ICEBERG A-68A

Assessing effects of iceberg A-68a on the Weddell Sea and South Georgia ecosystems

Master's Essay
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Abstract

On the 12th of July 2017 the large iceberg A-68a broke free from the Larsen C ice shelf located on the eastern side of the Antarctic Peninsula. In the past three years it travelled northwards towards the island of South Georgia, where it is currently located on the western side of the island. Due to the immense size of the iceberg, A-68a might have a big impact on the pelagic, benthic and coastal ecosystem surrounding the iceberg and South Georgia, dependent on its path and risk of getting stuck on the continental shelf of South Georgia. The aim of this essay was to find out what the effects are that the iceberg already had on the ecosystem of the Weddell Sea. And related to that, what is the effect of iceberg A-68a on the ecosystem around South Georgia? On the journey northwards the iceberg probably opened up new opportunities for benthic and pelagic organisms that are situated at the Antarctic Peninsula. In the open ocean, the iceberg created a biodiversity hotspot as it enhanced primary production thus leading to more zooplankton which benefits higher trophic levels. The effects of the iceberg on the ecosystem of South Georgia are debatable. The iceberg will probably have a positive effect on the pelagic system due to the increased stratification of the mixed layer. There is the probability of the iceberg significantly harming the benthic community due to ice scour. The iceberg might also block foraging routes and foraging areas for mobile foragers. The impact on these species might be less significant as they are used to travel long distances to find food and the iceberg also creates a new foraging habitat. However, the impact of the iceberg on the ecosystem of South Georgia seems to be dependent on how long it will stay in a certain area and how fast it melts. Breakage of the iceberg might make each of the effects less significant as it is less concentrated in a certain area.

Introduction

Antarctica is known for the extensive amounts of ice that can be found on this continent (Jacobs et al., 1992). There seems to be a natural balance for the amount of ice that is being accumulated and lost, the latter either by calving processes or melting (Jacobs et al., 1992). Calving seems to be the process that leads to the most loss of ice mass on the Antarctic continent (Jacobs et al., 1992). Calving is the process in which a block of ice breaks up from the glacier (Marshak, 2009). The iceberg that is formed in this way has a partly predictable route as it is influenced by e.g. ocean currents and gyres (T. Scambos et al., 2017). Icebergs that calve on the eastern side of the Antarctic Peninsula often move in a clockwise trend after which they follow a path in north-eastern direction through the Weddell Sea and Scotia Sea towards the island of South Georgia. Most larger icebergs pass the island on its south-eastern side (T. Scambos et al., 2017).

The origin of A-68a

Even though calving is thought to be a natural occurring process, it is believed that calving events leading to bigger icebergs might also be the result of a warming climate (A. E. Hogg & Gudmundsson, 2017). One such an iceberg is the iceberg called A-68 (CNN, 2017; A. E. Hogg & Gudmundsson, 2017). It broke off from the Larsen C Ice Shelf, the largest ice shelf of the Antarctic Peninsula present yet, on the 12th of July 2017. The created iceberg had at that time a total surface of 6.000 km^2, which makes it fall in the category of biggest icebergs ever noted (Amos, 2017; A. E. Hogg & Gudmundsson, 2017).

Through the years

Over the course of the last three years the iceberg moved northwards along the eastern coast of the Antarctic Peninsula after which it floated in the Weddell Sea towards the island of South Georgia. Over the years A-68 lost multiple pieces of ice, named A-68b and A-68c (Gibbens, 2020). The iceberg already lost a lot of its mass due to increasing melt rates on its path northwards (T. Scambos et al., 2017). As of the 17th of December, what is left of this iceberg, A-68a, is located on the western side of South Georgia (European Space Agency (ESA), 2020). The remainder of the iceberg is only a third of the original mass, when it broke free from the Larsen C Ice Shelf, and extends downwards up to 200 meters (Amos, 2017; European Space Agency (ESA), 2020; Gibbens, 2020). The path of the iceberg is shown in figure 1.

