} - \mu(BV)}{\mu(BV)} \quad (1)$$

where BV_{Obs} is the observed body volume, standardized against a body length of 1, and $\mu(BV)$ is the mean body volume, standardized against a body length of 1, of the sample population. A positive BCI means that an animal is in relatively better condition than an average whale from the sample population, whereas a negative BCI means that an animal is in a relatively poorer condition. To assess their body condition, the southern right whales measured on the SG/GS feeding ground were compared to whales measured on the Península Valdés breeding ground in Argentina in 2019 (for details about the study site and data collection, see Christiansen *et al.,* 2019).

Southern right whale trophic ecology

Putative prey species including Antarctic krill *Euphausia superba* and other zooplankton were collected from western SG/GS waters in Nov - Dec 2017/18 and Dec - Jan 2019/20 on the British Antarctic Survey (BAS) Western Core Box cruises (cruise numbers JR17002 and JR19001), for the purpose of identifying potential southern right whale prey species via stable isotope analysis of carbon and nitrogen (Jackson *et al.,* 2020). Skin samples were collected from southern right whales in January/February 2018 and 2020 using small, stainless steel biopsy darts deployed from a crossbow (Lambertsen 1987) or a Paxarm modified veterinary capture system (Krützen *et al.,* 2002). After a biopsy attempt, darts and/ or samples were retrieved via tether system reel or a dip net. Skin samples collected for isotope analysis were subsequently frozen at −80°C. Whale skin tissues were sampled approximately one month after zooplankton samples were taken. Samples were prepared for stable isotope analysis at the BAS and sent to the Scottish Universities Environmental Research Centre (SUERC) isotope facility (East Kilbride, UK) for analysis. All zooplankton and fish samples were lipid-extracted prior to carbon isotope analysis (following Reid *et al.,* 2012). Whale skin samples were both lipid-extracted and gelatinised following the standard laboratory protocol of the Department of Archaeology, University of Cambridge (as detailed by O'Connell *et al.,* 2001). The sex of each right whale was identified using molecular approaches (Carroll *et al.,* 2020).

Southern right whale blubber endocrinology

A small amount of underlying blubber tissue was collected incidental to the skin sampling process for one individual. This subsample was stored at −80°C for hormone analysis. Progesterone, testosterone and cortisol were extracted from the tissue using previously published methods for steroid hormone extraction (Kershaw *et al.,* 2017; Kershaw *et al.,* 2020). The protocol involves tissue homogenisation followed by tissue debris removal in a series of solvent rinses with the recovery of the supernatant each time. The resulting residues are washed to remove any remaining lipid, and the final extract dried down for resuspension and assaying using commercially available Enzyme Linked Immunosorbent Assays (ELISAs). Quality assurance and quality control checks are underway to validate the use of the ELISA kits with southern right whale blubber extracts to quantify these three hormones of interest. Hormone concentrations will be compared to those measured in southern right whales sampled in the New Zealand sub-Antarctic Campbell Islands (Kershaw *et al.,* 2019), and other baleen whale species for which more data are available.

Results

Population connections

The SG/GS right whale catalogue has been compiled using photo-IDs collected during the 2018 and 2020 field expeditions (Jackson *et al.,* 2020; Kennedy *et al.,* 2020), combined with an additional 308 opportunistic photographs taken by researchers stationed on Bird Island, by BAS researchers on other projects, or by passengers on commercial cruises to the region (submitted via Happywhale). This catalogue currently contains 76 individual right whales with ID numbers; one whale has been re-sighted in different years (see below), so one whale has received two ID numbers; consequently, total photographed right whale encounters number 77, with 76 unique IDs. There are 29 individuals with high-quality left head photos, 45 with high-quality right head photos, 7 with high quality aerial photos, and 20 definitely unique individuals with the full suite of ID images (i.e. high-quality left and right oblique head photos or one high-quality oblique head plus an aerial photo).

Photo-ID matching did not reveal any resights of southern right whales at SG/GS (within season, or inter-annually). Matching with contributed photo-IDs from other high latitude regions of the South Atlantic revealed one match between SG/GS (14th March 2019) and the Antarctic Peninsula (Gerlache Strait on 29th December 2011, shown in Figure 1). The sex of this animal is likely female as this whale appeared to be the mother of a mother-calf pair during the 2019 sighting at SG/GS. Matching with calving grounds also revealed one match between SG/GS (whale SG2009 sighted on 29th January 2020) and Brazil. Female whale B139-02, sighted in Brazil in her birth year in 2002, was subsequently seen solo in 2005 and then in 2007 with a calf.

