Diving patterns of air-breathing predators in Antarctica

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I have always been fascinated by the ocean, and becoming a "marine biologist" is a dream coming true.

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Abstract

Antarctic krill (*Euphausia superba*) is one of the most important species in the Southern Ocean, being critical in the food web. As a key species, it is subject to massive predation from both aquatic and avian predators, such as fish, birds, whales and penguins. Analysis of behaviour is important to assess the effect predation may have on the distribution and size of stocks. To analyse the diving behaviour of air-breathing predators, an echo sounder was deployed for one year near the South Orkney Islands. The data material collected shows both diving predators and distribution of krill, thus enabling addressing four hypotheses about the predators diving patterns: **1**. An increased concentration of sea ice will lead to a decrease of diving predators, **2.** Due to lower visibility during the night, the predation rate will decrease during the night, **3.** Diving activity will be closely related to the presence of krill, and **4.** During periods of parental care of offspring, predators will increase their foraging activity to provide enough food for their progeny. The results of the analysis show that the highest rates of diving predators occurred during austral summer, when there was little sea ice and the predators were taking care of their juveniles. Diving was also common without concurrent registrations of krill. Krill was present during the study period and do not explain why there is fluctuation in diving during the study year. The predators show a range of diving depths, from the surface and down to approximately 90-100meters. Diving normally occurred during the day, even though krill were somewhat shallower distributed during the night. This study shows that deployed echo sounders could be a powerful tool for long-term studies in otherwise inaccessible regions.

Abbreviations

AZFP	Acoustic zooplankton fish profiler
DVM	Diel vertical migration
IMR	Institute of Marine Research
POM	Particulate organic matter
S_A	Nautical area scattering coefficient ($m^2/n.mi^2$.)

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1. Introduction

1.1 The Antarctic peninsula

The water surrounding Antarctica is broadly called "the Southern Ocean", and within the Southern Ocean there are several bodies of water with different characteristics in terms of temperature, density and salinity (Shirihai, 2002). The Southern Ocean plays an important role in temperature regulation in the major oceans and the earth due to the mixing of deep – and surface water and deep water formation (Shirihai, 2002). Cooling and freezing make surface waters sink, while wind that moves water away from the continent transports surface water with it, thus making room for upwelling of deep, cold and nutrient-rich water to the surface (Shirihai, 2002). Waters surrounding the Antarctic peninsula are productive (Shirihai, 2002), creating favourable conditions for phytoplankton, zooplankton and marine mammals and birds. The productivity drops from April-July due to less light and sea ice. From August – October, the ice starts to melt, and the days get longer, resulting in increased productivity due to phytoplankton bloom, which will reach a peak in January (Shirihai, 2002).

1.2 Antarctic krill *(Euphausia superba)*

The Antarctic krill (*Euphausia superba)*, hereafter referred to as krill, serves a vital role in the Southern Ocean (Quetin et al., 2007), both as a grazer and as prey, and their distribution may impact the survival rate in many species.

Described in 1850, krill is the largest of the 86 Euphausiacea species in Superorder Eucarida crustaceans (Piepenburg and Siegel, 2016). They reach sexual maturity when females are approximately 35 mm long and males are 43 mm long (Piepenburg and Siegel, 2016), and they have a life-span of 5-7 years (Quetin et al., 2007). Krill start the reproductive cycle in spring, but the time of spawning depends on the maturation of oocyte (female gametocyte) and the lipid storage (Quetin et al., 2007). Maturation of reproductive organs such as oocytes depends on food supply. Krill thereby depends on a sufficient amount of food in the water column or ice algae living in the sea ice, to be able to develop mature oocyte and thus reproduce (Quetin et al., 2007). Light may trigger seasonal behaviour, such as the reproductive cycle (Piepenburg and Siegel, 2016). Ice algae are associated with ice-covered waters, while phytoplankton blooms are associated with melting ice. Such conditions give high food availability during early spring and early summer and can induce early gonadal development in the females (Piepenburg and Siegel, 2016). During the winter, seawater freezes to ice, and with it accumulates particulate organic matter (POM) (Quetin et al., 2007).

The quantity of POM available for consumption depends on the timing of the autumn phytoplankton bloom and ice formation. Winter is also characterized by darkness, thus leading to lower rates of primary production (Quetin et al., 2007).

As an endemic species to Antarctica, krill has a wide distribution, from shelf-slopes to the deep-ocean basin (Piepenburg and Siegel, 2016). In regions with high biological and physical variability, such as in the ocean south of the Polar Front, krill, herbivorous copepods and salps dominate as the main zooplankton (Piepenburg and Siegel, 2016).

Krill are usually aggregated in swarms, possibly as an antipredator behaviour, but they can also be dispersed (Hofmann et al., 2004). Diel vertical migration (DVM) can be present or non-existent (Gaten et al., 2008). Krill can inhabit the whole water column down to the bottom and have been found feeding at greater depths down to 3500m (Clarke and Tyler, 2008), but they usually occur in the upper 150 m and are considered to be an epipelagic species (Piepenburg and Siegel, 2016). However, the vertical distribution depends on geographic distribution, time of day and season.

1.3 The food web in the Southern Ocean

The food web in Antarctica is shorter than in other oceans (Shirihai, 2002), and predators forage low in the food web, meaning that higher biomass of large predators can be sustained on a given level of primary production.

Krill is the major component in many species' diet. This includes both endemic krill species to the Antarctic, and krill species that migrate to the southern oceans to feed. Marine mammals, such as Blue whale *(Balaenoptera musculus)* and Fin whale *(Balaenoptera physalus)* (Ratnarajah et al., 2014), seals e.g. Antarctic fur seal (Reid and Arnould, 1996), seabirds e.g. penguins (Chapman et al., 2010) and fish (Collins et al., 2007) are major predators that depend on the abundance of krill. The main focus of this thesis is to address the diving patterns of air-breathing predators, and this is done by using acoustic methods.

1.4 Acoustic studies

Low light levels at greater depths create a challenging environment for scientists to study behaviour and abundance of water-living organisms (Benoit-Bird and Lawson, 2016). However, sound is transferred as waves in water, and animals such as, e.g. whales use sound waves to communicate (Miller et al., 2000). There are mainly two ways to use sound as a method for research (1): passive acoustic – using a listening device, where reception of soundwaves is the only measurement and (2): active acoustic, where an echo sounder creates a pulse of sound waves. These waves will then travel through water, and when they meet an object, such as the bottom or an organism, will create a backscatter that the transducer will pick up (Benoit-Bird and Lawson, 2016). By calculating the speed of sound and the time delay from departure to arrival from the echo sounder, it is possible to measure the distance to the object, e.g. a krill swarm, responsible for the backscatter (Benoit-Bird and Lawson, 2016).

The use of autonomous echo sounders for studies of marine ecosystems is increasing as they can be deployed for longer periods of time. The advantages of such acoustic studies are high temporal (as in this study) and spatial resolution. It can give a picture of the abundance of different species, in some cases suggest the species composition and is used as a method to establish different behavioural patterns (Benoit-Bird and Lawson, 2016). With acoustical methods, we can identify different types of predators; for example, air-breathing predators that dive to catch prey or water-living predators that dwell in the depth.
Use of stationary echo sounders makes it possible to identify the movement of individuals in time and space and gives us an *in situ* picture of the behaviour of the organisms (Kaartvedt et al., 2009).

2. Objectives and hypothesis

This study aims to investigate the behaviour of air-breathing predators, hereafter referred to as diving predators, on krill and get a deeper understanding of the dive patterns. By using acoustic, this thesis will address predators that are foraging on krill throughout a full year and unveil information about the diving predators in the Antarctic marine ecosystem.