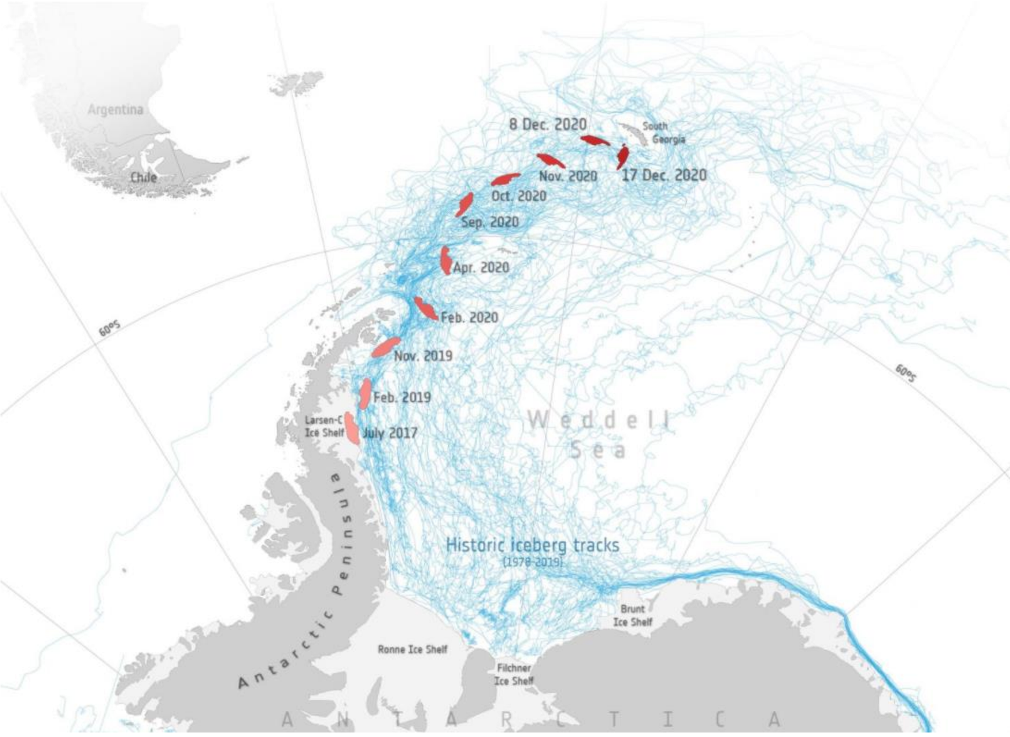

Figure 1. A map with the path of iceberg A-68a from 2017 until the 17th of December 2020. The map also contains the tracks of former icebergs, which shows that A-68a is following this trajectory (European Space Agency (ESA), 2020).

South Georgia

South Georgia belongs to the subantarctic islands, and is the most northly positioned of all of them. The island is immensely secluded with the nearest land point not within 1000 km. The closest point of the Antarctic continent, positioned southwest of the island, is still more than 1500 km away, be it in the absence of winter sea ice (Clarke et al., 2012; Zwally et al., 2002). The island is positioned in the zone of the Antarctic Circumpolar Current, which is characterised by waters that range between 0 and 4 degrees. On the north-eastern side of the island, this current meets the colder waters of the Weddell sea which creates productive waters, of significance to South Georgia's wildlife (Clarke et al., 2012). The ocean around South Georgia does not fall into the category of High Nutrient Low Chlorophyll waters, which is extraordinary (Atkinson et al., 2001). The waters around South Georgia are characterised by a high primary productivity with numerous phytoplankton blooms, a high zooplankton abundance as waters are rich in krill, loads of fish and squid and numerous marine mammal species (Atkinson et al., 2001; Clarke et al., 2012; Trathan et al., 2014). The island is known for the countless bird species that nest here (Clarke et al., 2012). Figure 2 shows the island of South Georgia and its oceanographic location in relation to Antarctica.

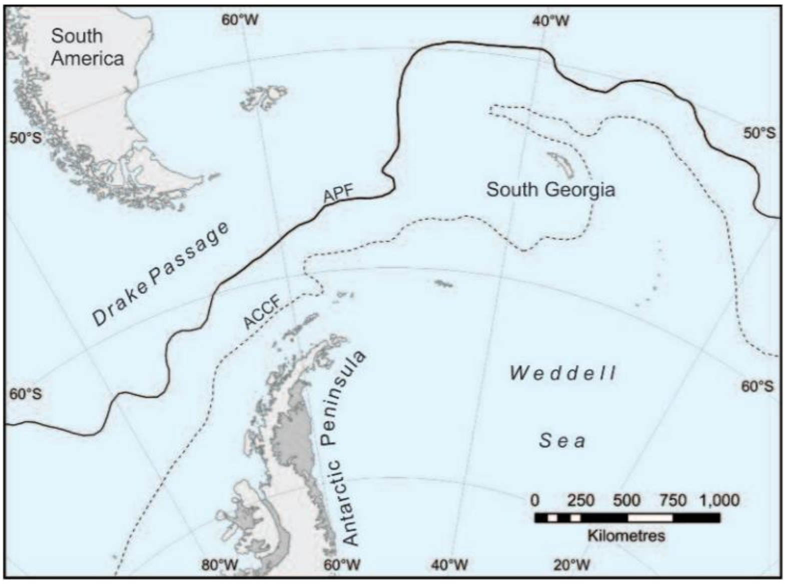

Figure 2. A map with the oceanographic location of South Georgia. South Georgia is north-easterly positioned compared to the Antarctic Peninsula. The map also shows the Antarctic Circumpolar Current Front (ACCF) in which it lies, the Weddell Sea to the south of the island and the Antarctic Polar Front (APF) north of the island (Clarke et al., 2012).

Research Question

Iceberg A-68a is closing in on South Georgia on the western side of the island or might even move towards the eastern side of the island as its path is still uncertain. A-68a might have a big impact on the pelagic, benthic and coastal ecosystem surrounding the iceberg and South Georgia dependent on its path and risk of getting stuck on the continental shelf of South Georgia (Gibbens, 2020). The following research question is formulated: What are the effects iceberg A-68a already had on the ecosystem of the Weddell Sea? And the sub question: What is the effect of iceberg A-68a on the ecosystem around South Georgia?