Health condition

Of the 76 catalogued southern right whales, a total of 47 whales had adequate photographic coverage to support a complete health assessment (Table 3). Eighteen whales could only be partially assessed, while 12 individuals could not be assessed for any of the four health parameters due to a lack of adequate imagery of the associated body region. None of the whales in the catalogue showed any obvious signs of past or existing fishing gear entanglement. Of the 65 southern right whales available for analysis, more than half of the whales received a "Good" rating for one of the four parameters overall, and no whales received a "Poor" body condition rating. However, 44.3% of the 61 animals analyzed for body condition were characterized as "Medium", indicating some level of body fat loss in the cervical region immediately caudal to the blowholes. Additionally, 46.2% were given a "Poor" skin condition rating due to patches of sloughed skin, cyamids, or lesions on the body. Over half of the animals (61.1%) were rated "good" for rake marks forward of the blowhole. Only one whale with appropriate imagery displayed any significant cyamid coverage around the blowhole (Figure 2). A comparison of these assessments between 2018 and 2020 (Figure 3) suggested that overall whales sighted in 2020 were in poorer condition; however small sample sizes preclude a quantitative assessment of this observation.

Of the 76 catalogued whales, eight showed evidence of kelp gull lesions comparable to those observed at Península Valdés, and a further two had possible kelp gull lesions. For 36 whale IDs, the back area was reviewed and did not have visible kelp gull lesions, while the presence of kelp gull lesions could not be confirmed for 31 identified whales.

Five whales in SG/GS had sufficient overhead images to enable assessment of body condition and comparison with the Península Valdés calving grounds (67 adults and 165 juveniles). Of

the two juveniles (one male, one female) and three adult females assessed, juvenile body condition was slightly higher than the mean body condition of juvenile right whales in Argentina, while the adult females had similar body condition to that seen in adults at the end of the calving season in Argentina (Figure 4).

Table 3. SG/GS right whale health condition

	Body condition	Skin condition	Rake marks	Cyamids
Total assessable	61	54	54	54
Good (%)	34 (55.7)	28 (53.8)	33 (61.1)	53 (98.1)
Medium (%)	27 (44.3)	NA	19 (35.2)	NA
Poor (%)	0	26 (46.2)	2 (3.7)	1 (1.9)

Foraging ecology

The nine southern right whale skin samples (n = 6 females and n = 3 males) collected at SG/GS in 2020 had an overall mean $\delta^{13}C$ of -20.0 ± 1.7 (range -22.9 to -17.2) and mean $\delta^{15}N$ of 8.6 ± 1.9 (range 6.8 to 12.3). Sample sizes were too small to assess the significance of sex - specific differences, but the males had higher $\delta^{15}N$ values than all but one of the females (Figure 5a), a similar pattern to that seen for the two southern right whale samples collected in 2018 (Jackson *et al.,* 2020). When compared with prey samples collected from SG/GS in 2018, the SG/GS right whales showed trophic patterns suggestive of feeding on both euphausiid and copepod prey (Figure 5b).

Blubber endocrinology

While the cortisol ELISA passed the necessary quality assurance and quality control checks, further tests are being carried out to validate the use of the commercially available progesterone and testosterone ELISAs to quantify these hormones in southern right whale samples. These preliminary results indicate that hormone concentrations are comparable to those measured in the blubber of southern right whales sampled in the Campbell Islands, and other baleen whales using these extraction and quantification methods. The interpretation of measured concentrations in this sample from SG/GS requires a larger sample size with a greater range in concentrations for comparison.