Depending on its concentration, sea ice can create impossible barriers to get through. During austral winter, the ice gets too thick for penetration, and it might force animals to migrate to open water to forage, thus leading to the first hypothesis:

1. **An increased concentration of sea ice will lead to a decrease of diving predators.**

Daylight creates an environment that is beneficial for the detection of prey among visual predators. Penguins are predominant predators on krill and known to rely heavily on their vision to find prey (Wilson et al., 1989), thus creating the second hypotheses:

2. **Due to lower visibility during the night, the predation rate will decrease during the night.**

Predation is an energy-costly affair, and efficient predation tactics are essential to get energy at a low cost. Prey-dense areas can create easy targets, and can also increase successful dives where the predator catches prey. Based on this, hypothesis three states:

3. **Diving activity will be closely related to the presence of krill.**

In periods with parental care, animals that do not lactate must collect enough energy for themselves as well as transferring enough energy for survival of their offspring. This creates the fourth and last hypothesis:

4. **During periods with parental care of offspring, predators will increase their foraging activity to provide enough food for their progeny.**

Penguins and seals are examples of diving predators, yet feed their offspring in different ways so that the last hypothesis would depend on the type of prevailing predators. The numbers of penguins outnumbered seals by a factor of ~15 among predators observed during deployment of the echo sounders (Skaret al., 2015). Also, based on the dive patterns observed in the current study, with diving predominantly occurring at daytime, penguins likely prevailed among the records presented here. Antarctic fur seals perform the majority of their dives during the night (Croxall et al., 1985), while species of penguins dive mostly during the day (Wilson et al., 1993). Species referred to in this thesis were either observed by the Institute of Marine Research (IMR) in the area at the initiation and/or termination of the study period, or are commonly found in the study area.

3. Material and methods

3.1 The area of study

The fieldwork was carried out by the Institute of Marine Research (IMR), during their "Antarctic krill and ecosystem monitoring survey at the South Orkney Islands in 2015" (Skaret et al., 2015). It was their fifth annual survey and aimed to look at the krill stock and how it differs from year to year. The study is important due to krill's prominent status in the food web, as a decrease in krill stock will presumably cause a negative bottom-up effect on rest for the ecosystem (Skaret et al., 2015).

During the expedition, an observer registered marine predators, for approximately 42 hours in total, such as whales, penguins and seabirds during the day (06.00-20.00 local time). This led to 2971 observations of marine predators, with a representation of 25 species. Dominating in numbers were chinstrap penguins (*Pygoscelis antarcticus*) with 2762 individuals, Antarctic fur seals (*Arctocephalus gazella*) with 177 individuals and 258 whales (Skaret et al., 2015).

Figure 1: Photo collected from google maps, where the red "point" indicates location of the echo sounder (Google maps, n.d.).

3.2 The echo sounder and method of data collection

The acoustic data were collected by an acoustic zooplankton fish profiler (AZFP) (serial number 55062) and deployed in Little Canyon (S60°24.276 W045°57.923). The echo sounder was deployed the 10.02.2015 and retrieved on the 09.02.2016 (Skaret et al., 2015).
The AZFP transducer was looking upward and floating at 263-meter depth. The echo sounder was moored at the bottom (480-meter depth) and equipped with an acoustic release that releases the echosounder when triggered by a signal (appendix A). The AZFP is a 125-kHz single-frequency echo sounder and was operated with one ping every fourth second (T.A Klevjer 2019, personal communication, 13.03).

Before analysing the acoustic data, the data were "cleaned" for removal of noise. This was done by scientist Thor A. Klevjer, IMR, as outlined in Appendix B. Thor A. Klevjer also provided data on S_A - the nautical area scattering coefficient ($m^2/n.mi^2$.) - a proxy for the abundance of krill throughout the year. Thor A. Klevjer also provides data on vertical krill distribution. I have here chosen to use data on the second quartile of the depth of the backscatter as a measure of krill availability. The second quartile is the depth with 25% of the backscatter above and 75% of the backscatter below. This provides a measure of the shallow portion of the population, which is relevant to a diving predator. The other analyses presented here are done as part of this thesis.

3.2.1 Analysis in Sonar5-Professional

The data was analyzed in Sonar5-Professional (version 6.0.4 – R359), hereafter referred to as Sonar5-pro, a program used to process acoustic data. This program is made by Dr. Helge Balk (University of Oslo Department of Physics, n.d.).

The data was loaded into Sonar5-pro and used to analyze the behaviour of predators relative to the distribution of krill. The settings in Sonar5-pro were set to a threshold value of -78 dB, meaning that stronger signals were accepted and weaker signals were rejected.

The dives were logged by using the mouse-click monitor function in Sonar5-pro to mark the dive depths, and then these data were exported into a text file for further analysis in Rstudio. Diving predators were identified based on their acoustic signature, often appearing as "brush marks/strokes" (figure 2). The lowest point of the brush mark was used as an indicator of the maximum diving depth and recorded with depth and time of day. If there was an interaction between predator and prey, where the predators go into the school of krill, the predators deepest dive was logged at the edge of the school of krill (figure 3). In cases where it was difficult to distinguish between individual predators, records were counted as one predator.

When processing the material in excel, days with no registered predators was registered as 0.

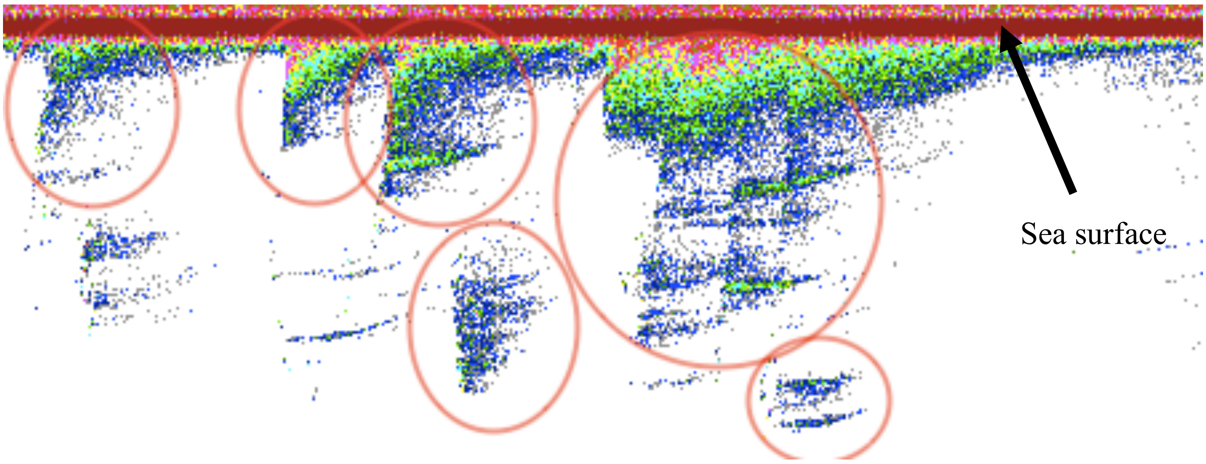

Figure 2: Acoustic targets defined by brush marks (screen print from Sonar5-pro). Arrow points to the sea surface (red line). Circles indicate the brush marks of diving predators.

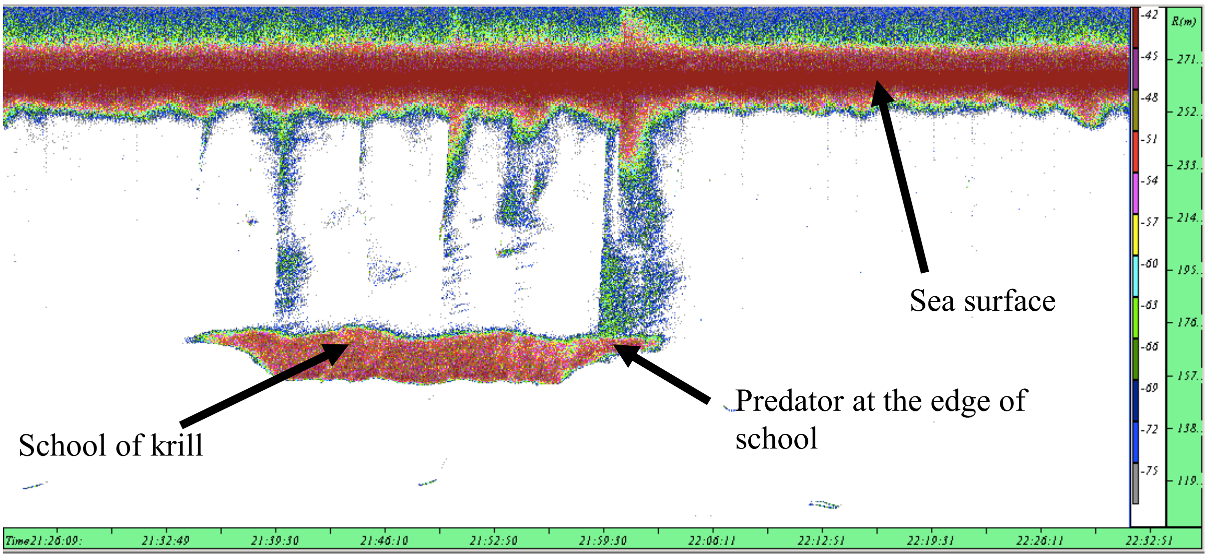

Figure 3: The deepest dive of predator defined by edge of school. The echogram has a range bar to the right, measured in meters. This bar indicates the distance from the transducer with the sea surface about 260m range. The color scale is proportional to the signal strength, where red color indicates high signal strength and grey color indicates weak signal strength (Simrad, n.d.).