In the first part of the essay, the possible effects of the iceberg on its journey northwards will be discussed. These possible effects are based on literature about past iceberg events. Further, the possible effects of the iceberg on the ecosystem of South Georgia are based on the biodiversity present at South Georgia.

A-68a and its impact the last three years

Impact on and close to the Antarctic Peninsula – pelagic system

In the two years the iceberg did not move much, A-68a might have had a negative influence on the ecosystem surrounding the iceberg. The calving of iceberg C-19 off the Ross Ice Shelf in 2002 resulted in local declines in primary production due to an increase in sea ice cover (Arrigo & Dijken, 2003). C-19 was about the same size as A-68a when it broke away from the Larsen C ice shelf. Iceberg C-19 had a width of more than 30 km and a length of 200 km, exceeding that of A-68a, with a length of 150 km (Arrigo & Dijken, 2003; Gibbens, 2020). This increase in sea ice cover visible at the break away of C-19 was the result of the iceberg blocking the passage of sea ice towards the open ocean. In this way there was less open water area available during spring and summer for phytoplankton blooms and also the period of the blooms was diminished. The impact of the calving event was not only visible in the lowest trophic levels, but cascaded to higher trophic levels, as they are dependent on the lower trophic levels (Arrigo & Dijken, 2003). A similar situation could have been the case for the period between July 2017 and November 2019 as A-68a did not move much. A-68a might have also resulted in the blockage of sea-ice towards the Weddell Sea. Locally this might have also led to lower phytoplankton productivity which then also impacted the higher trophic levels as stated above.

However, due to the collapse of the ice shelf, locally new areas of open ocean were formed in summer, creating possible new opportunities for primary producers (Peck et al., 2010). The study by Peck et al. already showed that the loss of sea ice led to the formation of new phytoplankton blooms. This then generated new zooplankton and seabed communities. Similarly, due to the breakage of iceberg A-68a from the Larsen C ice shelf, new opportunities have possibly arisen for the local biodiversity of the ecosystem. The breakage of the iceberg might have made an area of about 6000 km^2 available for new productivity opportunities in the summer as it drifted to open ocean. Due to a possible increase in primary production, which is then impacting the higher trophic levels, an extra carbon sink is potentially generated on the eastern side of the Antarctic peninsula (Peck et al., 2010). There is much reason to believe that phytoplankton productivity at the calving site of A-68a increased substantially as this has already been observed for the decaying Larsen A and B ice shelves (Fillinger et al., 2013). At the time, the Larsen A and B ice shelf lost respectively an area of 4200 km^2 and 3320 km^2, which is considerable less than the Larsen C ice shelf (Rott et al., 1996; Ted Scambos et al., 2003).

Impact on the Antarctic Peninsula – benthic system

The benthic community might have or will respond to this increase in primary production. Some benthic species might respond rapidly to the new opened up habitat due to the loss of the iceberg, such as glass sponges have done as a result of the loss of ice shelves Larsen A and B (Fillinger et al., 2013). The fast response of the glass sponges to the decaying ice shelves shows that the Antarctic benthic community present at the Larsen C ice shelf might also react in a similar way (Fillinger et al., 2013).

The Antarctic benthos present at the Larsen C ice shelf might have also been impacted in a different way. In the first two years after calving the iceberg did not move much, which might mean it was stuck on the seafloor (Gibbens, 2020). There is reason to believe this to have happened as the bed elevation at the Larsen C ice shelf varies between 0 and -1000 m (Brisbourne et al., 2020). From the moment iceberg A-68a broke free from the ice shelf until it reached open ocean, it might have scoured the seafloor at the Antarctic shelf, leading to the local destruction of the seabed community, which might not have recovered yet. Ice scouring is known to have an effect on the benthic community present on the seafloor as it leads to the loss or damage of Antarctic benthos (Dunlop et al., 2014). The impact of ice scour can become very significant as it is known that the Antarctic benthos recover at slow rates. The colonisation and recruitment of a certain area and the growth take considerable time, compared to lower latitudes. Brown et al. suggested that scouring events might even lead to a high abundance of mobile scavengers that benefit from the organisms that have been killed during the scouring process (Brown et al., 2004).