Discussion

Our data compiled here provide further evidence of the prevailing hypothesis that southern right whales feeding at SG/GS are broadly connected to southwest Atlantic calving areas (Best *et al.,* 1993), with photo-ID matching providing direct evidence of connection to Brazil, and identification of kelp gull lesions providing indirect evidence associating this feeding ground with the Península Valdés calving ground in Argentina. This is also consistent with recent genetic analyses which associated this feeding ground with the southwest Atlantic more strongly than the southeast Atlantic (South African) calving grounds (Carroll *et al.,* 2019) and also with satellite tracking data showing that some individuals tagged on the Argentine coast visit SG/GS during the feeding season (Zerbini *et al.,* 2015; Zerbini *et al.,* 2018). SG/GS has long been considered an important feeding area for southern right whales associated with the southwest Atlantic calving grounds; southern right whales were the species most commonly observed by visitors and a survey at SG/GS in the 1990s (Moore *et al.,* 1999) and by visitors in the 2000s (Richardson *et al.,* 2012). A more recent study linked estimates of SG/GS krill abundance to right whale calving rates off Brazil (Seyboth *et al.,* 2016). However, opportunistic observations of this species at SG/GS in the last two decades do not suggest an upward trend in occurrence (Jackson *et al.,* 2020), in contrast to observed patterns of population

growth on the southwest Atlantic calving grounds (Groch *et al.,* 2005; Cooke *et al.,* 2015; Crespo *et al.,* 2019). This suggests that while SG/GS is part of the feeding ground range for southwest Atlantic southern right whales, the expanding population is likely using feeding areas in other parts of the southwest Atlantic to an increasing extent (for example Patagonian Shelf waters, frontal zones including the Blue Hole, lower latitude offshore areas and high latitude Antarctic waters, Ohsumi & Kasamatsu 1986; Hoffmeyer *et al.,* 2010; Smith *et al.,* 2012; Zerbini *et al.,* 2015; Argüelles *et al.,* 2016; Zerbini *et al.,* 2018; González Carman *et al.,* 2019; Weir & Stanworth 2020). Southern right whales that winter in South Africa have shown a shift from low to higher latitude foraging grounds over the past 30 years. Although this coincided with a decline in reproduction, it shows that this species can change their foraging strategies and may have been shifting away from high latitude areas in the South Atlantic in recent years (van den Berg *et al.,* 2021).

The western Antarctic Peninsula encounter is one of 12 southern right whale encounters opportunistically recorded in Happywhale (up to March 2021) from citizen science contributors along the Antarctic Peninsula and east into the southern Scotia Sea/Weddell Sea boundary. The southernmost of these encounters with a reliably recorded location is from Dallman Bay, latitude -64.19°. Southern right whales are occasionally reported in the Antarctic Peninsula region (Goodall & Galeazzi 1986; Stone & Hamner 1988) although they are not common. Given a lack of sightings further south along the west Antarctic Peninsula despite substantial effort by knowledgeable expedition cruise tourism guides working from platforms of opportunity who regularly contribute quality data to Happywhale, it appears unlikely that southern right whales regularly forage in near coastal Peninsula waters at present. This area may be at the range edge of the foraging area for southwest Atlantic right whales, and will perhaps be more regularly visited as this population grows.

The visual assessments of right whale health from vessel-based imagery are semi-quantitative because the entire outline of the whale cannot be seen, yet high quality lateral images can still yield vital information (Hunt *et al.,* 2013; Rolland *et al.,* 2016). The health assessment methods used here have been widely applied to a catalogue of vessel-based images of North Atlantic right whales (*Eubalaena glacialis*) collected since 1980 (Pettis *et al.,* 2004; Hamilton & Marx 2005; Rolland *et al.,* 2016). Rolland et al. (2016) analysed images from over 48,000 sightings, mostly during summer and autumn feeding ground surveys, and found that health scores varied by sex, age-class and reproductive state, with juveniles and adult males receiving the best health scores, while resting and lactating females received the poorest health scores. Visual health assessment of SG/GS right whales using expedition-collected and opportunistic photos following the approach of Pettis et al. (2004) suggested that the whales using this feeding ground are in reasonable body condition, with no animals identified as "poor" and over 50% identified as "good" (Table 3). Body condition is measured by looking at the dorsal profile behind the blowhole, which reflects the fat reserves of the whales (Pettis *et al.,* 2004). This metric can be related to feeding success for juveniles and adult males. For adult females, body condition is also influenced by calving state, with lactating females tending to have the poorest scores. The SG/GS photo-ID catalogue is a mixture of expedition and citizen contributed photographs: most animals are not identified to sex and the presence of a calf may not always be reported, so these demographic aspects cannot be deduced from the current catalogue. These body condition results, albeit from a small sample size, are a positive sign suggesting that the whales observed in SG/GS were obtaining sufficient food over the main observation periods in austral summers 2017/18 and 2019/20. However we also note that body condition may improve over the course of the feeding season, and so measures will be influenced by the time at which surveys are conducted (in this case, halfway through the feeding season).