3.3 Data treatment

All the figures included in this thesis (excluding the echo charts and pictures) are made in R studio version 1.1.423 (Rstudio Team, 2009-2018).

3.4 Satellite images from NASA EOSDIS Worldview

Information about sea ice cover was collected from NASA EOSDIS worldviews webpage (NASA Worldview, n.d.). It was not possible to get the exact coordinates with the mouse cursor, but the area defined in the screenshots (figure 4a, b, c and d) are as close as possible to where the echo sounder was deployed.

Four screenshots are presented to illustrate the development of sea ice cover from four months during the study year, February 2015 (figure 4a), July 2015 (figure 4b), December 2015 (figure 4c) and February 2016 (figure 4d). These four periods were selected because they present seasonal traits which represent different challenges the predators are facing relative to ice cover.

4. Results

4.1 Ice cover

Figures 4 a-d gives an indication of how the sea ice concentration develops throughout the year, and how it was during the period of data collection at the study site. The approximate location of the echo sounders is marked with a yellow circle. At the start of the study (figure 4a), the sea ice concentration in the area of the echo sounder was approximately 13%, with open water at the area of data collection. The percentage represents the relative concentration of sea ice in a grid cell, in this case, for 25km × 25km (NASA Worldview, n.d.). After five months, in mid-July (figure 4b), the sea ice concentration had increased from 13% to 92%, with the study area almost completely covered by ice (figure 4b). In the middle of December 2015, the sea ice concentration had decreased to 14% (figure 4 c), and the area of study was again located in more or less open water. At the end of the study year, February 2016, the sea ice concentration was down to 13% (figure 4 d). A more continuous presentation of ice cover relative to the location of the echo sounder is given in figure 9.

Due to decreased amount of light during austral winter, there is not enough light when the satellite passes Antarctica, and the satellite cannot capture imagery in the visible spectrum, thus leading to black spots/ pole hole like in figure 4b (R Boller 2019, NASA, personal communication, 28 May). Pole holes like this are common in the Antarctic from March-September (R Boller 2019, NASA, personal communication, 28 May).

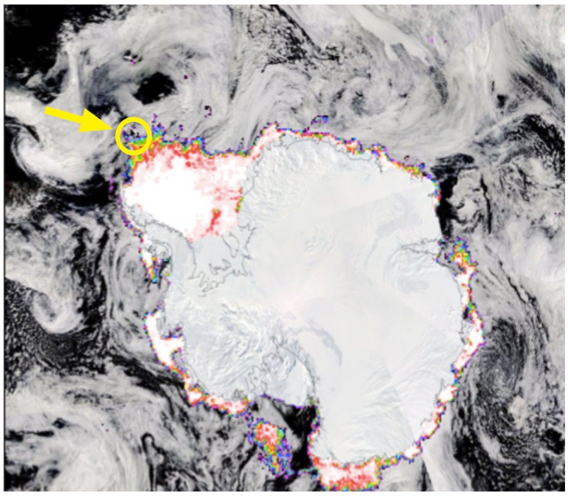

Figure 4a

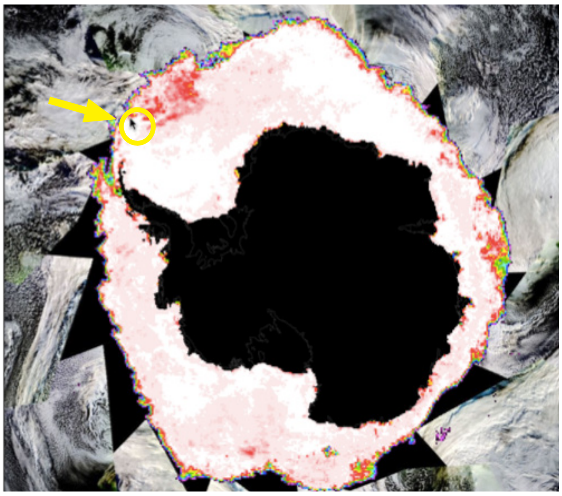

Figure 4b

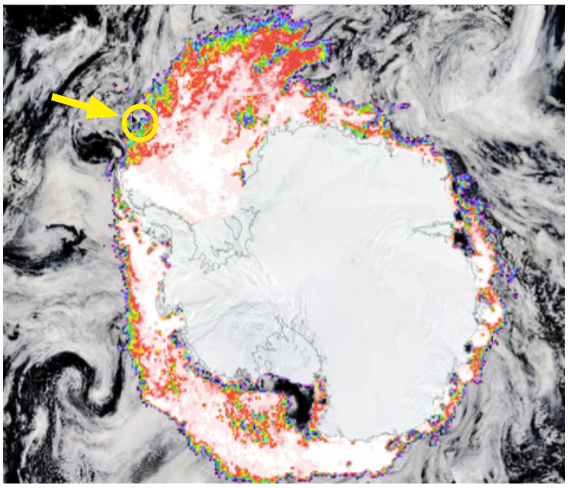

Figure 4c

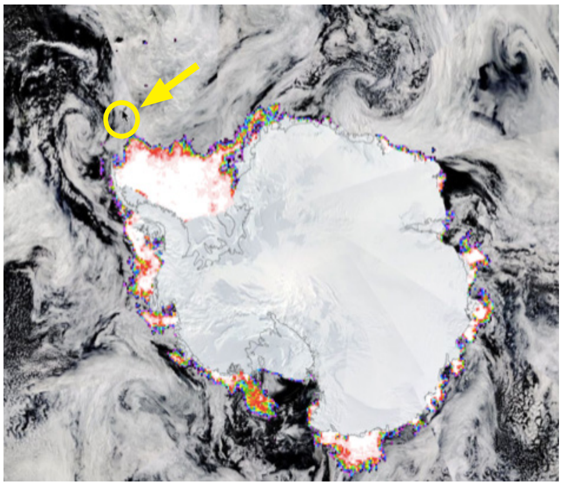

Figure 4d

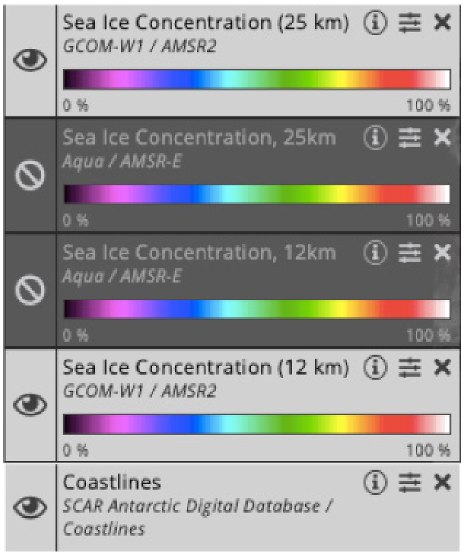

Figure 4e

4a 16.02.2015. (NASA EOSDIS Worldview, n.d.-A)

4b 15.07.2015. (NASA EOSDIS Worldview, n.d.-B)

4c 16.12.2015. (NASA EOSDIS Worldview, n.d.-C)

4d 10.02.2016. (NASA EOSDIS Worldview, n.d.-D)

4e Color scale showing the concentration of the ice-cover. This is a screenshot from the same URLs as figure 4a-d.

Echo sounder position indicated by yellow arrow and circle in each figure

4.2 Examples of diving behaviour

Diving was recorded both in the presence and absence of nearby krill schools, as exemplified in figure 5 and 6. The relative frequencies of apparent successful and unsuccessful dives were not quantified, yet search dives, where the predators dive without finding prey occurred frequently.

