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ABSTRACT

Sightings of large whales at South Georgia/Islas Georgias del Sur (SG/GS) have been increasing in recent years as they recover from severe depletion by 20th century industrial whaling. As cruise ship traffic around SG/GS has also increased, there is a need to address the risk of collisions between ships and whales. Here, we use sightings data collected during a research survey around SG/GS in summer 2020 to calculate whale density, together with AIS data on shipping traffic to estimate shipping density (in terms of km travelled per km^2), in order to examine ship strike risk and possible mitigation options. During 2430 km of visual transects, there were 337 sightings of humpback whale groups totalling 661 individual whales. The resulting average estimated density was 0.089 individuals.km^{-2}. Densities were particularly high across the shelf to the north of the island, which corresponds to the area most used by cruise ships. There were also 38 sightings of 58 individual blue whales with a resulting density estimate of 0.009 individuals.km^{-2}.

Vessel traffic at GS/GS is dominated by fishing vessels and cruise ships, which are separated seasonally. Fishing is concentrated in the winter months while cruise ships visit in summer and follow predictable routes along the north coast of the island, visiting designated landing sites. A simple encounter model was used to estimate a risk index based on whale and cruise ship densities in summer 2020. This index was the estimated annual number of lethal ship strikes from cruise ships assuming no avoidance by the vessel or whale, and was estimated at 28 humpback whales and 1.5 blue whales. These should not be considered as estimates of likely mortality but do show that in a global context, SG/GS could be considered a high-risk area based on the whale densities observed in 2020.

As it is unlikely that there would be any particularly important areas for humpback whales that could be avoided by simple routeing measures, we suggest consideration of speed restrictions for vessels in SG/GS waters. At present about 35% of the distance travelled by cruise ships on the SG/GS shelf is at speeds less than 10 knots which suggests that it may be possible to limit all speeds to less than 10 knots without huge inconvenience to schedules through careful voyage planning. IAATO cruise ships in areas around the Antarctic Peninsula adhere to a 10 knot speed restriction to mitigate ship strike risks, primarily because of concern about humpback whales. The SG/GS and South Sandwich Islands Marine Protected Area Management Plan includes objectives to manage human activities including shipping to minimise impacts on the marine environment. Slower ship speeds can also have other environmental benefits of lower emissions and reduced underwater noise.

INTRODUCTION

South Georgia/Islas Georgias del Sur (SG/GS) was a focus for early 20th century commercial whaling due to very high densities of baleen whales which were exploited to commercial extinction. Following decades of relatively low whale densities, higher numbers have been observed in recent years. The whale species that are most commonly reported around SG/GS (humpback, blue, fin, southern right) are all known to be vulnerable to ship strikes and are among the species most commonly reported globally (van der Hoop et al., 2015, Winkler et al. 2020).

Wherever whales and ships coincide there is a risk of collisions. In areas with high densities of whales there may be a need for measures to reduce collision risk. Measures that have been demonstrated to be effective involve routeing away from known areas of whales or speed reductions through the high density areas. Routeing measures require predictable and well-defined areas of high whale density that it is practicable to avoid, whereas speed reductions can effectively reduce risk for vessels that have to pass through areas of likely high whale density (IWC, 2016).

During a scientific whale survey in 2020 (Kennedy et al., 2020), the 36m long survey vessel, MV Braveheart was involved in a collision with a humpback whale. The Braveheart is a relatively small vessel of 177 GT and the collision was felt by everyone on board. The ship was travelling at 9.5 knots with several visual observers on effort. The whale was not seen prior to the collision and presumedly it surfaced beneath the vessel. The vessel was around 5nm from the coast in a water depth of 140m with no other vessels in sight. The whale was followed for 20 minutes and there were no apparent signs of injury and no blood was observed in the water. This incident highlights that collisions can occur even with experienced observers on effort. The lack of injury was possibly a result of the slow speed of the vessel.

The incident has been reported to the IWC global database of ship strikes. Humpback whales are one of the most frequently reported species in the IWC database. Members of the International Association of Antarctica Tour Operators (IAATO) have reported nine strikes to the IWC database since 2001 (IAATO, 2019) but for most cruise ships, collisions are likely to go unnoticed because of the relative size of the vessel compared to a whale.

Cruise ship traffic has increased at SG/GS in recent years with 82 visits from vessels in the 2017/18 season compared to 34 in 1999/2000 (Figure 1 from GSGSSI, 2018). Although shipping densities are relatively low compared to heavily populated areas, cruise ships visiting SG/GS that are covered by SOLAS are all members of IAATO which is committed to ensuring that their activities have no more than a minor or transitory impact on the environment. In 2019, IAATO members unanimously adopted mandatory procedures to mitigate ship strike risks from vessel operations in the Antarctic Peninsula region. These measures came into effect for the 2019/20 season and involved a 10 knot speed restriction between 1 January and May 30 in the Gerlache Strait and adjacent waters and from February 1 through May 30 in the Marta Passage entering Crystal Sound. IAATO operators who have a whale strike mitigation training program and post an extra watchman on the bridge for the sole purpose of being on whale lookout are not bound by this speed limit. IAATO will take steps to study the implications of these procedures, including the expected efficacy of using observers to mitigate collision risk (IAATO, 2019).

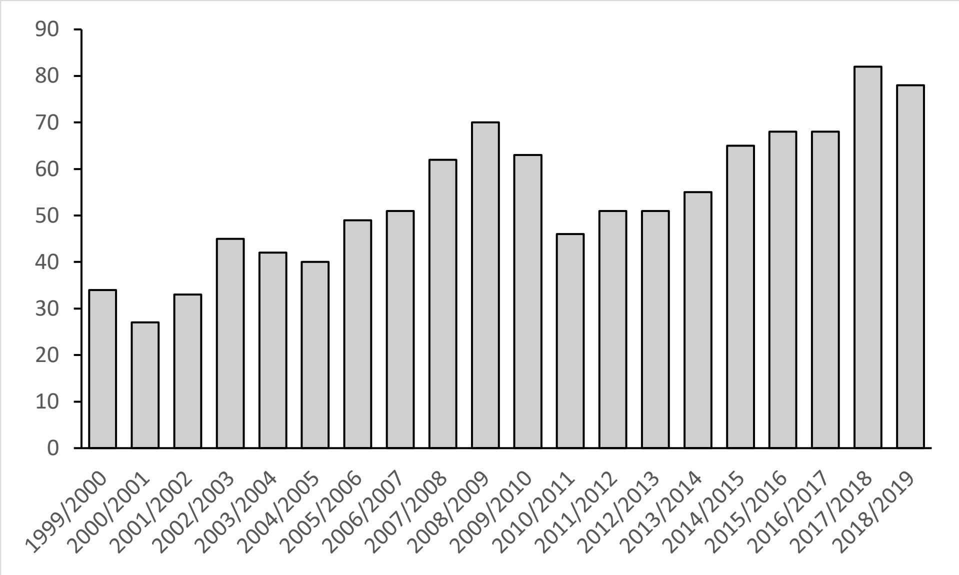

Figure 1. Number of cruise ship visits to SG/GS by season (from GSGSSI Annual Tourism Report 2017/18 and 2018/19).