Impact as a free drifting iceberg

On its path northwards the iceberg might also have had a significant influence on the waters surrounding it. Free drifting icebergs are often viewed as ecosystems themselves as they affect the surface waters around them (Smith et al., 2007; Maria Vernet et al., 2012). On its journey northwards A-68a already lost some mass, which was also predictable as the study by Scambos et al. (2017) showed there was a rapid loss of ice mass as soon as icebergs entered the open ocean (European Space Agency (ESA), 2020; T. Scambos et al., 2017). On the journey northwards, A-68a probably encountered increasing melt rates (T. Scambos et al., 2017). In the surface ocean surrounding icebergs, meltwater results in a lower salinity and a locally higher amount of terrigenous material deposited in the water that is in close proximity to the iceberg. Further away from the iceberg, this effect is diminishing (Smith et al., 2007). Nonetheless, meltwater was detected up to 19 km away from iceberg C-18a, with a significantly smaller surface area of 250 km^2 and remained visible for a minimum of ten days, which shows the impact of A-68a on surrounding waters to have possibly been substantial (Hobson et al., 2011; Maria Vernet et al., 2012). The terrigenous particles that are released with the melting of the iceberg are a source of iron to the surrounding waters (Smith et al., 2007, 2013). Meltwater is released into the environment by multiple processes such as basal melting and sidewall melting. As meltwater spreads horizontally, the surface waters are far more enriched with e.g. iron compared to turbulent mixing (Smith et al., 2013). The study by Smith et al. (2007) showed that both the waters surrounding icebergs W-86 and A-52, respectively with a surface area of 0.12 and 300.8 km^2, showed increased amounts of dissolved iron that was detected up to 5 km away. The iron enrichment is mostly visible in the mixed surface layer where there is also a lower salinity present (Maria Vernet et al., 2012). The enrichment of iron to the surrounding waters is a potential source for enhanced phytoplankton growth and can lead to a change in the composition of primary producers, with the most beneficial phytoplankton group being diatoms. Phytoplankton growth might also be stimulated as the input of freshwater results in the upwelling of nutrients such as nitrate and silicate from the deeper water layers (Cefarelli et al., 2011; Smith et al., 2007, 2013). The meltwater that is released into the surrounding saltier water also stabilizes the water column due to the input of fresh water. This leads to a decrease in the mixed layer depth which brings the phytoplankton closer to the surface. This results in an increasing amount of light that comes available to the phytoplankton. Due to this increase in light availability, the phytoplankton growth and bloom formation are stimulated (Rozema et al., 2017; Venables et al., 2013). This might also lead to a shift towards phytoplankton species that thrive well under high irradiance conditions, such as diatom species that are either 20 µm or bigger (Clarke et al., 2008; Rozema et al., 2017; van de Poll et al., 2009)

Often found microzooplankton and micronekton in close proximity to the iceberg consist of Antarctic krill *(Euphausia superba)* and salps *(Salpa thompsoni)* and together can make up to 90% of the community (Kaufmann et al., 2011; Smith et al., 2013). The study by Smith et al. even found there to be twice the amount of zooplankton and micronekton under the iceberg compared to surrounding waters (Smith et al., 2013). The study by Vernet et al. showed a high abundance of krill and salps to be present up to 2 km surrounding iceberg C-18a (M. Vernet et al., 2011). Due to the high productivity and high zooplankton biomass lots of seabirds are attracted to icebergs as was shown in the study by Ruhl et al. (2011). Seabirds were more abundant compared to penguins, whales and seals (Ruhl et al., 2011; Smith et al., 2013). However, chinstrap penguins *(Pygoscelis antarcticus*) and Antarctic fur seals *(Arctocephalus gazella)* are known to be related to icebergs as well (Joiris, 1991; Ribic et al., 1991; Smith et al., 2013). The influence of a free-floating iceberg on the ecosystem surrounding it can be substantial as the impact reaches up to e.g. 19 km away, up to 1500 meters of depth and holds on for up to two weeks in the wake of the iceberg (Smith et al., 2013; Maria Vernet et al., 2012). Figure 3 shows the processes that are related to free floating icebergs in the north western part of the Weddell Sea. Due to the different processes that are enhanced in close proximity to the iceberg, icebergs are known to increase carbon export e.g. twice in surrounding waters compared to waters without icebergs as was seen with iceberg C-18a (Smith et al., 2007, 2011; Maria Vernet et al., 2012).

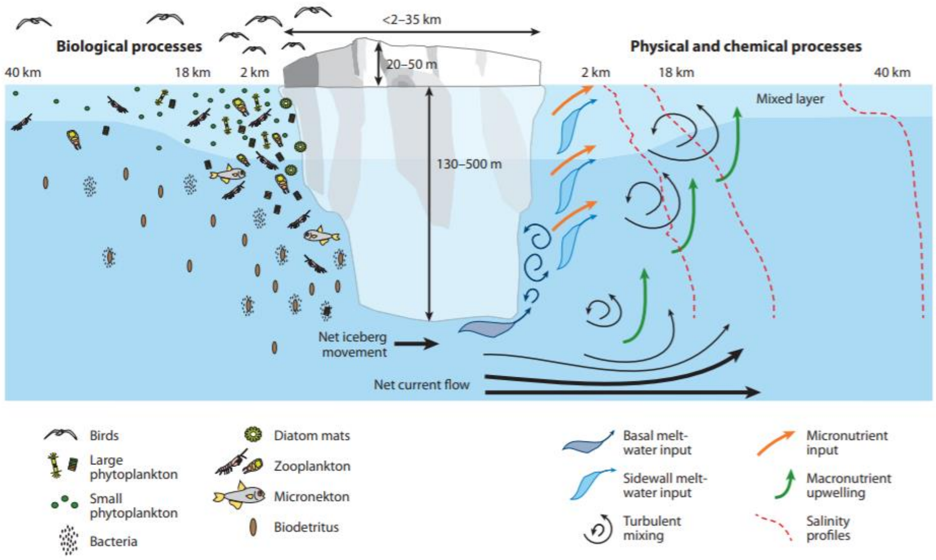

Figure 3. Physical, chemical and biological processes related to free floating icebergs in the northwest Weddell Sea (Smith et al., 2013).