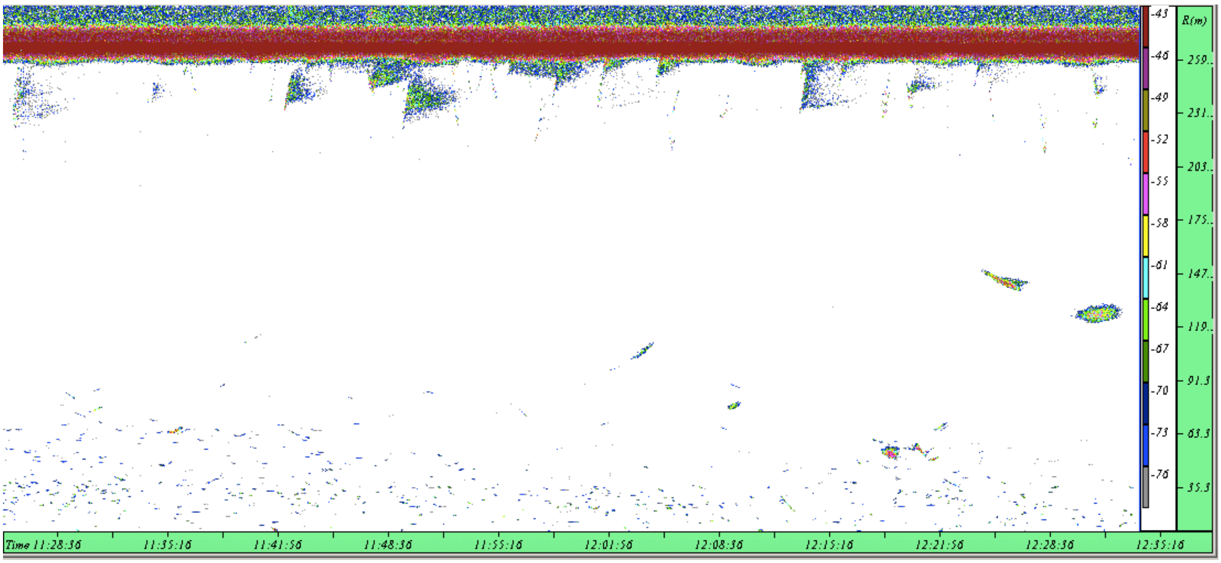

Figure 5: Diving predators.

Contrary to figure 5, where the dives are seemingly unsuccessful, figure 6 shows another story. In this case, the predators find a massive aggregation of krill, thus leading to high diving activity.

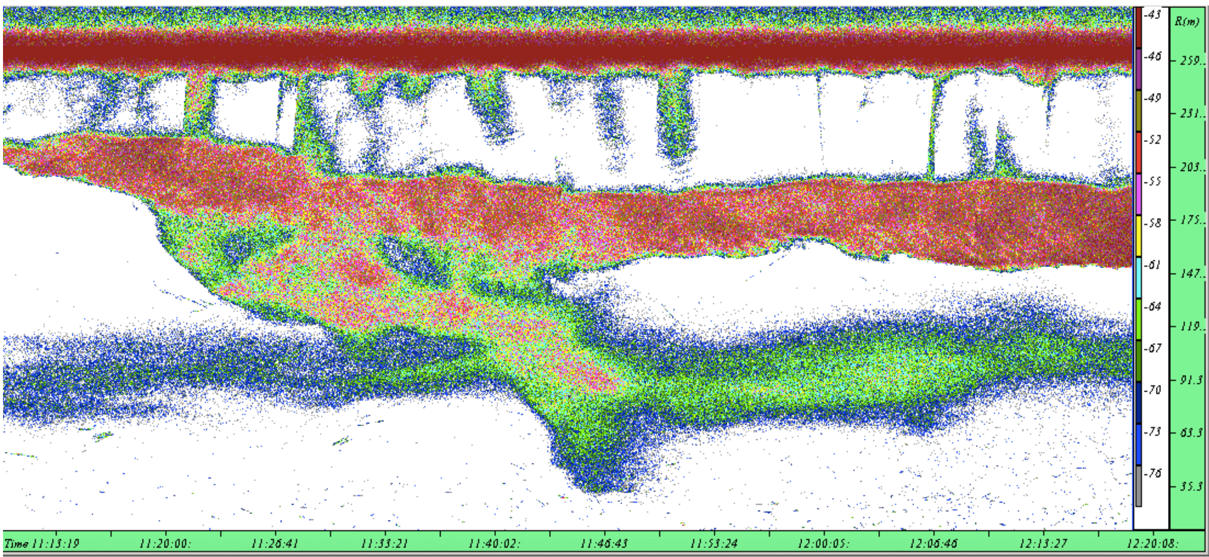

Figure 6: Predators diving into school of krill.

In September, during Austral winter, there was limited (see figure 9), yet a few examples of diving predators. Figure 7 gives an example of diving behaviour in a period of apparent ice cover, where the predators dive into a school of krill. This could be a situation with intermittent ice cover, giving access to open waters. During austral winter, it was not unusual to see krill distributed near the surface (figure 8).

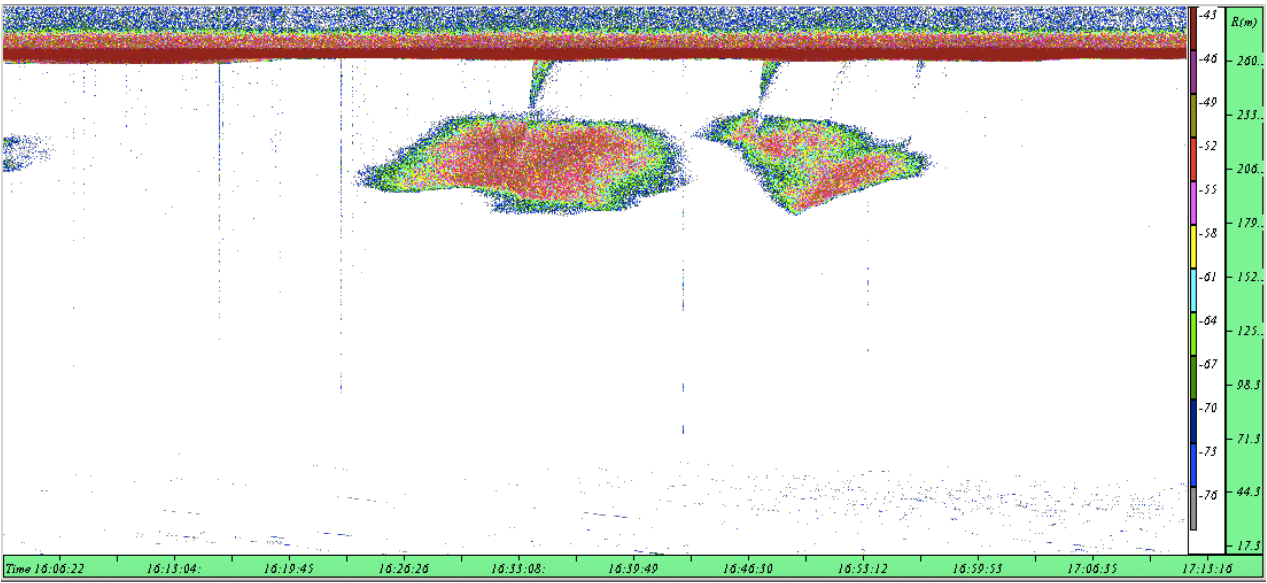

Figure 7: Diving predators during austral winter (September), diving into a school of krill.