The IAATO measures in the Gerlache Strait were primarily motivated by concern over humpback whales. There is evidence from high pregnancy rates that the population using the Antarctic Peninsula area may be growing rapidly (Pallin et al., 2018) and the species can occur in large aggregations (Nowacek et al., 2011).

The South Georgia and South Sandwich Islands Marine Protected Area (SGSSI MPA) was established in 2012 to protect and conserve the region's marine life. The MPA Management Plan was published in 2013[1]. The objectives of the SGSSI MPA include to manage human activities including shipping, tourism and scientific research to minimise impacts on the marine environment.

This paper reviews information on humpback and blue whale density and distribution around SG/GS including preliminary results from a survey conducted in January/February 2020 to examine ship strike risk and possible mitigation options.

METHODS

Patterns and speeds of vessel traffic

Ship density estimates were based on data from Automatic Identification System (AIS) transmissions received from satellite receivers linked to the Marine Traffic network (www.marinetraffic.com) for the period 01/06/2018 to 01/05/2020. Shipping density was defined according to Leaper and Panigada (2011) as the distance travelled in km per km^2 (i.e. the units are km^{-1}). The methods used to estimate density were similar to those of Frantzis et al. (2019) except based solely on satellite received signals. When a satellite receiver is available then transmissions are received frequently (every few seconds) and the complete track of the vessel can be established. In these situations, the contribution of that vessel transit to the density in each grid square was the reported speed over ground (SOG) multiplied by the time interval from the previous transmission for all transmissions with the location in that grid square. However, there may be periods when satellite coverage is not available. In order to check for bias related to this we compared the estimates of distance travelled derived from the sum of the distances between AIS transmissions with the total great circle distance

[1] www.gov.gs/docsarchive/Environment/Marine%20Protected%20Area/MPA%20Management%20Plan%20v2.0.pdf

for straight tracks of ten sample vessels approaching SG/GS. For the tracks examined, the average bias due to lost AIS signals was less than 5% with a maximum of 10%. These biases were considered small enough not to require the application of a correction factor. However, some of the earlier data from 2018 appeared to have lower levels of satellite coverage. Thus, estimates of annual shipping density were based on data for a one year period from 01/04/2019 to 01/04/2020.

Index of collision risk

To estimate a crude index, *N,* of the likely number of interactions involving physical contact over a year (assuming no response by whales or vessels), we used the approach of Tregenza et al. (2000), giving

$$N = \frac{(B_S + 0.64W_L)}{1000} \times S \times L_S \times D_W \tag{1}$$

Where

B_S = The beam of the ship in m (we used an average for the 12 vessels that contributed >50% of the distance travelled from this study)

W_L = Mean length of a whale in m (we used 14m for a humpback whale, 18m for Antarctic blue whale)

S = Proportion of time spent at risk close to surface (we used 0.5 for humpback whales and 0.26 for blue whales based on telemetry data in Rockwood et al. 2017 assuming an average draught for vessels of 5m)

L_S = Total distance travelled by the ship (km)

D_W = Whale density (individuals km^{-2})

The relationship between probability of a strike being lethal and vessel speed has been studied in most detail for North Atlantic right whales. Vanderlaan and Taggart (2007) estimated the probability of lethal injury with vessel speed at the time of impact ($M_{v,}$) which was later updated by Conn and Silber (2013) with additional data. In that case M_v for speed v (in knots) was expressed as:

$$M_v = \frac{\exp(\beta_0+\beta_1 v)}{\exp(\beta_0+\beta_1 v)+1} \tag{2}$$

Where β_0 was estimated as -1.905 (SE = 0.821) and β_1 as 0.217 (SE = 0.058).

To generate an index of ship strike risk for comparison with other studies we calculated Ls by ship speed (rounded to 1 knot) and multiplied by M_v for that speed. This gave an estimate of N_v for each speed bin that could then be summed to a total risk index taking speed into account.

The assumption that whales would not avoid approaching vessels is not realistic and in most cases whales would be expected to take appropriate action to avoid a collision, but it is a useful measure to compare risk between areas.

Whale surveys

In reviewing ship strike risk across species, we considered whale surveys conducted in 2018, 2019 and 2020 in SG/GS waters (Baines et al. 2019; Jackson et al. 2020; Kennedy et al. 2020). In 2020, surveys were conducted from the MV Braveheart between 09/01/2020 and 03/02/2020 on the continental shelf around SG/GS. The survey design is described in Kennedy et al (2020) and included some pre-determined transects along with other, more opportunistic, searching based on logistical and weather constraints. Visual observations were carried out by two observers at a time from an observer platform with an eye height of 4.88m above sea level in weather conditions of Beaufort 5 or less. Angles and distance estimates to sightings were made using angle boards and reticle binoculars.

Detection functions for species with sufficient sightings (blue and humpback whales) were estimated using the programme Distance (Thomas et al. 2010). No attempt was made to estimate the absolute detection probability on the trackline (g(0)), which was assumed to be 1. This is a common assumption for blue whale surveys and where g(0) has been estimated in other studies it has been close to 1 (e.g. Calambokidis and Barlow, 2004).

In addition to Distance analysis, transects were divided into 1 km segments for the purposes of spatial modelling. The results presented here are for a simple spatial Generalized Additive Model (GAM) including possible covariates of latitude, longitude (scaled to be isotropic with latitude), depth, weather, visibility, swell and Beaufort sea state. The response variable was the number of whales sighted in each 1 km segment of survey track. Modelling was performed using the mgcv package in R (Wood, 2006; R Development Core Team, 2008). Depth data were taken from the Gebco_08 grid (version 20100927 www.gebco.net) at 30 arc-second (approximately 925 m spacing).