In contrast to body condition, skin condition (e.g. presence of lesions or sloughed skin) was more of a concern, with nearly half of all images (46.2%) scoring poorly for this feature, and one whale showing evidence of cyamids around its blowhole, an affliction which can be associated with whales in very poor health (e.g., Osmond & Kaufman 1998). The causes of skin conditions are unclear and may be linked to many factors aside from human or Kelp gull impacts (Marón *et al.,* 2015), including lack of recent migration to low latitudes (Durban & Pitman 2011; Pitman *et al.,* 2020), perhaps changes in water temperature or salinity (Bierlich *et al.,* 2018). The relationship between the long-term health of a right whale and visual health assessment scores is difficult to interpret without a time series of comparable images spanning months or seasons. Aside from the visible lack of body fat caudal to the blowhole, the significance of the three other health parameters, and their relationship to body fat scores, and to overall animal health, is not fully understood (Pettis et al. 2004, Angell 2006). Images from future dedicated and opportunistic platforms working at SG/GS should allow researchers to increase these sample sizes in order to better capture general trends in body condition, skin condition, and other health indicators over time. Further refinement of some of these indicators may also be useful, to consider the severity of injury scars or open wounds, or to assess skin conditions in more detail (for example there are a few pathogens causing skin lesions in southern right whales, including poxvirus and a bacterial infection by Erysipelothrix rhusiopathiae, Fiorito *et al.,* 2015; Fiorito *et al.,* 2016).

The quantitative body condition measurements from the aerial photographs shows that southern right whales in SG/GS were in relatively good condition, with SG/GS juveniles being slightly fatter than juveniles observed on the Península Valdés calving grounds, and SG/GS adults (none observed to be nursing females) being of similar condition as adults in Península Valdés towards the end of the calving season (1st November). Although the sample size from SG/GS is low, these data represent the first ever measurements of body condition of southern right whales from a feeding ground. Additional surveying throughout the feeding season in SG/GS (e.g. in March) could provide valuable insights into the feeding rates (rate of recovery in body condition) of southern right whales in relation to prey availability, which in turn links to reproductive rates and population dynamics.

Stable isotope analysis of right whales at SG/GS was conducted using samples of skin, which due to metabolic turnover rates likely reflect their prior feeding habits during winter and early spring (June to October), 3 - 7 months prior to the time of sample collection (based on an estimated assimilation time of 169±91 days in blue whales, Busquets-Vass *et al.,* 2017). This period is coincident with the winter calving period for right whales so some whales may have been fasting during this time. None of the right whales sampled appeared to be nursing mothers (no calves were sighted), but since calves have higher mortality than adults, it is possible that some of these animals calved and subsequently lost a calf. However seven of the samples collected (six females and one male) showed $\delta^{15}N$ values between 6.5-8.5‰, indicative of feeding on prey analysed from SG waters during this period (Figure 5B). Two males showed higher levels of $\delta^{15}N$ values than the rest of the group (11-12.5‰, Figure 5A). These enriched nitrogen values are similar to those seen in whales feeding on copepods and euphausiids on the Patagonian shelf (Valenzuela *et al.,* 2018), although prey at other lower latitude regions also visited by southern right whales are under-surveyed, so could come from other unsampled regions such as at or north of the sub-tropical convergence. Of the 11 southern right whale sightings in SG/GS waters in 2020, all but two encounters were of solitary animals, with two pairs also encountered (Kennedy *et al.,* 2020). Preliminary microsatellite analysis of these pairs suggests that they were not related (Carroll, pers comm). None of the female right whales seen

at SG/GS in 2020 were accompanied by calves, and the stable isotope patterns shown here suggest these females may have been feeding in polar waters prior to visiting SG/GS in 2020. This is consistent with the idea that female right whales primarily visit calving ground locations for calving every three years, with their locations outside of this calving period largely unknown; in this case, the stable isotope pattern and lack of calves suggests they may have been feeding rather than visiting calving grounds the previous winter. Further analysis of both prey and southern right whale skin samples using fatty acids (e.g., Marón *et al.,* 2020) would be helpful to better establish the prey sources and in particular to distinguish the dietary contribution of copepod and euphausiid prey to the high latitude diet of southern right whales.