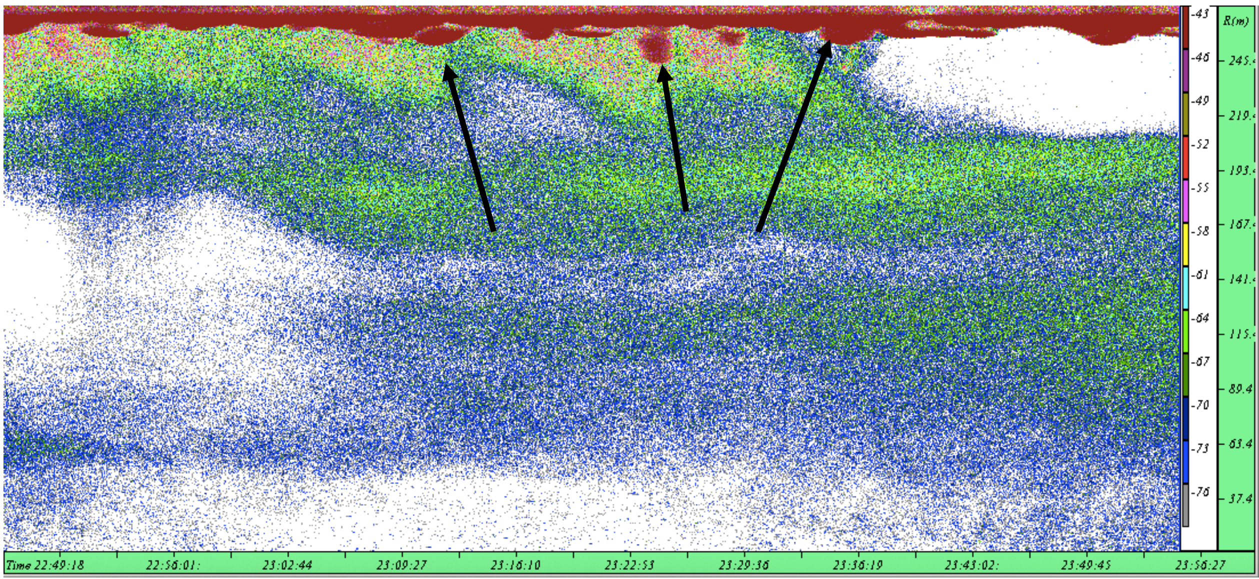

Figure 8: Krill distributed in the water column during austral winter. The arrows point to examples of possible ice bergs.

4.3 Frequency of dives and presence of krill

The frequency of dives peaked during austral summer, from February – late April, with about 45 dives per day during the most active periods (figure 9). A major decrease in dives followed this period during austral fall and winter (May-January). However, there are days during the austral winter with some dives, i.e. the end of September, November and December (figure 9). The solid black line represents completely ice-covered waters, while the leading black line represents a transition face between open – and ice-covered water. The result gives a strong pattern of reduced diving activity with increased ice cover.

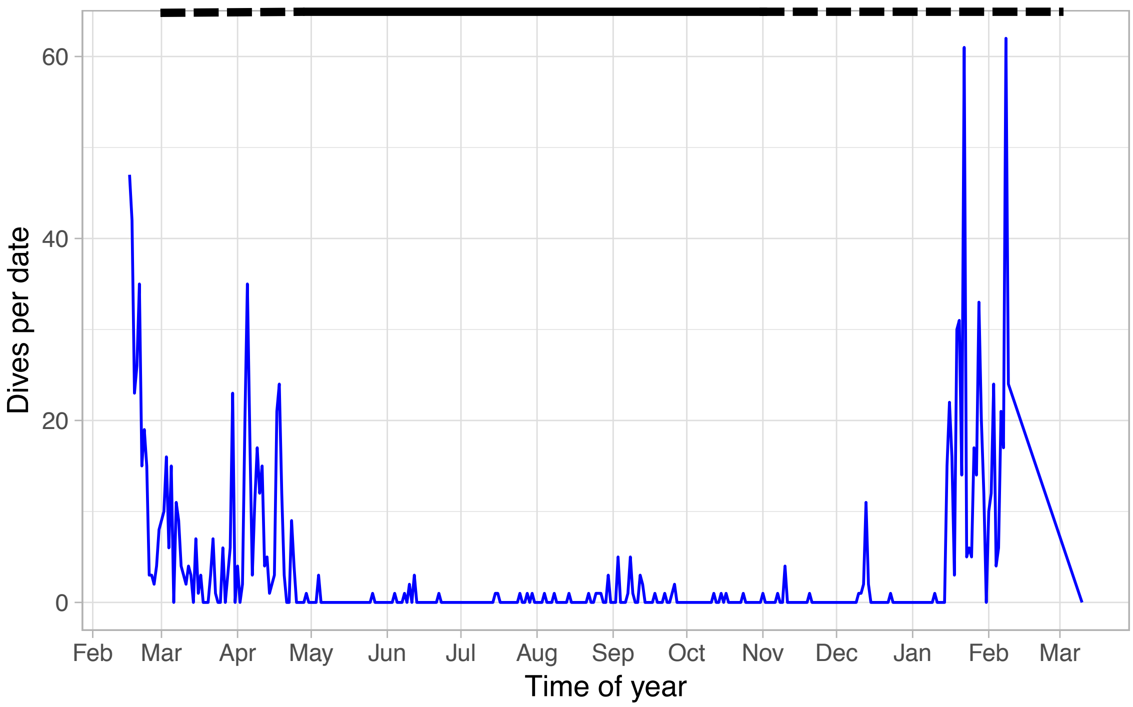

Figure 9: Plot of the study period that gives an overview of the frequency of dives per day (daily averages per week). Black solid line represents ice-covered water and leading black leading line represent transition face.

Overall, krill occurred throughout the year (figure 10). By comparing abundance day and night, there is generally a higher S_A of krill during the day than night, particularly from August to late October.

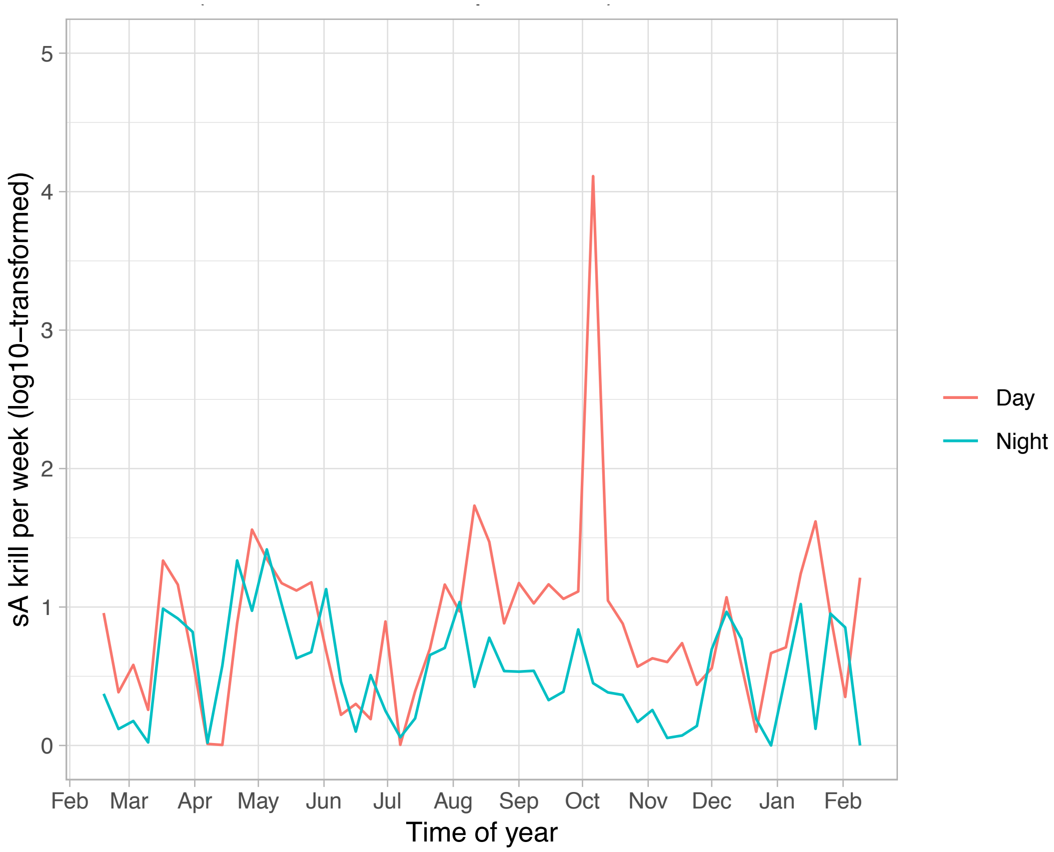

Figure 10: Mean sA (backscatter of krill per week) day and night.

4.4 Depth of dives

The predators have a wide range of diving depths, from the surface and down to approximately 90-100 meters (figure 11). There were no evident seasonal patterns in diving depth; apparent shallow depths in, e.g. July and December may have resulted from low numbers of records.