RESULTS

Whale distribution and density

During 2430 km of visual transects in 2020 there were 337 sightings of humpback whale groups totalling 661 individual whales; a raw sighting rate of 0.27 individuals.km^{-1}. The estimated strip half width from program Distance for humpback whales was 1522 m (Figure 3a), resulting in an average estimated density of 0.089 individuals.km^{-2}.

There were 38 sightings of blue whale groups with a total of 58 individuals. The estimated strip half width from program Distance for blue whales was 1369 m (Figure 3b), resulting in an average estimated density of 0.009 individuals.km^{-2}. Blue whale data from 2020 and previous surveys are analysed more comprehensively in Calderan et al. (2020).

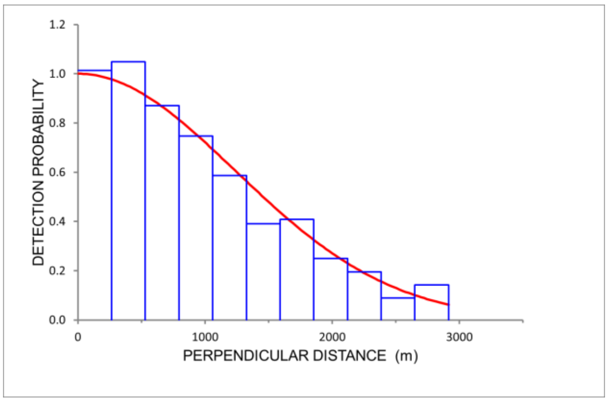

Figure 3a. Distribution of perpendicular distances to humpback whale sightings on visual transect effort. Perpendicular distances truncated at 3km giving 323 observations. Fitted detection function (half normal key) using program Distance gives Eshw =1522 m (CV= 4.2% 95% CI 1400-1654 m)

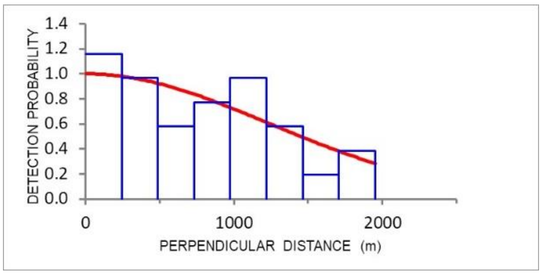

Figure 3b. Distribution of perpendicular distances to blue whale sightings on visual transect effort. 29 observations. Fitted detection function (half normal key) using program Distance gives Eshw =1369 m CV = 17% (95% CI 964-1944 m)

The survey effort and locations of humpback whale sightings are shown in Figure 4. Based on minimum AIC the final spatial model for humpback whales included latitude, longitude, depth and sea state. The intensity of the purple shading indicates the predicted relative density from the spatial model. There are a number of caveats with these predictions and the model should really only be used as an indication of the distribution within areas that were well surveyed. The only habitat variable included in the model was depth and it is likely this is related to krill availability but there are likely many other drivers of krill which were not included in the model. In order to capture the limited ability to model habitat, the model is over-fitted to latitude and longitude and so has very limited predictive ability. This is apparent to the west and SE of the island where high density areas are predicted outside of the survey coverage. Nevertheless, the observed data do demonstrate that in Jan/Feb 2020 densities were high across the shelf to the north of the island and generally lower on the shelf at the western end of the south coast.

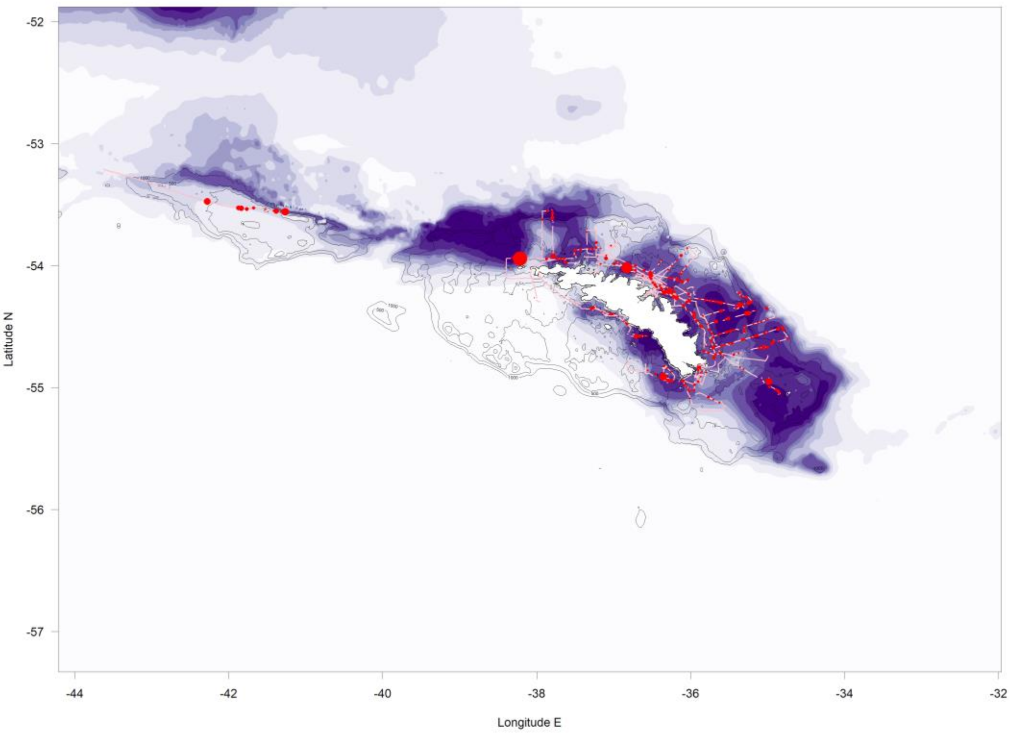

Figure 4. Spatial model of humpback whale distribution. Pink lines indicate visual transect effort in January and February, 2020. Red dots indicate sighitngs of humpback whales on visual transect effort with size of dot indicating group size. Purple shading indicates relative predicted density from spatial model.