A-68a and its possible impact on the island of South Georgia

On January the 11th , iceberg A-68a was still located on the western side of the island of South Georgia (BAS Press Office, 2021; European Space Agency (ESA), 2020). However, pieces of the iceberg have been breaking off and moved in a more south-eastern direction before turning north (BAS Press Office, 2021). The remaining part of A-68a might also move in this direction as Scambos et al. (2017) already mentioned.

The impact on the South Georgia ecosystem depends on the future path of A-68a. Figure 4 shows the route of A-68a over the past few months. It is clearly visible that the iceberg was closing in on South Georgia on the western side and continued its journey towards the south-eastern part of the island, after which it might move northwards. For this reason the ecosystem of South Georgia is discussed below.

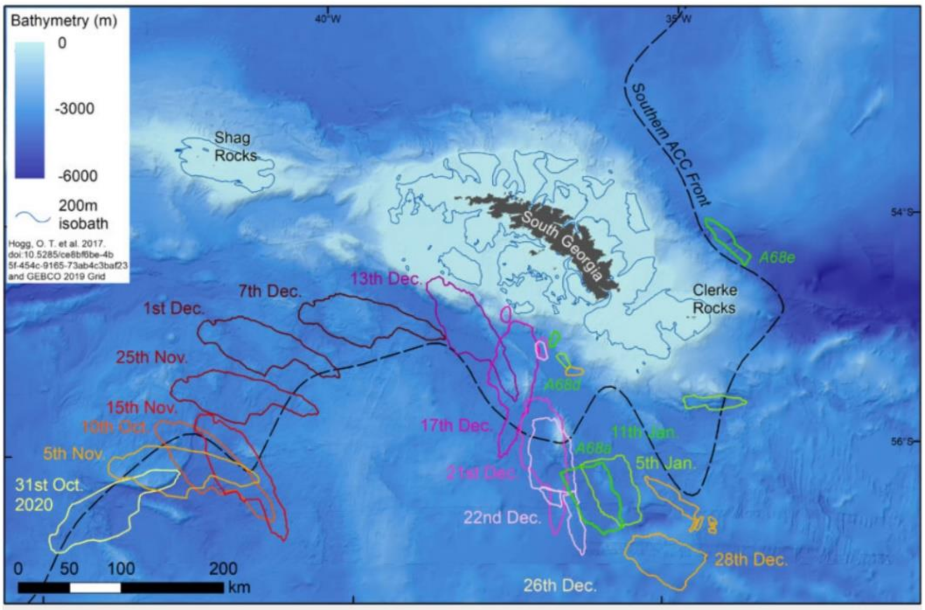

Figure 4. Route of iceberg A-68a tracked over the past few months. The map also shows the depth profile close to South Georgia (BAS Press Office, 2021).

Impact on South Georgia – benthic system

On the western side of the island, the iceberg might have already had an impact on the benthic community present at the continental shelves of South Georgia as there is the potential that the iceberg scoured the seabed at this side of the island. The seafloor on the shelf around South Georgia often consists of coral reefs and sponges with related benthos (Benedet, 2017). The benthic community present at South Georgia consist of native and range-edge species, resulting in a high species richness that is Antarctic in nature (D. Barnes et al., 2006; O. T. Hogg et al., 2011; Trathan et al., 2014). A lot of species seem to be at their thermal tolerance constraint (Trathan et al., 2014). The study by Hogg et al. suggested that from 700 m and upwards the shelf is among the richest in species compared to other parts in the Southern Ocean (O. T. Hogg et al., 2011). Almost half of all the benthos present there is native to the area, which clearly shows the significance of this community (O. T. Hogg et al., 2011). The benthos at South Georgia are very diverse, comprising of 22 different phyla in which the chordates and crustaceans were the most represented of all (O. T. Hogg et al., 2011). The study by Barnes et al. showed the shallower benthic fauna consisted of e.g. flatworms, bivalve and gastropod molluscs, amphipod and isopod crustaceans and e.g. echinoderms (D. Barnes et al., 2006). It is known that the benthic fauna present at these latitudes take a considerable time to grow and recover which makes them vulnerable to disturbance, e.g. from ice scour from A-68a (Brown et al., 2004; Trathan et al., 2014).