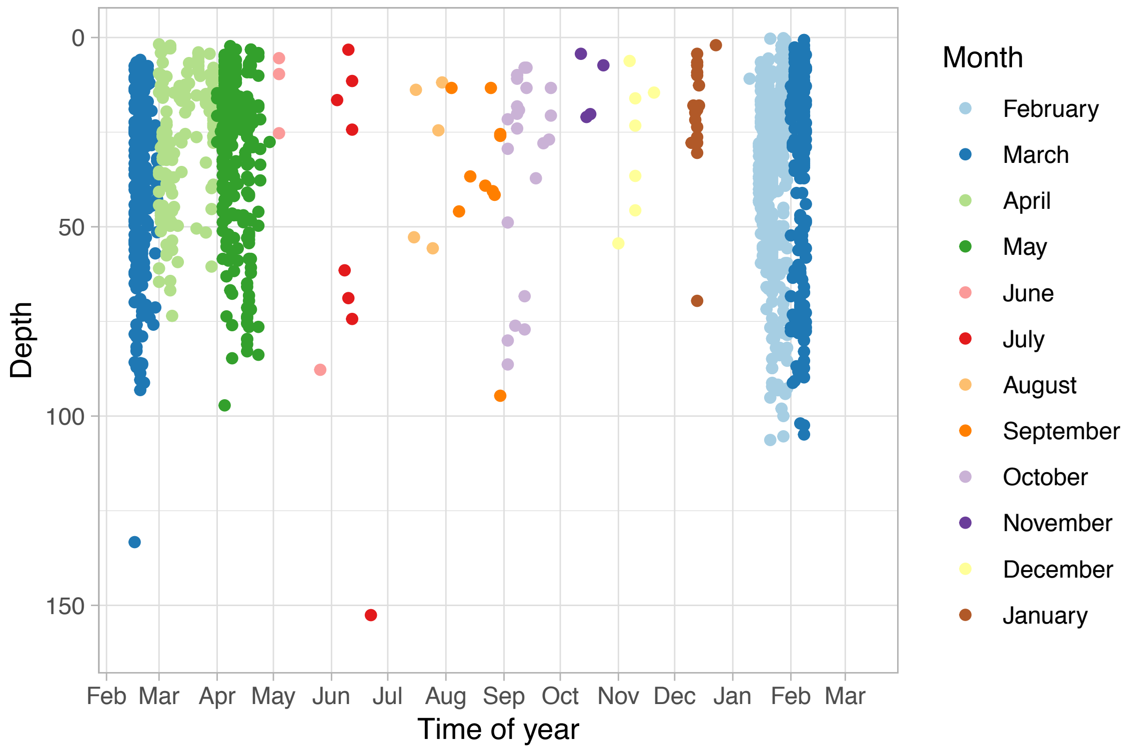

Figure 11: Plot show the depths of the diving predators from February 2015 to February 2016.

4.5 The number of dives after sunrise and sunset

There were clear diel patterns in the diving activity, where most of the dives occurred during the day (figure 12). The majority of dives was between 05.00 in the morning to 20.00 in the evening, with only a few dives during the night. The time is normalized to UTC -4 to get as close to local time as possible. The duration of day length decreases from Austral summer to Austral winter, and is the shortest from May to September, while the longest days are between November to February (figure 12).

The diving depths of predators (i.e. from daytime) are overlapping with the upper 25 percentiles of the krill distribution (figure 13 A, B and C). During the night krill are closer to the surface (figure 13 C).

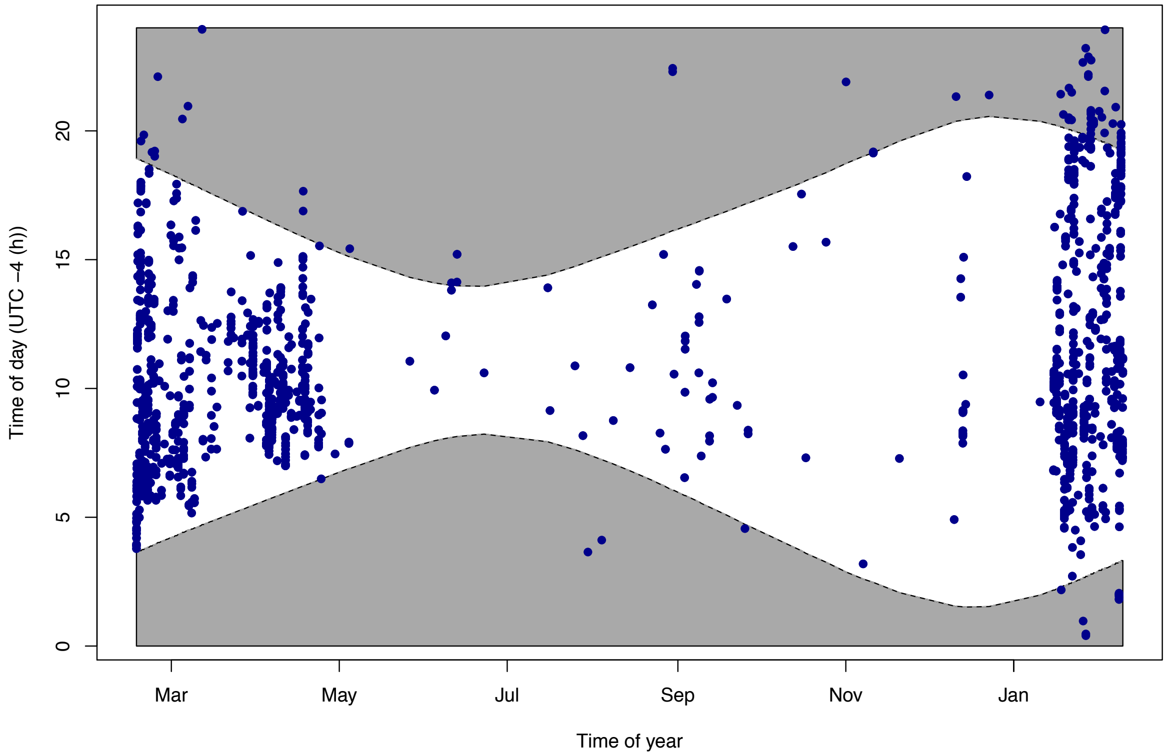

Figure 12: Graph showing the time of each individual dive over the whole study period (blue dots) and the time of sunrise and sunset in the dashed lines. The lower line represent sunrise and the upper line represents sunset. The grey area indicates the night (between sunset and sunrise). The time is normalised to UTC -4 to get as close to local time as possible.

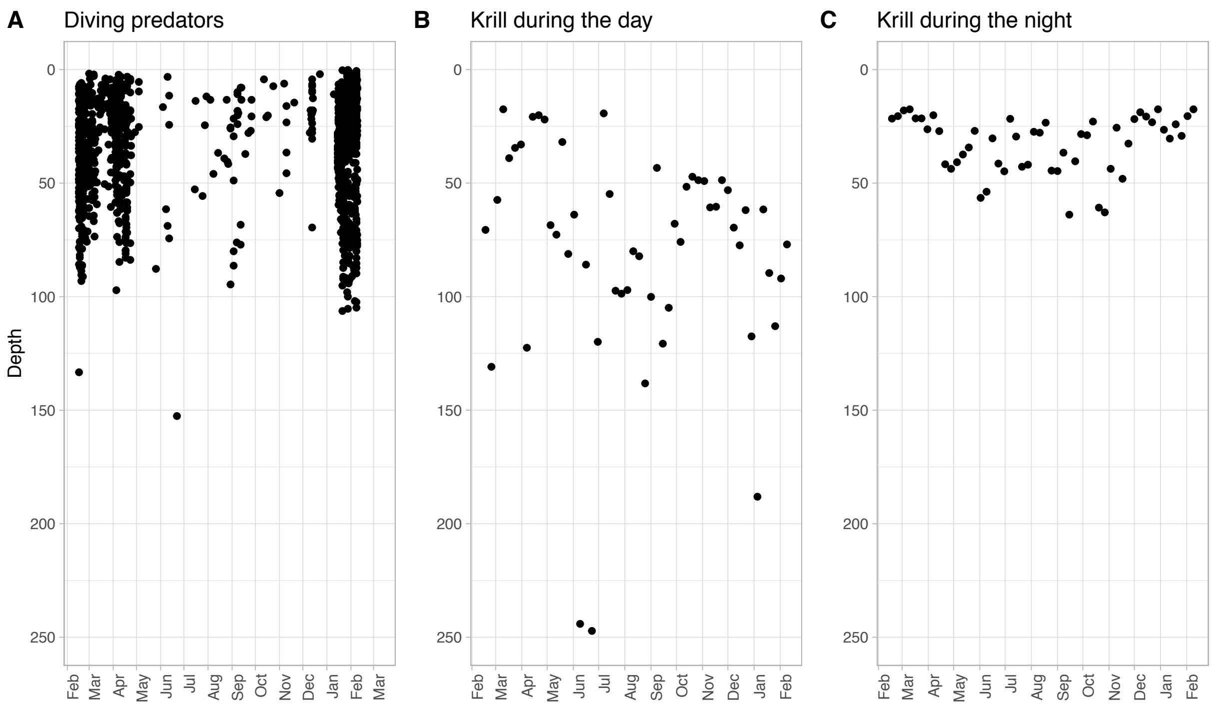

Figure 13 A, B, C: Figure A, B and C gives an indication of the depth of the predators (A) and the depth distribution of krill (25 percentile) during the day (B) and during the night (C).