In addition to the 2020 survey, the first survey as part of the SG/GS right whale project had been conducted around SG/GS from 28 Jan to 16 Feb 2018 with 606 km of effort. This resulted in only two sightings of humpback whale groups totalling 6 individuals (Jackson et al. 2018). The sighting rate of 0.01 individuals.km^{-1} in 2018 was only 3.6% of the sighting rate in 2020, although the sightings platforms were not directly comparable. On the 2018 survey, southern right whales were the most frequently sighted species

In 2019, whale observations were conducted in the northern and eastern Scotia Arc during the CCAMLR international synoptic krill survey. Humpback whales were the most frequently sighted cetacean with 226 sightings of 495 individuals. This generated a density estimate for humpback whales for the SG/GS stratum of 0.08 individuals.km^{-2}. There were only a few fin whale sightings around SG/GS but they were the second most frequently sighted species overall (Baines et al. 2019).

Shipping density

The four main types of large vessel traffic in SG/GS waters are cargo, research, passenger and fishing vessels. Of these, fishing vessels, followed by passenger vessels (cruise ships) contribute the greatest total distance travelled (Figure 5).

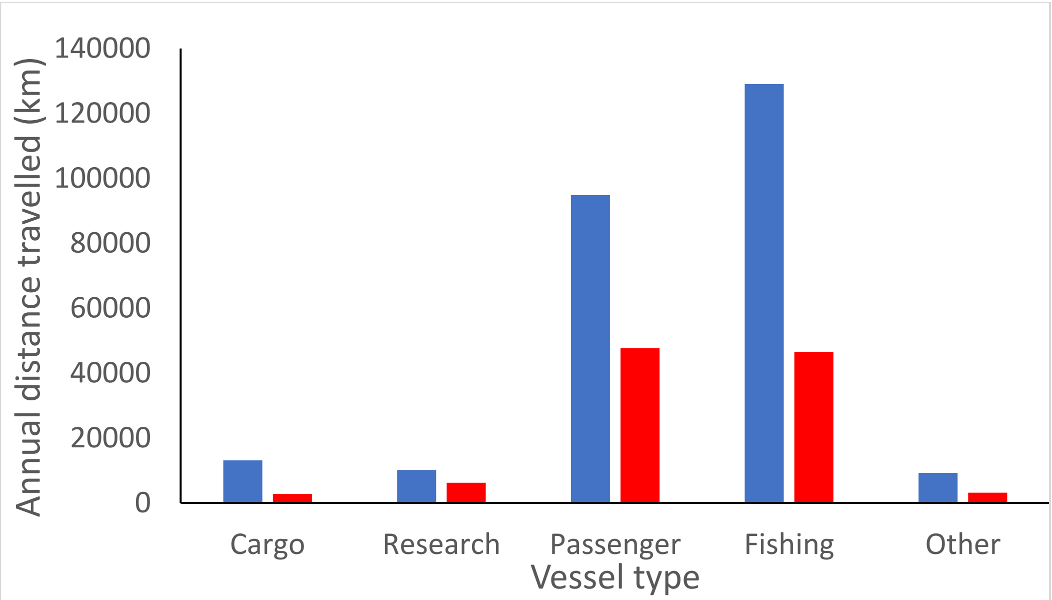

Figure 5. Annual distance travelled (km) by different shipping sectors for whole study area (blue bars) and SG/GS shelf (red bars, depth <1000m and east of 40°W).

However, the speed profiles in the whole study area of the four ship types are different (Figure 6). Cruise ships show a clear peak in speeds of around 12 knots whereas the peak in speed of fishing vessels is less than 10 knots. Cargo vessels (mainly refrigerator ships associated with fishing operations) tend to have the highest speeds but make relatively few visits.

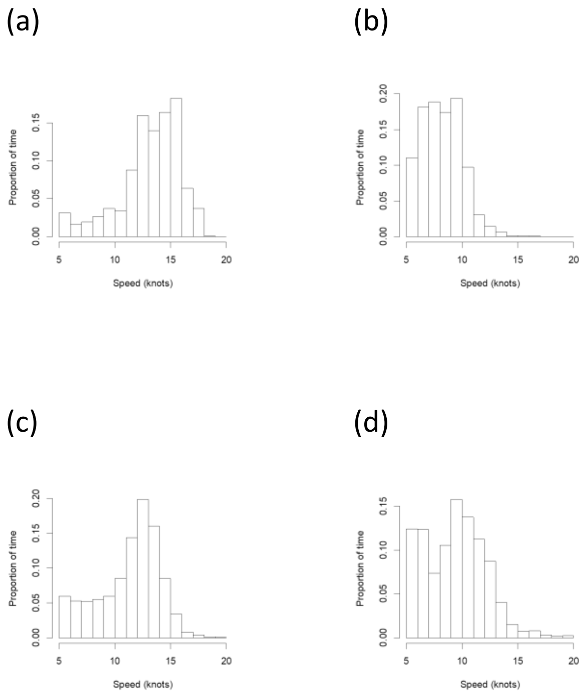

Figure 6. Speed distributions of different vessel types in SG/GS waters when travelling at > 5 knots, a) cargo vessels, b) fishing vessels, c) passenger ships and d) research vessels

There are also very clear seasonal patterns in activity of the two dominant vessel types. Fishing vessel activity is limited to winter months largely April-September (Figure 7). In contrast, cruise ships only visit during summer, mainly November to March.