Impact on South Georgia – pelagic system

The iceberg might not only affect the benthic environment, but might also have a big impact on the pelagic ecosystem in the waters around South Georgia. As mentioned before, the presence of an iceberg can have a big impact on the surrounding waters due to the enrichment of the waters with iron (Smith et al., 2007, 2013). With the iceberg present on the western side of the island, this might mean the waters on this side of the island to be enriched in iron due to the meltwater, possibly leading to a different composition of phytoplankton. The phytoplankton present in the waters surrounding South Georgia mainly consist of diatom species however the enrichment of iron and increased macronutrients might favour diatoms of bigger size classes(Cefarelli et al., 2011; Korb et al., 2008; Smith et al., 2007, 2013). Even with the iceberg stuck on the western side, potential breakage of ice from the big iceberg which in turn moves towards other sides of the island, might lead to enhancement of the local waters with iron and macronutrients at those parts of the coastal waters. The addition of more iron and macronutrients to the environment might also lead to more productive and longer phytoplankton blooms, which in turn can lead to more krill present, which is the food source for many predators present on the island or in surrounding waters (Kaufmann et al., 2011; Reilly et al., 2004; Smith et al., 2013). However, it is also known that the waters surrounding South Georgia do not fall in the category of the High Nutrient Low Chlorophyl waters typical for the Southern Ocean as there are many blooms in the waters surrounding South Georgia (Atkinson et al., 2001). This might mean that the positive effect portrayed for the pelagic ecosystem might be less pronounced. If indeed, the phytoplankton community here was never limited by iron, the additional iron and macronutrients will probably not make much of a difference. However, it remains important to mention that the effect of the meltwater on the water column most likely will be visible. The input of meltwater in the waters surrounding South Georgia might still lead to an increase in primary productivity due to the stratification of the water column. As a result of the stratification, the phytoplankton are exposed to a higher irradiance and combined with an increase in nutrients, such as nitrate and silicate due to upwelling, this can increase productivity (Rozema et al., 2017; Smith et al., 2013; Venables et al., 2013). Even so, the iceberg can also have a negative effect on the pelagic ecosystem.

Due to the presence of iceberg A-68a on the western side of the island, a large area of water becomes unavailable to phytoplankton. Due to the large surface of the iceberg, the light that is available to the phytoplankton will be lower under the iceberg (Arrigo et al., 2002). This might result in a decrease in phytoplankton growth and diminishes the phytoplankton growing season on this side of the island leading to a delay in blooms or even lead to the absence of blooms (Arrigo et al., 2002; Arrigo & Dijken, 2003). The possibility of this negative influence on the pelagic ecosystem is not far-fetched, as the study by Arrigo & Dijken showed that increased amounts of sea ice in the Ross Sea led to significant lower rates of primary productivity due to a lower surface of open water present to the phytoplankton community. This might lead to a decrease in zooplankton, in turn also affecting trophic levels above, such as krill eating species, like bird species and seals (Arrigo et al., 2002; Arrigo & Dijken, 2003; Trathan et al., 2014). In the case that the iceberg is either stuck on the western side of the island, or gets stuck on its journey on the eastern side of the island, the iceberg might significantly lower the local primary production, negatively impacting the trophic levels above.

The potential stall of the iceberg on either side of the island might also impact the food web in a different way. It is known that the krill present in the waters surrounding South Georgia do not originate here. There is a flow of krill from the western Weddell Sea, into the Scotia Sea towards South Georgia (Murphy et al., 1998). Most of the krill is transported along the coast of South Georgia on the south eastern end of the island (Murphy et al., 1998). There is also a pathway that leads the krill to pass the island on the northern side (Murphy et al., 1998). The iceberg might on either side partly block the delivery of krill to the waters surrounding South Georgia, resulting in krill delivered to other places. The potential decrease in krill present due to diverted advection, will probably have a negative effect on the krill eating species that are present on the island or in the surrounding waters, such as seals, penguins, other seabirds, fish and squid (Trathan et al., 2014).

Impact on South Georgia – foraging opportunities for penguins, birds, seals and whales

The presence of A-68a on either side of the island might impact the ecosystem of South Georgia in yet another way. The big iceberg might block certain foraging areas or foraging routes of wildlife living at South Georgia or wildlife present in the surrounding waters. South Georgia is known to house multiple seabird species that are abundant at this island (Clarke et al., 2012). There are four species of penguins that breed at South Georgia, the first being the king penguin *(Aptenodytes patagonicus)* with all the colonies present on the eastern side of the island (Clarke et al., 2012). The study by Scheffer et al. showed that the king penguins present at South Georgia all travelled northwards towards the Southern Antarctic Circumpolar Current Zone (SACCZ), Antarctic Zone (AAZ) and Polar Front waters to find food, which mainly consists of myctophids (Cherel & Ridoux, 1992; Scheffer et al., 2012). The gentoo penguin *(Pygoscelis papua)*, macaroni penguin *(Eudyptes chrysolophus)* and chinstrap penguin are also known to breed on this island. The macaroni penguin has the largest colonies on the north coast of the island, the chinstrap penguin on the south eastern coast and the gentoo penguin has colonies all around the coast (Clarke et al., 2012). All three predate on krill (Boyd et al., 2002; Clarke et al., 2012; Rombola et al., 2010). Similar to king penguins, macaroni penguins also forage in the waters north of South Georgia (Ke Barlow & Croxall, 2002). Other seabirds that are associated with the island are e.g. multiple species of albatross, petrels and prions (Clarke et al., 2012). South Georgia is of great importance for multiple seabirds as it is for numerous species one of the most important or the most important breeding site (Clarke et al., 2012). The island is also home to the Antarctic fur seal and the southern elephant seal *(Mirounga leonine).* Populations of Antarctic fur seals can be found on the north western side of the island (Clarke et al., 2012). Antarctic fur seals are known to travel up to more than a 1000 km either in north western direction towards the eastern part of Patagonian Shelf or in south-westerly direction towards the northern part of the Antarctic to forage. Antarctic fur seals are known to predate on zooplankton like krill (Boyd et al., 2002). Southern Elephant Seals have multiple populations across the whole coast of the island and comprise together of more than 300.000 individuals, which is substantial (McCann & Rothery, 1988; McConnell et al., 1992). The study by McConnell showed that southern elephant seals originating from South Georgia swam up to 2650 km in south-westerly direction towards the Antarctic Peninsula to forage there (McConnell et al., 1992). Southern elephant seals mainly predate upon fish and squid species (Boyd et al., 1994). The waters surrounding the island also have multiple baleen whale species that visit the area to feed on krill, such as right whales *(Eubalaena australis)*, minke whales *(Balaenoptera bonaerensis)*, fin whales *(B. physalus)* and humpback whales *(Megaptera novaengliae)* (Reilly et al., 2004). In the study by Reilly et al. most of the right whales were found in the waters north of South Georgia. Minke and fin whales were abundant in the waters surrounding the island but also in the Scotia Sea closer to the Antarctic Peninsula. Humpback whales were also sighted closer to the island but were mainly found on the north western part of the Scotia Sea (Reilly et al., 2004).