5. Discussion

As penguins and seals are observed in the area of study (Skaret et al., 2015), it is plausible that they are the diving predators seen in the data. In addition, there are apparent air bubbles in the acoustic signal, which is likely that penguins prevail. However, as it is not possible to confirm this assumption, there are some limitations in the discussion. Nevertheless, regardless of the unconfirmed identity, the data gives a clear picture of diving predators in Antarctica and their diving patterns relative to the season, day, depth and distribution of krill.

5.1 The role of ice cover in relation to predators diving behaviour

"Hypothesis 1: An increased concentration of sea ice will lead to a decrease of diving predators."

Based on to the results of the analysis, periods with open water and transitions phases (ice to open water), February - April 2015 and late January-February 2016, represent periods with the highest rates of dives (figure 9). On the contrary, periods where the sea is covered with ice, present the lowest diving rates. One plausible cause for the decrease in dives is that the ice prevents the predators from diving because it acts as a lid. This might force the animals to migrate across the ice and towards open sea to feed. Penguins are known to migrate during winter, and some travel to open water, such as, e.g. Chinstrap penguins (Trivelpiece et al., 2007). Others like Adélie penguins keep relatively close in proximity to their breeding site and the ice edge (Hinke et al., 2015). Trivelpiece et al. (2007) found that chinstrap penguins migratory behaviour vary from year to year, most likely due to weather changes. Hinke et al. (2015) support the finding that Chinstrap penguin's migratory behaviour varied, having a "higher diversity of individual movement patterns" (2015, p.7).

Further, Hinke et al. (2015) found that the Chinstrap penguins can exhibit two overwintering strategies where they either go west to the Pacific part of the Southern Ocean or east to the south Atlantic, where some individuals had travelled as far as 3900km from the location they were tagged. On the opposite of going out in the open sea, Dunn et al. (2011) found that Adélie penguins *(Pygoscelis adeliae)* breeding on Signy Island would leave their colony late January- early February and migrate towards the edge of the ice. Here they would moult for about four weeks before continuing their migration north/north-eastward. Some would also go into open water, but they would keep close to the ice edge (Dunn et al., 2011). This raises the question if the Adélie penguins rely on the ice edge for survival, considering that they keep close to the edge. Hinke et al. (2015) findings could support Dunn et al. (2011) hypothesis suggesting that the Adélie penguins probably use sea ice as a habitat for 15-50% of the winter. By using the ice as a habitat, feeding opportunities can arise, for instance, if the ice has weak spots/holes where the predators can break through. There was a major decrease in dives during austral winter in the study area; however, there were also some periods with records of dives. This could mean that there were cracks in the ice, or areas where the ice was thinner, enabling the predators to go through. In summary, the ice concentration is most likely the cause of decreasing diving rates, but given the opportunity, the predators would go through the ice to forage.

5.2 The role of light to locate prey.

"Hypothesis 2: Due to lower visibility during the night, predation rate will decrease during the night."

The data shows clear patterns of higher diving rates during the day (figure 12), which suggest that predators are dependent on vision and light to catch prey. This finding is supported by Wilson et al. (1989), who argue that Adélie penguins rely heavily on vision to detect prey (Wilson et al., 1989). This is also supported by Chappell et al. (1993), who emphasize the importance of vision as it "make foraging most efficient at shallow, well-lighted depths even if prey density is higher at greater depth" (1993, p.1211). These statements could also argue that Adélie might be a species registered during the study as they probably are dependent of light to find prey.

Diving depths among the predators are distributed from the surface down to about 100m (figure 11). The krill's distribution in the water column differed between day and night, suggesting diel vertical migration (DVM) (figure 13 B and C). The deeper distribution of krill during the day might be an antipredator behaviour, where they descend to hide in deeper and darker water to avoid visual predators. During the night, they migrate up to the more food-rich surface waters, still protected by the night.

As stated earlier, it is assumed that Adélie penguins are amongst the predators. However, Chinstrap penguins were the dominating penguin species observed by the scientific cruise, and are also most likely among the acoustic targets recorded here. Kokubun et al. (2010) found that Chinstrap penguins do their majority of dives in epipelagic or midwater in off shelf regions, where the depth range would spread from 0-90m. This correlates well with my results, where the dives registered were between 0-100m. Takahashi et al. (2003) state that the diving pattern of Chinstrap penguins seems to vary within depth and time of the day. They either go hunting diurnally, meaning that the activity occurs during the day, or they would go on overnight trips. A diurnal pattern corresponds well with the results of my study. Takahashi et al. (2003) found that dives during the day showed little variation, and was between 10-100m, which correlates well with the findings in this study. It should be noted that Takahashi et al.'s (2003) study focused on predation on near-bottom Antarctic krill and that the sea floor could limit the penguins diving depth. Takahashi et al. (2003) found that Chinstrap penguins had a shallower diving pattern during the night, which would correspond well with krill having a shallower distribution, and diving into deeper waters would also limit the visualization of prey. However, there was little registration on dives during the night in my study.

Another species that was observed during the study cruise was the Antarctic fur seal. Croxall et al. (1985) found that species like the Antarctic fur seal prefer hunting at night in areas like South Georgia, although some dives could take place at day. The results show that there were some dives during the night (figure 12), but due to the majority of dives being during the day, the temporal pattern of Antarctic fur seal does not apply to my results. However, if there were any Antarctic fur seals diving during the day, the depth range would correlate well with the results (0-100m), where Antarctic fur seals have a depth range from 40-75 m during dives at daytime (Croxall et al., 1985). Further, in their study, Croxall et al. (1985) found diel vertical migration (DVM) with the krill, that matched the seals behaviour. At night, the krill would migrate to the surface, and the seals could forage in the shallow water (Croxall et al., 1985).

In summary, most of the registered dives were presumably penguins who are visual predators foraging during the day. With further research, and other techniques, e.g. cameras and tracking of animals, it might be possible to find out what types of species are seen in the echo charts.

5.3 The effect prey distribution has on predators.

"Hypothesis 3: Diving activity will be closely related to the presence of krill"

Krill was present throughout the whole study period (figure 10), and the distribution of krill is therefore no valid explanation for why predation increased/decreases in certain periods of the study. It is however interesting to discuss how the predator-prey interaction looks on a short time-scale. Figure 5 and 6 are examples of diving without and with success (respectively). Predation is a time- and energy demanding behaviour, making dives without success, where the predator doesn't find or catch any prey, costly. Hunt et al. (1992) found that predators preferred staying close to their colonies, and the density of predators would decrease with increased travel time and distance to prey. Further on, they suggest that predators would search for prey in areas they have been successful prior, or go in directions where successful predators are coming from (Hunt et al., 1992). By doing this, they are risking using energy in vain searching for prey. Although the frequency of unsuccessful dives was not established in the current study, they appeared to occur relatively frequently. Given the energy costs and related to unsuccessful dives, it would be interesting to quantify the apparent diving success in future studies.

5.4 Foraging during parental care.

"Hypothesis 4: During periods with parental care of offspring and mating activity, predators will increase their foraging activity to provide enough food for their progeny. "

The results show increased activity of diving from February 2015 to the end of April (2015) (figure 9). Chicks of Adélie penguins hatch mid-December, and Puddicombe and Johnstone (1988) found that after hatching, the occurrence of krill as prey compared with other prey species increased considerably. In January-February, when the Adélie chicks are forming crèches, the adults have more time to go out and forage (Puddicombe and Johnstone, 1988). Establishing crèches is a behaviour where the chicks go together in groups, possibly to protect themselves against predators or other adult birds in the colony (Le Bohec et al., 2005). This formation of groups makes the chicks more independent, where the parents have some time to go out foraging. This could explain the increased diving activity in this period, and Lishman (1985) study supports this theory, as chicks that were guarded by their parents received less food than chicks that were in crèche.