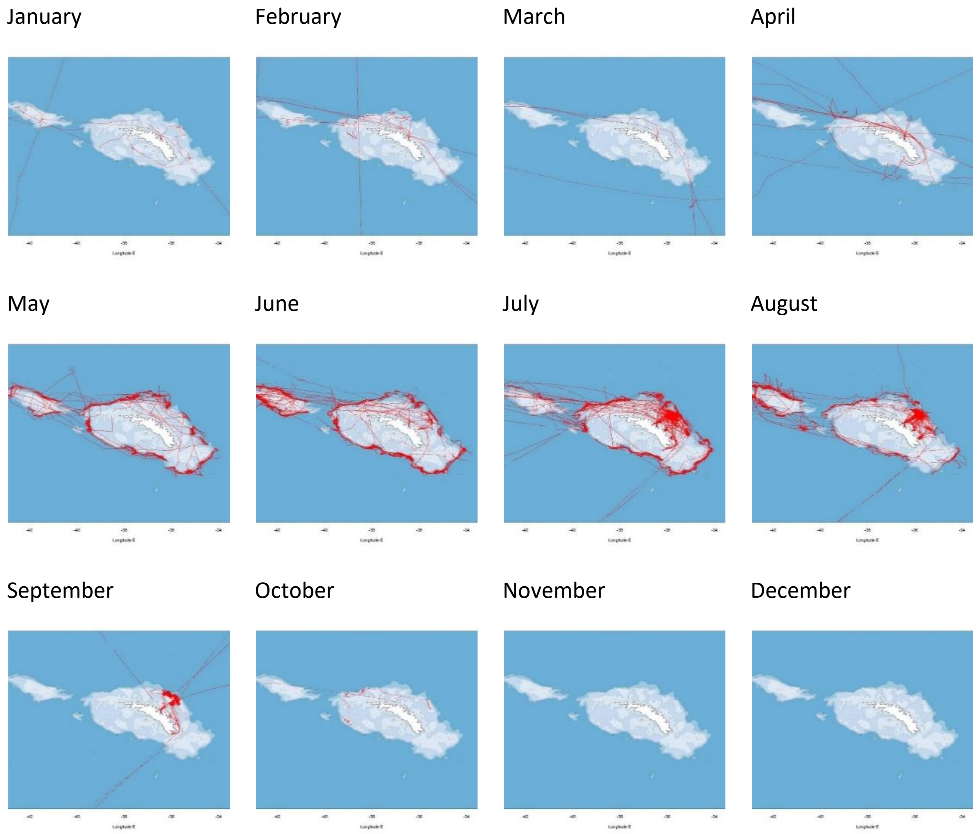

Figure 7. Fishing vessel activity by month.

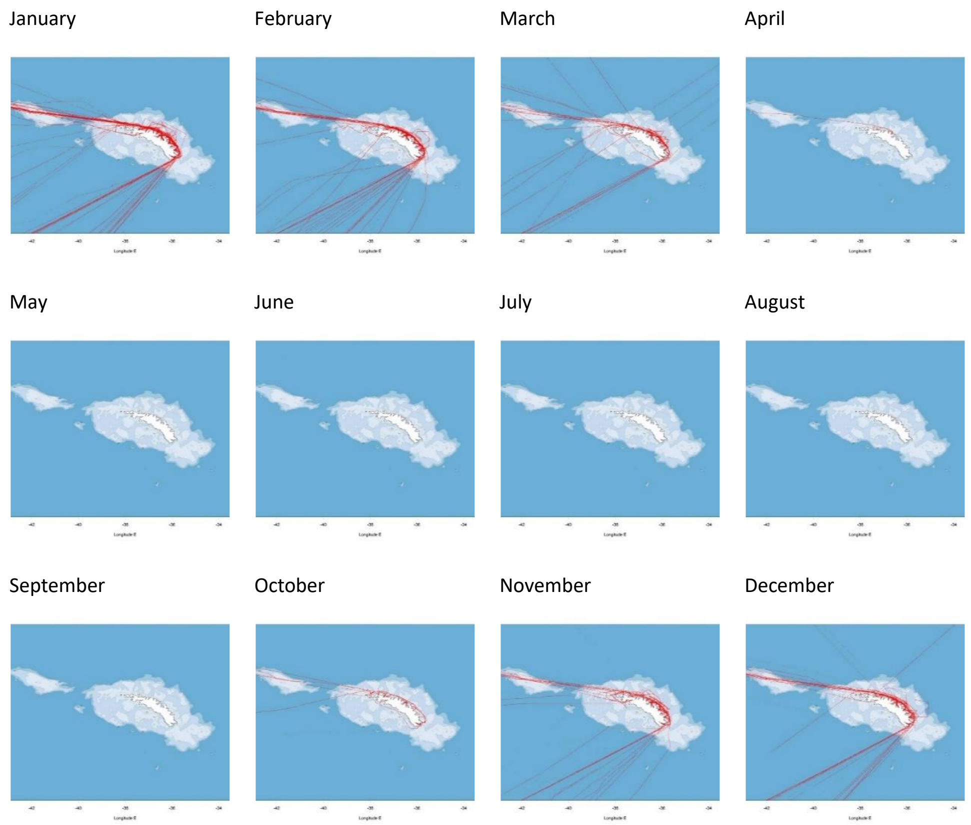

Figure 8. Passenger vessel activity by month.

Cruise ships visiting SG/GS tend to follow very predictable routes. The two approaches to the island are either from the west passing close to the north of Shag Rocks and then along the north coast of the island, or from the SW, coming around the east end of the island and along the north coast. In 2018/19, 60 out of 78 cruise ship visits approached from the Falkland Islands (Islas Malvinas) with 51 departing for the Antarctic Peninsula. Only four vessels departed the island heading east (GSGSSI, 2020).

Cargo vessel activity was concentrated to the north of the island but with a greater variety of tracks on approach or departure (Figure 9). Research vessel activity is more varied and covers a greater area (Figure 10).

Once at the island, cruise ships generally visit a number of designated landing places. Figure 11 shows the track of a single vessel on multiple visits. All coastal activity was on the north coast except for visits to King Haakon Bay on the south side of the island.