Conclusion

Studies on southern right whale summer feeding grounds provide a unique opportunity to understand the behaviour and dynamics of this species away from the much better studied calving areas. There is a small summer dataset collected in SG/GS to date, with stable isotope patterns suggesting that some of the whales using this area have been feeding south of the polar front prior to visiting SG/GS. Studies of southern right whale feeding grounds also provide an opportunity to assess how foraging impacts body condition, and in this case we do not see any evidence that southern right whales were in poor body condition at SG/GS in 2018 and 2020, although skin condition assessments suggest whales were in poorer condition in 2020 than in 2018. These results are early stage but with further data collection may provide helpful comparisons with calving grounds, in particular in relation to the high latitude habitat preferences and health status of southern right whales as they recover in the southwest Atlantic.

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Figures

Figure 1. Map of the Scotia Arc showing the location of South Georgia (Islas Georgias del Sur) with a yellow star showing the locations where southern right whale SG1901 was photo-identified and re-sighted.

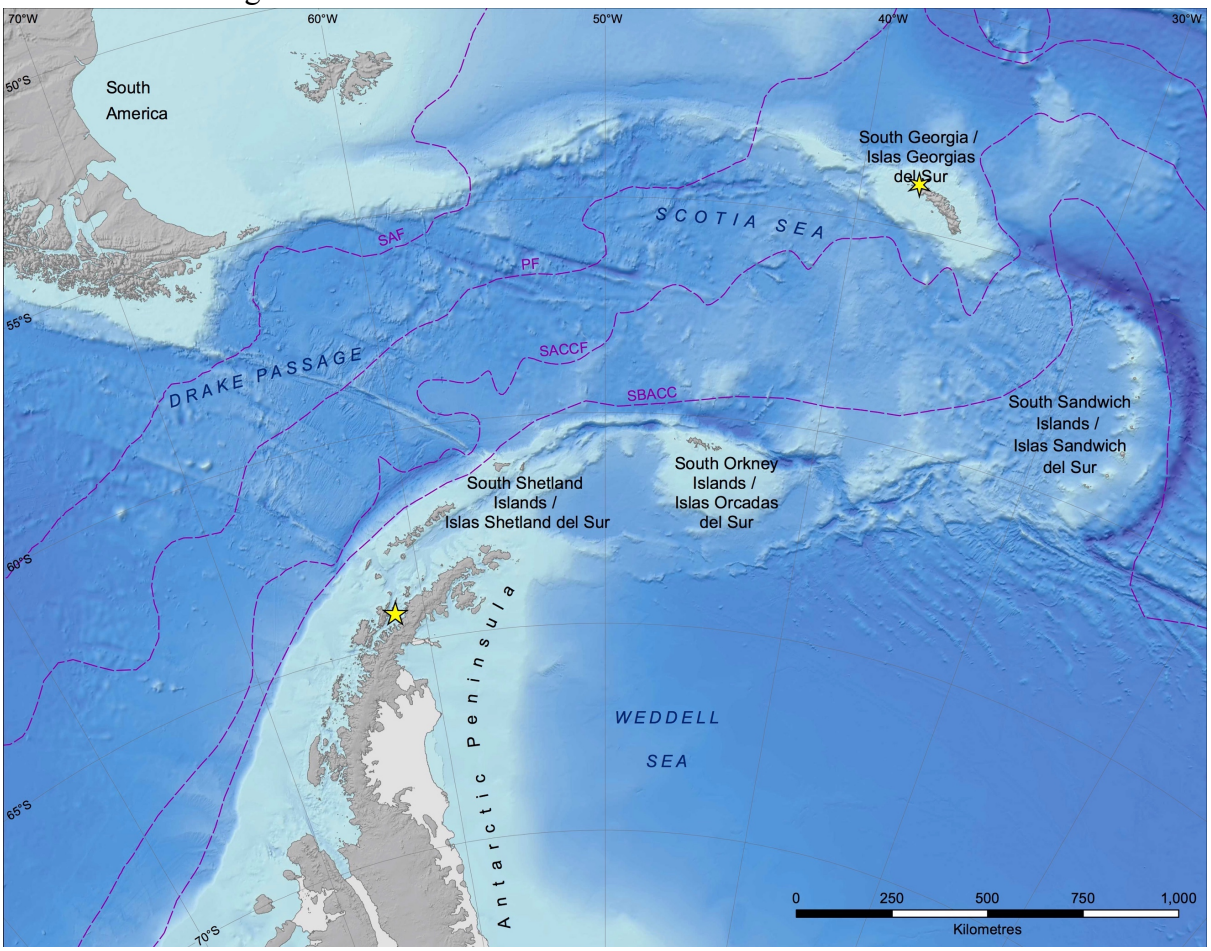

Figure 2. Southern right whale SG2001, showing cyamids present around the blowhole. This whale was visually assessed as having medium body condition and poor skin condition, with no evidence of rake marks anterior to the blowhole.