Dependent on where the iceberg is headed it might partly block foraging routes and foraging areas for penguin species, seals or whales. If A-68a remains on the western side of the island it might block foraging routes for the Antarctic fur seals and southern elephant seals that are present on the island of South Georgia. This might mean that the seals are restricted to foraging areas closer to home which might make them compete for prey with seabirds, whales and each other (Kate Barlow et al., 2002; Trathan et al., 2014). It might also mean that they have to swim around the iceberg to reach foraging sites further away, which can lead to more energy loss to foraging (McConnell et al., 1992). The whales that feed on this side of the island might either be positively or negatively affected, as part of their feeding habitat is possibly lost or a new one is created by the iceberg. If the iceberg moves towards the eastern side of the island this might mean king penguins and macaroni penguins to be more heavily affected as they might be potentially blocked trying to reach foraging areas north of the island.

Discussion and conclusion

For this essay, the following research question was proposed: What are the effects iceberg A-68a already had on the ecosystem of the Weddell Sea? And the sub question: What is the effect of iceberg A-68a on the ecosystem around South Georgia?

A-68a might have already had a significant impact on the ecosystem surrounding the shelf of the Antarctic Peninsula as the iceberg possibly created the opportunity for certain benthic species to colonize the shelf as was shown by Brown et al. (2004). However, this is dependent on the chance that there was ice scouring present. A-68a might not have been close enough to the shelf to have scoured the seabed as the map by the European Space Agency (ESA) (2020) possibly indicates and the seabed to possibly be located at a depth of 1000 m which was shown by Brisbourne et al. (2020). Nonetheless, the fact that the iceberg did not move much in two years makes the possibility of ice-scour more likely. Even if, the effects of potential ice scour on the benthic community are also dependent on the type of substrate and benthic species that have been in contact with the iceberg.

On top of that, the magnitude and rate of the scouring incident also influence the overall state of the seafloor (Brown et al., 2004). This shows that it is hard to quantify the precise impact on the benthos present at the Antarctic Shelf. Even so, the breakage of the iceberg probably did lead to an increase in fast responding benthos species, such as glass sponges as was the case in the study by Fillinger et al. (2013).

The iceberg presumably first reduced phytoplankton growth due to the potential ice blockage, thus light availability, as was shown by Arrigo & Dijken (2003). Nonetheless, this negative impact was likely counterbalanced as phytoplankton growth was probably stimulated from the moment the iceberg moved away as a result of more open water that came available as was also mentioned by Peck et al. (2010). Again, this makes it hard to correctly assess the impact of the iceberg on the pelagic ecosystem surrounding the Antarctic Peninsula.

A-68a presumably created local biodiversity hotspots along the way due to enhanced primary production, resulting in an increase in krill and salps. This likely created an extra foraging habitat for higher trophic levels and might have led to an increase in carbon export. This effect was the result of multiple studies on effects of icebergs, however it remains important to mention that the impact of the iceberg might be different with different size classes, which is why there is a lot of speculation. Due to the immense size of A-68a, the effects of the iceberg on its environment are probably more significant compared to the smaller icebergs discussed above leading to a bigger area with an enhanced productivity.