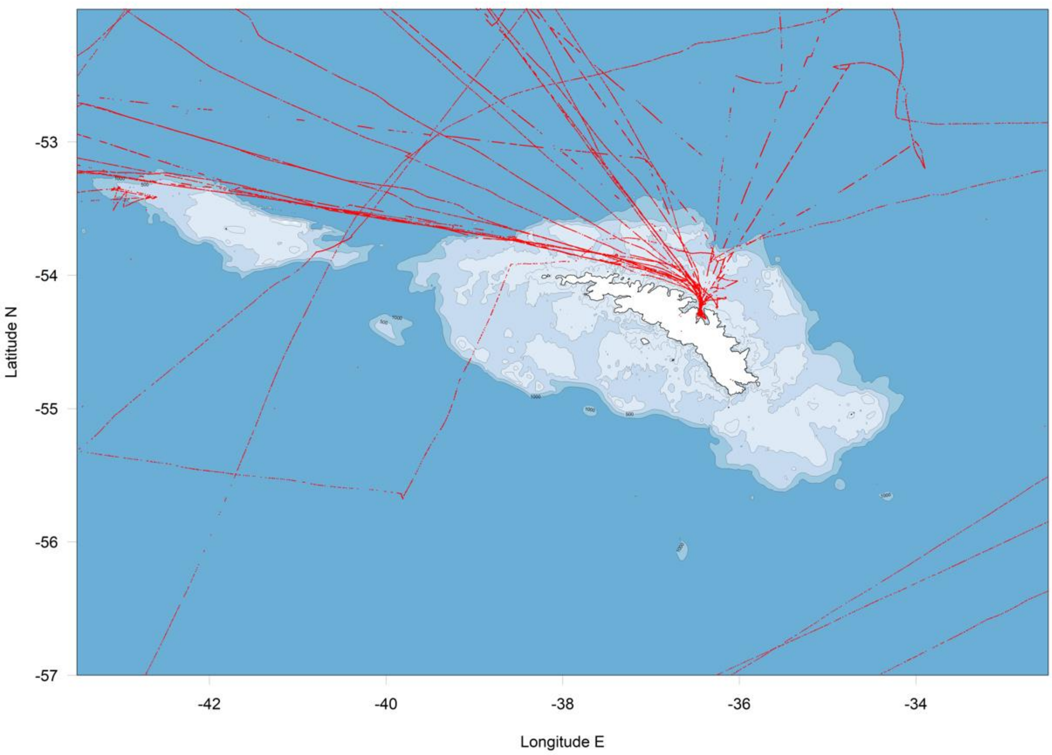

Figure 9. Tracks of all cargo vessels.

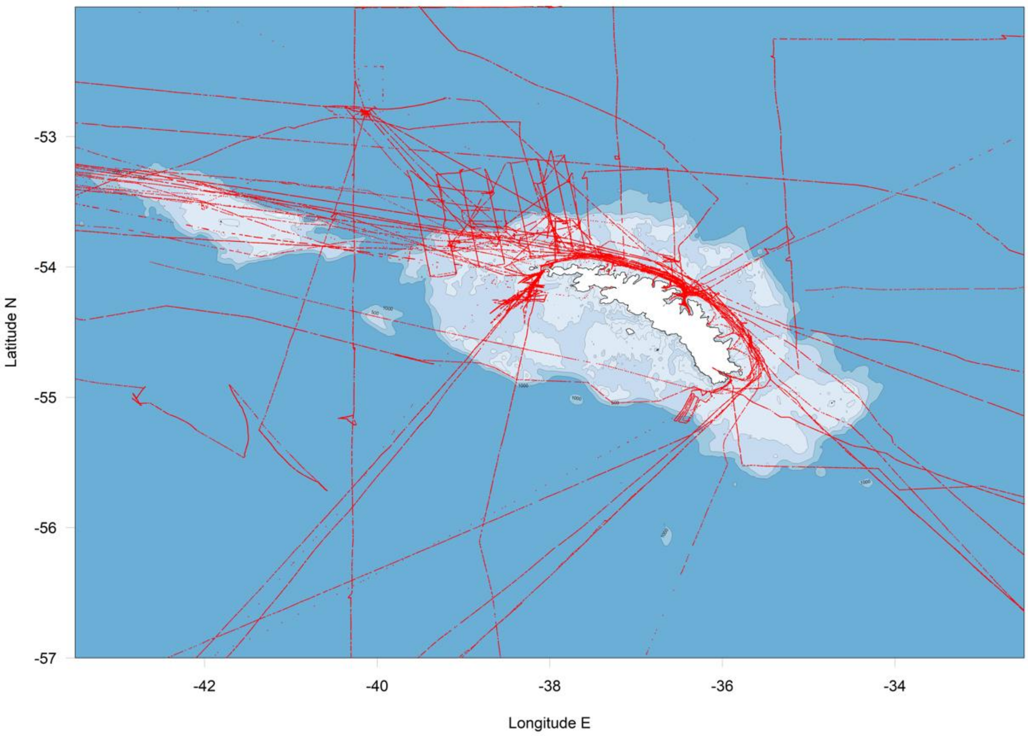

Figure 10. Tracks of all research vessels.

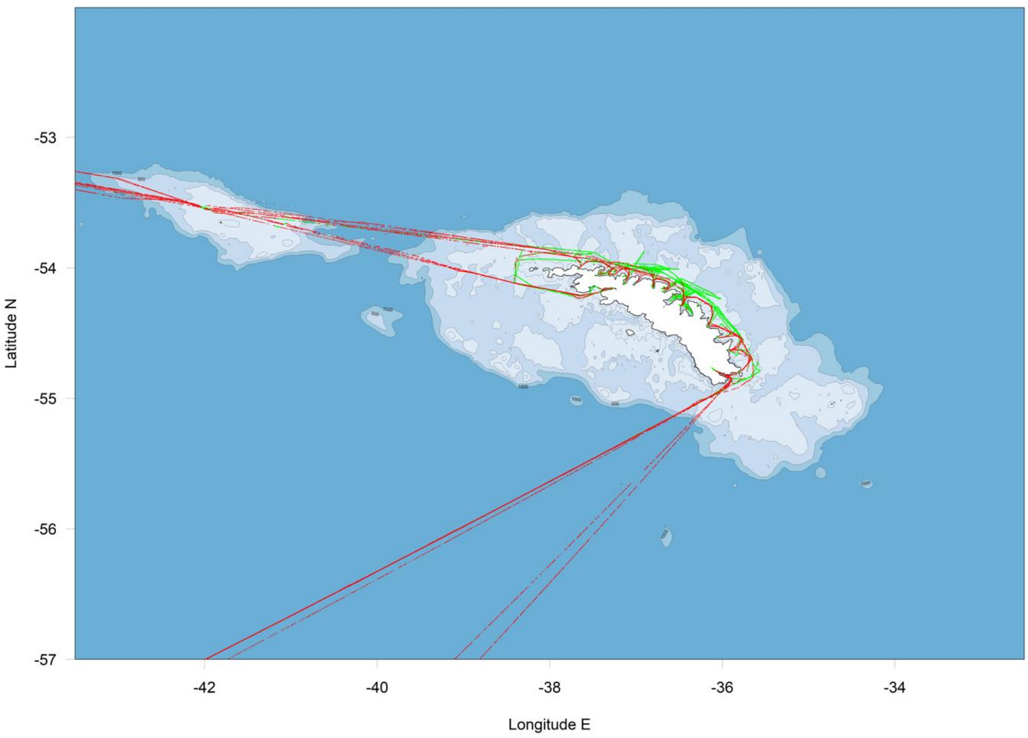

Figure 11. Tracks of a single cruise ship on multiple visits. Red tracks are speeds greater than 10 knots, green are speeds less than 10 knots.