Figure 3. Bar plots comparing health assessments of body condition, skin condition and rake marks for southern right whales sighted in summer 2017/18 and 2019/20. Numbers of images assessed are shown next to each year and health assessment type. White = good condition, blue – medium condition, red = poor condition (as defined by Pettis et al. 2004).

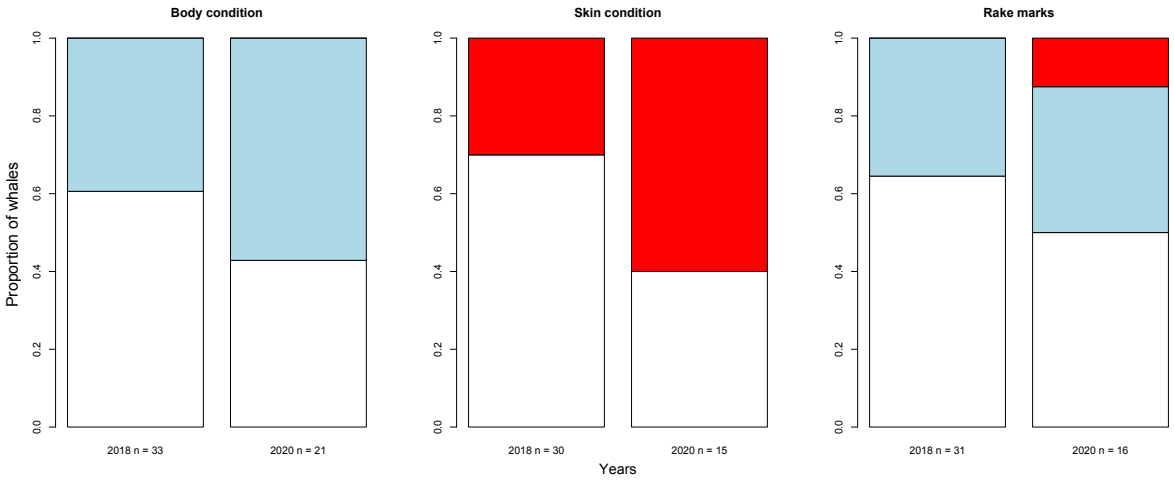

Figure 4. (A) Body condition of juvenile and adult southern right whales measured in SG/GS (feeding ground) and Península Valdés (breeding ground). The sample size of each age class at each location is given below each boxplot. The dashed horizontal line indicate the mean body condition (BCI=0) of all the whales sampled in the two locations. (B) Southern right whale body condition as a function of day of year. The colour of the data points indicate the age class and sampling location (see key). The solid blue and red lines represent the fitted values of a linear model fitted to the Península Valdés adults and juveniles, respectively, to show the intra-seasonal change in body condition. F-statistic comparison between adults and juveniles: 2.704 on 3 and 228 degrees of freedom, *p*-value = 0.04626, R^2 = 0.03435. Juveniles: Slope = -0.00074, SE=0.00036, t-value = -2.071, p-value = 0.0395. Adults: Slope = -0.00001, SE = 0.0003, t-value = -0.047, *p*-value = 0.9628.