It is clearly visible that the effect of iceberg A-68a on the island of South Georgia is debatable. During the time the iceberg was present on the western side of the island or in the future when closer to the island, the iceberg might have had or have a negative impact on the benthic community present there as the scouring of the seabed leads to the local destruction of this community, which can be significant. Hogg et al. (2011) showed that most of the benthic species richness can be found on the north-eastern side of the island, which might make the effect of ice scour on the western side less significant. In fact, even though ice scouring can locally have a catastrophic impact, ice scouring also promotes regional biodiversity as this process creates possibilities for new species (D. K. A. Barnes et al., 2018; Gutt, 2001). The seafloor will consist of areas in different succession stadia due to different events of scouring, which leads to different species occupying these patches, leading to a higher biodiversity (D. K. A. Barnes et al., 2018; Gutt, 2001). As mentioned before, ice scouring might also lure motile hunters that predate on organisms that were killed as a result of the ice scouring (Brown et al., 2004). Even though the impact of the ice scouring event might be less significant than earlier predicted, it might be of significance if the iceberg moves towards the south-eastern side of the island and then northwards (O. T. Hogg et al., 2011). This side of the island harbours substantially more diverse benthic communities that will likely be negatively affected, some of which endemic to this place.

The iceberg might have some positive and negative effects on the pelagic ecosystem and therefore on higher trophic levels. Even though the waters will probably not benefit from the iron and macronutrient enrichment, it is important to mention that the stratification of the mixed layer likely positively affects the phytoplankton by increased light availability and thus still increases primary productivity. The input of meltwater also brings nutrients like silicate and nitrate to the surface. A study by Borrione & Schlitzer showed that the waters surrounding South Georgia might be low in silicate (Borrione & Schlitzer, 2013). Due to the presence of the iceberg, diatom growth will probably be stimulated due to the increased amount of silicate in the surrounding waters. Due to the blockage of light at the location of the iceberg the primary productivity will probably be non-existent below the iceberg, however will be enhanced in the surrounding waters. The enhanced primary productivity leads to more krill present in the surrounding waters. This shows that the presence of A-68a can have a probable positive effect on the food web of the ecosystem of South Georgia with way more food available. A possible increase in krill available might open up new foraging areas on either side of the island for krill eating predators e.g. seabirds, penguins, seals and whales (Barlow et al., 2002; Trathan et al., 2014). The possible new foraging areas might also counteract the possible negative effect of diverted advection caused by the presence of the iceberg. Due to the diverted advection, one would expect the waters surrounding South Georgia to be lower in krill, possibly substantially impacting the higher trophic levels. However, this might not be the case due to the enhanced primary production surrounding the iceberg.

The potential blockage of foraging routes and areas and thus lowered krill available might put pressure on the wildlife present at South Georgia. Krill eating predators might be competing more with each other. The species that often forage further away from the island have to find new feeding grounds, closer to the island, or swim an additional distance to be able to reach the foraging areas. Dependent on the position of the iceberg, the effect on the wildlife might be different. If the iceberg remains on the western side of the island, the seals are presumably blocked from foraging areas further away. The whales that use these waters are likely positively affected as they benefit from the locally enhanced productivity. The study by Reilly et al. (2004) also showed that the whales feed in the whole Scotia Sea, so will probably simply move towards other feeding grounds. If the iceberg moves towards the eastern side of the island, which can be expected for an iceberg of this size, the king penguin and macaroni penguin might be affected more (T. Scambos et al., 2017). However it remains important to take in consideration that the presence of the iceberg, wherever located, also creates new foraging opportunities with a higher abundance of krill in the surrounding waters as was shown by Smith et al. (2013) and Kaufmann et al. (2011).

The impact of the iceberg might be less substantial as with time the iceberg melts more of its mass away potentially leading to the breakage of the iceberg in multiple sections, which is already shown to have happened recently (BAS Press Office, 2021; T. Scambos et al., 2017). Due to these smaller sections, the different effects might be less concentrated in certain places. The effects on the pelagic system might be less negative as more water comes available to the phytoplankton and routes for krill might become less blocked. The impact of ice scour on the benthic community can still be substantial but can also be less significant due to the breakage of the iceberg. On top, even though the iceberg potentially blocks foraging routes and grounds for multiple species such as penguins and seals, these species are mobile species and are probably more flexible with finding food in other areas or just swim the extra miles.

A study by Neshyba & Josberger showed that with an increase in water temperature from 0 to 3 degrees, the sidewall melt rate increases from 0 towards 10 m per year (Neshyba & Josberger, 1980). As the waters of South Georgia range in temperature between 0 and 4 degrees, the melting process of the iceberg might be enhanced compared to closer to Antarctica. Even though the iceberg is only a third of its original mass, it is still immense which might mean that even with increasing melt rates, it takes a considerable time for the iceberg to be totally melted away, making its effects on the ecosystem of South Georgia possibly lasting for multiple years, if the iceberg does not continue its journey northwards.

To conclude, the iceberg likely had a mostly positive effect on the ecosystem surrounding the iceberg from the moment it broke free in 2017 until it reached South Georgia enhancing primary productivity, creating opportunities for benthos and generating new foraging opportunities. At South Georgia, it will probably have a positive effect on the pelagic system, negative effect on the benthic community and a debatable significant effect on higher trophic levels. Even though the island of South Georgia is of ecological importance to a lot of wildlife living here, the possible negative impact of the iceberg on this wildlife will be less disastrous than previously thought as new foraging opportunities are created. The impact on the ecosystem of South Georgia might be long lasting.

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