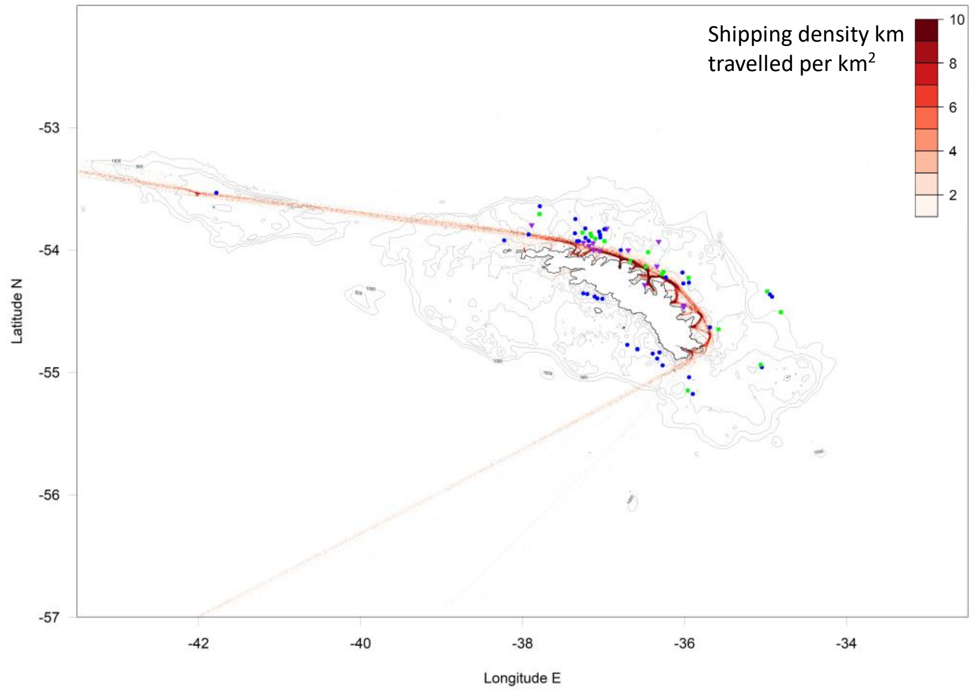

Figure 12. Annual passenger ship density averaged over 2019 and 2020 seasons. Sightings of blue (blue circles), fin (green squares) and right (purple triangles) whales from BAS 2018 and 2020 surveys.

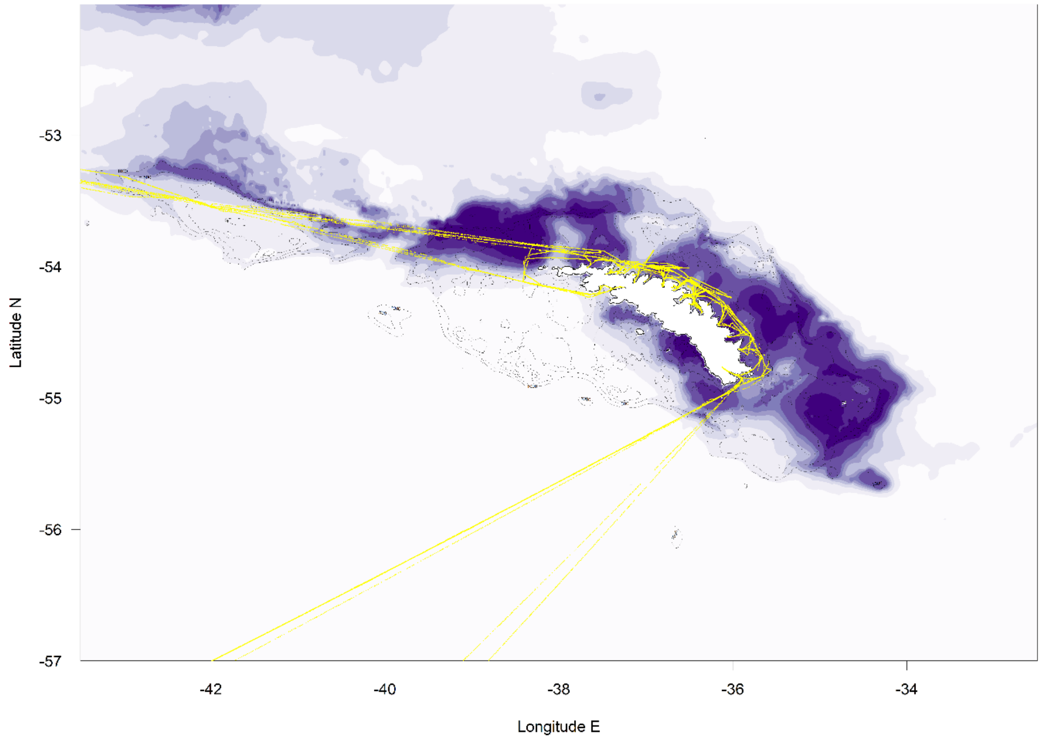

Figure 13. Tracks of a cruise ship (yellow) over humpback whale predicted densities from 2020 surveys (purple shading).

Risk analysis
There are insufficient data on whale density and distribution in winter to make assessments of ship strike risks from fishing activities. Thus the risk analysis was focussed on passenger ship traffic during the summer months. Although the shipping density of fishing vessels is higher than that of passenger vessels, the slower speeds suggest an overall lower level of a ship strike occurring and concomitant risk of serious injury in the event of a collision (Conn and Silber, 2013). Nevertheless, satellite telemetry data do indicate the presence of southern right and humpback whales around SG/GS during the winter, suggesting that there will be some level of ship strike risk.

Density estimates from surveys in 2020 were sufficient to obtain average densities for the surveyed area for blue and humpback whales. The number of sightings of humpback whales also allowed for a simple model to investigate the variation in density across the shelf area around SG/GS. The density plot in Figure 4 and the overlay of typical passenger vessel tracks in Figure 13 suggest that it is unlikely that there would be any particularly important areas for humpback whales that could be avoided by simple routeing measures. In addition, it is important to note that the density model is just based on a single survey and there has been considerable inter annual variability in humpback whale numbers around SG/GS in recent years. Based on the modelled density patterns it seems reasonable to use the average humpback whale density for the shelf area as a whole to estimate collision risk along the shipping routes. The areas to the SW of the island predicted to have low densities of whales also have no passenger ship traffic.