Kato et al. (2009) studied the Adélie penguins' behaviour at Lützow-Holm Bay and found that they lay eggs during the middle-or last part of November, and females will then go out foraging for approximately 12-14 days, before switching place with the males. During the incubation time, the adults would use more time foraging, compared with chick-rearing time (Kato et al., 2009). The results from the analysis of data, diving in the study area starts to increase slightly in late November/December, which could be explained by this parental foraging trips before the eggs hatch. Kato et al. (2009) study showed that the penguins dived throughout the day, but they dove less around midnight. This matches well with the results, with lower diving rates during the night, and higher rates of diving during the day (figure 12).

According to Borboroglu and Boersma (2013), the adult chinstrap penguins will go out to sea after chick rearing in February, feed and build up their reserves before an annual fasting-moulting period of approximately two months. If this is true for the study area, it is most likely not Chinstrap penguins that are registered in my study, where most of the dives occur from January – March.

6. Conclusion

In conclusion, using acoustic is a suitable method for analysing the ecosystem, and in this study - looking at behavioural patterns with the diving predators.

Diving predators in Antarctica are highly affected by the ice concentrations. Diving rates increase when there is low ice concentrations/open water, while the diving rates decrease when the sea is covered with ice. This creates a seasonal migration pattern amongst some of the diving predators in Antarctica. Further on, diving predators are likely to be highly dependent on their vision and light to find prey, and thus, most dives occur during the day. The depths of dives were spread out from the surface down to approximately 100 meters, with some even deeper. This correlated with krill's distribution during the day. During the night, there were little registrations of dives, while the krill migrated towards the upper layers and surface. During periods with parental care, diving trips increase, possibly to collect enough food to support their progeny as well as themselves.

In a world with climate change, melting ice can have a significant effect on the ecosystem. Further studies need to be conducted to monitor the impact that decreasing ice concentration have on the predator and prey distribution.

Further studies on the data material used in this thesis could be to establish diving speed and the duration of time the predators are diving. It would also be interesting to quantify the rate of successful/not successful dives. These studies could give deeper knowledge about predators behaviour and their role in the ecosystem.

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8. Appendix A

Data record book for self registrating instruments detail

Ship/Platform:	Juvel
Location:	Little Canyon
Latitude:	S 60° 24.276
Longitude:	W 045° 57.923

Instruments / Sensors

#	Brand	Type	Serial No.	Depth	Comments
1	ASL	Acoustic Zooplankton Fish Profiler	55062	263	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

Bottom depth:	480 m
Outgoing date:	2015.02.10
Outgoing time (UTC):	15:20
Incoming date:	2016.02.09
Incoming time (UTC):	13:00

Comments:

~~ARGOS~~
~~PTTID: 00000~~

Acoustic release: IXSEA ARX61
Serial no: 0301
Range code: 1421
Release code: 1455

Station name: Krill 2015 ASL AZFP	
Color code:	
Sum weight (incl. anchor): [kg]	
Sum weight (excl. anchor): [kg]	
Sum volume: [l]	
Buoyancy (anchor on): [kg]	
Buoyancy (anchor off): [kg]	
Shackle Stainless Steel	S
Shackle Galvanized Steel	G
Thimble Stainless Steel	
Thimble Galvanized Steel	
Thimble Nylon Stainless Steel Bolt	

Description	Spec	No.
Shackle Stainless Steel		0
Shackle Stainless Steel	2.50	0
Shackle Galvanized Steel	0.50	0
Shackle Galvanized Steel	2.00	0
Shackle Galvanized Steel	3.25	0
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
ThimblesStainless Steel		0
Thimble Galvanized Steel		0
Thimble Galvanized Steel		0
Thimble Nylon		0
Bolt Stainless Steel (RCM-7)		0
		0
		0

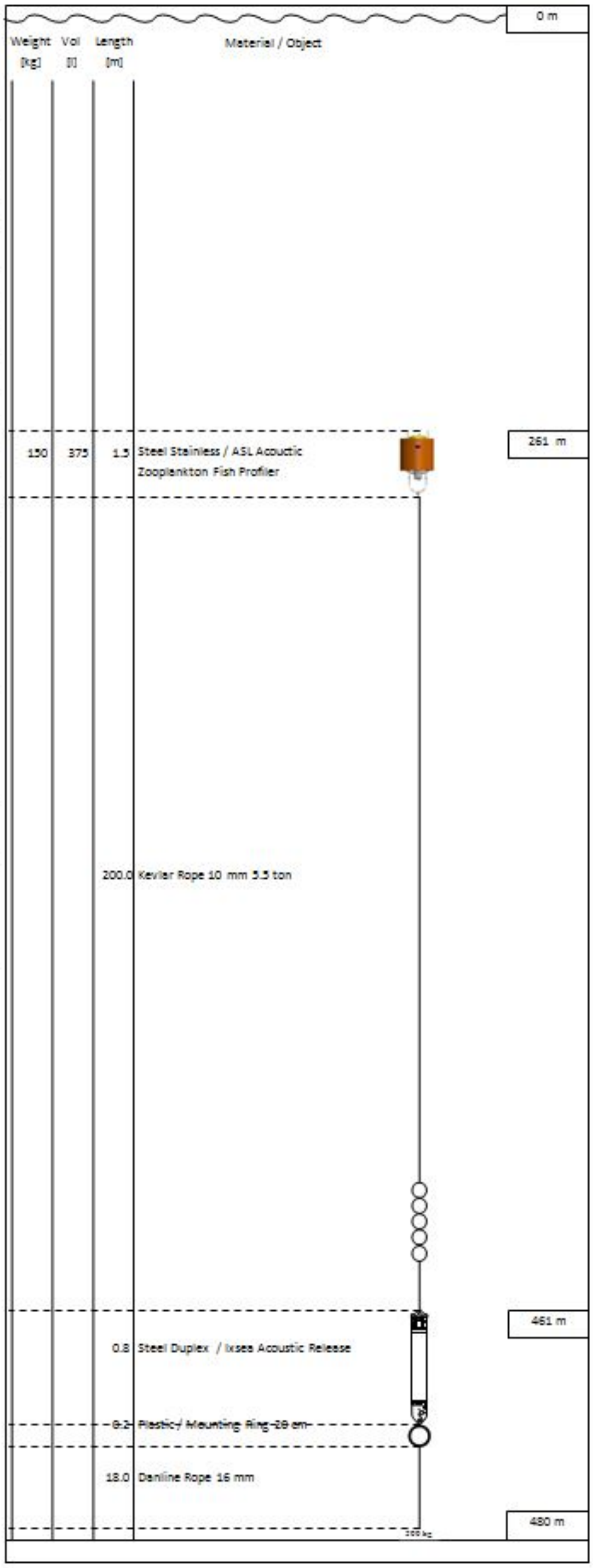

Figure 14: Data record book for self-registration instrument detail (Skaret et al., 2015)

Appendix B

Filtering and removal of TVF noise prior to analysis done by Thor A. Klevjer and described below:

In periods, rough weather and surface ice added noise to the raw data. The effects of this noise were worse toward the surface, but at lower thresholds the effects were also evident at depth. As a first order attempt at removing these periods from the dataset a running median filter compared 10-minute median echo levels in 15 separate depth channels against the daily median for each channel. If all 15 depth channels had a median echo level that was higher than -80 dB, and more than 2 dB above the daily median, the time period was flagged as bad data and dropped from the dataset. Prior to calculations the echograms were smoothed using a 9 x 3 (vertical samples x pings) convolution kernel. The filter proved efficient at removing intermittent periods of increased noise levels, but also removed a few periods where there were high levels of krill backscatter distributed in the entire water column, as well as data from a few passing's of icebergs. After the removal of periods of suspect data, daily ambient TVG noise levels in the remaining data were estimated as the 10.th percentile of remaining data below a threshold of -68 dB, and these levels were subtracted from the raw data to estimate real scattering levels. In practice the TVG noise removal algorithm did not remove all TVG noise toward the surface but lowered the TVG noise enough to allow the use of moderately low threshold settings.]