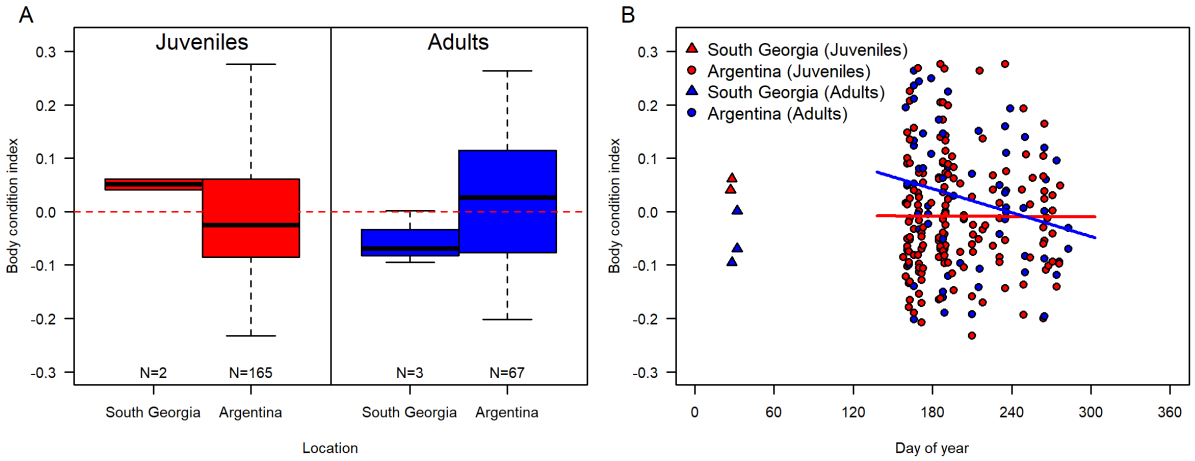

Figure 5. Stable isotope patterns of SG/GS southern right whales. Figure 5A shows samples identified by sex and compared with stable isotope patterns from the Península Valdés calving ground (Valenzuela *et al.,* 2018). Figure 5B shows stable isotope values of whale skin collected in 2018 (red open circles) and 2020 (red closed circles) compared to potential prey species collected in SG/GS waters in 2018. All prey species indicated in blue belong to the order Calanoida (copepods) and all prey species indicated in green belong to the order Euphausiacea (krill).