Hence in equation 1 we used the total distance travelled by passenger ships on the SG/GS shelf area in the 2019/2020 season and the average density for humpback and blue whales to estimate the relative risk index, *N* (Table 1).

Table 1. Estimates of the expected numbers of collision incidents (*N*) on the SG/GS shelf area (depths < 1000m), excluding Shag Rocks, that would occur if no avoiding action was taken by whales or vessels for the period 01/10/2019 to 01/04/2020

Vessel speed	Total distance travelled by vessels (km)	Mean vessel beam (m)	Whale density Individuals.km^{-2}	Proportion of time within risk zone (< 5m below surface)	Relative risk index (N)
Humpback whales					
All	47461	17.4	0.089	0.5	55.9
>10 knots	30847	17.4	0.089	0.5	36.3
>12 knots	21228	17.4	0.089	0.5	25.0
Blue whales					
All	47461	17.4	0.009	0.26	3.1
>10 knots	30847	17.4	0.009	0.26	2.0
>12 knots	21228	17.4	0.009	0.26	1.4

The risk index for 2020 corrected for the complete distribution of cruise vessel speeds based on the probability of a collision being lethal from equation 2, which would be the estimated number of lethal ship strikes assuming no avoidance by the vessel or whale, was 28 for humpback whales and 1.5 for blue whales.

DISCUSSION

Although shipping densities around SG/GS are relatively low compared to major shipping routes, surveys in 2019 and 2020 showed high densities of whales in areas which cruise ships regularly pass through during summer. Density estimates for humpback whales were an order of magnitude greater than for blue whales; humpback whales also spend a greater proportion of time closer to the surface resulting in the overall higher relative risk index. Density estimates were not possible for other species but sighting locations of fin and right whales also occurred on routes used by cruise ships. All of these baleen whale species are amongst the most frequently reported involved in ship strikes globally (SC/68b/HIM09). Antarctic blue whales are listed as critically endangered and are still highly depleted. The densities observed at SG/GS in 2020 indicate a substantial proportion of the Antarctic blue whale population are using the area (Calderan et al. 2020). The collision of a humpback whale with the MV Braveheart highlights that even with dedicated observers on watch, collisions may occur with whales that have not been sighted. Even if whales are sighted, taking avoiding action is often not possible for large vessels although there are ways that the effectiveness could be enhanced (Gende et al. 2019).

The high average density of humpback whales in the last two years is comparable to other high density areas such as the Gerlache and Bransfield Straits where measures have been taken to reduce ship strike risk (IAATO, 2019). The estimated average density for the SG/GS stratum of 0.08 in 2019 and 0.09 individuals km^{-2} for the surveyed area in 2020 are very similar to the autumn estimates for the Gerlache/Bismark Strait from surveys in 2009 reported by Johnston et al. (2012) and to the density of 0.1 individuals.km^{-2} estimated by Secchi et al. (2011) from surveys of the Bransfield Strait in 2006. Herr et al. (2016) reported slightly, but not significantly, lower densities of 0.06 individuals.km^{-2} from surveys in the Bransfield Strait in 2013.

Apart from an area on the south coast at the western end of the island, the data suggest that high densities of humpback whales may occur anywhere on the shelf. Hence from the perspective of ship strike risk it would be appropriate to instigate any measures throughout the shelf waters.

Experienced researchers on the 2020 survey estimated that many of the humpback whales observed near SG/GS were small juveniles that may have only recently left their mothers. Globally, juvenile whales appear to be more vulnerable to ship strikes (Laist et al. 2001), possibly due to lack of experience. This suggests a potentially higher risk around SG/GS due to the high proportion of young whales. The whale that was involved in the collision with MV Braveheart was judged to be a small juvenile.

Using a similar encounter rate approach, with an adjustment applied for the probability of mortality as a function of speed based on Conn and Silber (2013) and also assuming no whale or vessel avoidance response, Rockwood et al. (2017) estimated a ship strike mortality of 48 humpback whale-vessel encounters for the entire US west coast. The equivalent estimate for SG/GS in 2020 was 28, so over half of the equivalent risk for the whole US west coast. Some measures have been taken to reduce ship strike risks along the US west coast but Rockwood et al. (2017) suggest that further measures are needed. Thus, in a global context, SG/GS would be considered a high risk area based on the situation in 2020.

Guzman et al (2020) highlight the ship strike risk to humpback whales in the Magellan Strait and recommend a 10-knot speed restriction during the five months of maximum whale abundance, applying to all merchant vessels traveling through the Strait. They estimate risk based on telemetry data which is difficult to compare directly to whale densities derived from surveys. However they estimate the average exposure of a humpback whale in the Magellan Strait to be one ship within the same 1 km grid square as the whale just over once a month. Based on conversion factors to estimate distance travelled from number of transits (Leaper and Panigada, 2011), this would be equivalent to an average total shipping density at each whale over a five month period of 4.5 km^{-1}. Around 50 (13%) of humpback whale sighting locations at SG/GS in 2020 were exposed to shipping densities in excess of this.

Cruise vessels visiting SG/GS generally have a number of specific locations along the north coast that they wish to visit. These are apparent from the AIS tracks into various bays in Figures 11 and 12. This pattern of activity could not easily be modified to reduce risk through alternative routes. However, slower speeds have been shown to effectively reduce risk (Conn and Silber, 2013; IWC, 2016) with a 10 knots speed restriction being the most commonly accepted speed limit that reduces collision risk to acceptable levels (Laist et al. 2014). Slower speeds can also have other environmental benefits of lower emissions and reduced underwater noise (Leaper, 2019). At present about 35% of the distance travelled by cruise ships on the SG/GS shelf is at speeds less than 10 knots. This suggests that it may be possible to limit all speeds to less than 10 knots without huge inconvenience to schedules through careful voyage planning. The long daylight hours during summer allow for greater flexibility in schedules than may be available in other areas. Although we have not been able to quantify the ship strike risk during winter, satellite telemetry data do indicate whales using the SG/GS area in winter and hence there is a need for more data on winter whale numbers and distribution.

It remains to be seen whether the high numbers of whales observed in summer in 2019 and 2020 continue, but the increase in both whale numbers and ship traffic suggest that measures to reduce collision risk would be timely and appropriate in order to meet the objectives of the South Georgia and South Sandwich Islands Marine Protected Area and IAATO.

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