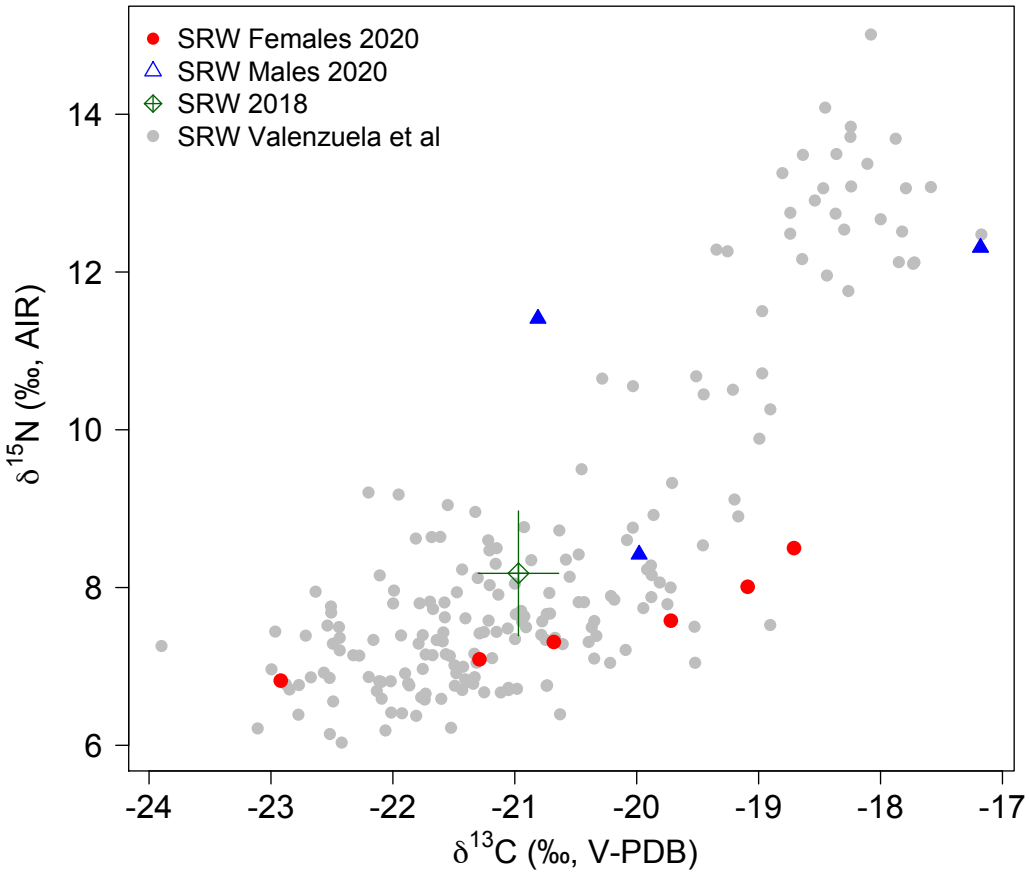

Figure 5A

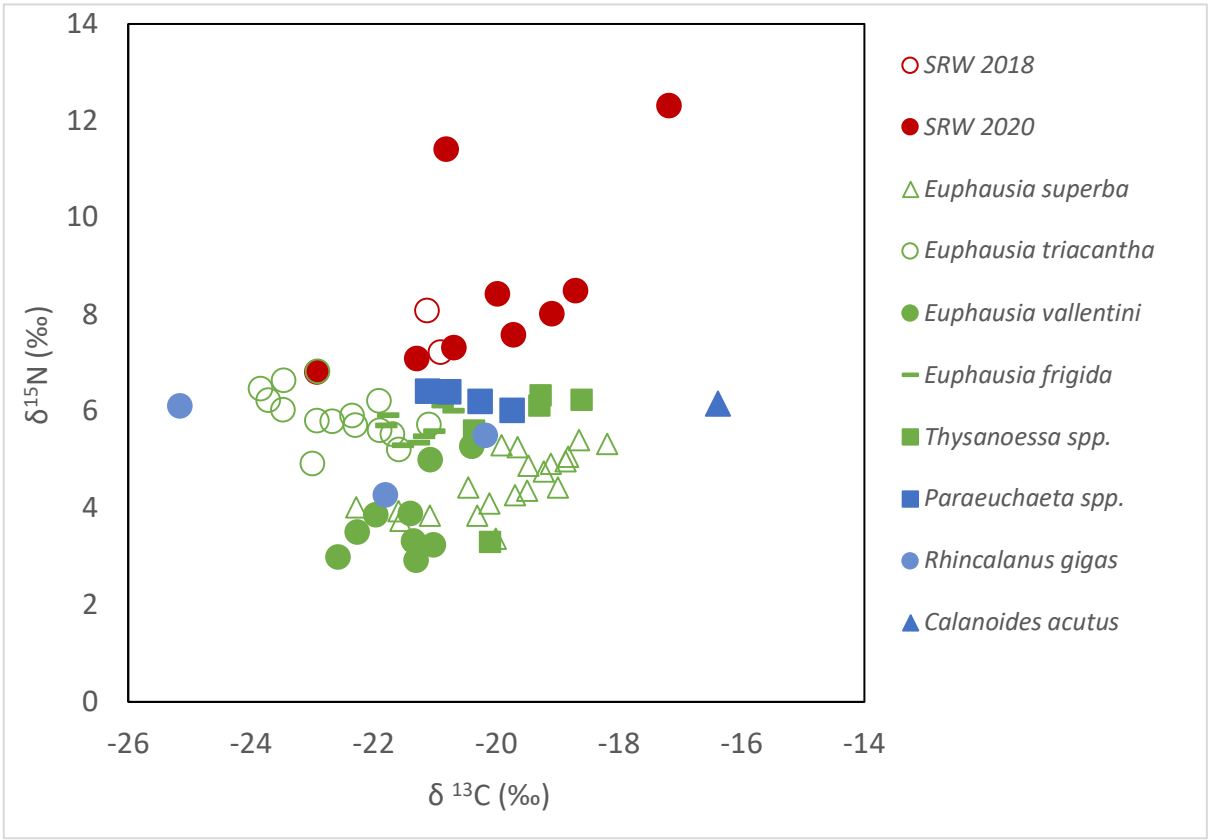

Figure 5B

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