The distribution of foraging arctic tern (*Sterna paradisaea*) and black-legged kittiwake (*Rissa tridactyla*) along the coastline of a glacial fjord (Kongsfjorden, Svalbard)

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Preface

Personal statement

The beauty and the complexity of ecosystems with their beautiful creatures, have always fascinated me. Due to climate change, changes occur rapidly in the Arctic ecosystem. I hope that with this thesis I can contribute to understanding and protecting the ecosystems with its organisms in the vulnerable Arctic. Animals are unable to verbally share their life story with us, but as curious students and scientists, we can.

Brief motivation on choice of subject

When I was a child, I read a book about Svalbard. Going there has always felt like an adventure to me. Years later I decided to focus on birds during my studies. The arctic tern amazed me since it travels up to 90 000 km per year and it flies to Svalbard: the wild land of the polar bears, glaciers, mountains and more Arctic life. Arctic terns share this environment with the black-legged kittiwake. I wanted to discover what they do in this land. Where do they breed? What and where do they eat?

Relation of subject with personal objectives and aims

This thesis gave me the opportunity to unravel the foraging patterns of migratory birds in the Arctic. I could experience fieldwork, data analysis and literature research in the role of a scientist.

Abstract

1. The extent to which glaciers influence bird distribution in Arctic areas is an important question in the light of climate change in the Arctic. Migratory birds flying to the Arctic for breeding profit from a high food availability that is partially mediated by glacier meltwater. Literature provides evidence that Arctic bird species visit glacier fronts. Tidewater glaciers discharge large volumes of fresh water, thereby releasing sediment with nutrients. These nutrients enhance primary production (algae), which promotes the consumption thereof by fish. The (turbid) freshwater discharge may paralyze zooplankton and fish and may also affect their vertical migration behavior: they move closer to the surface, thus enlarging predation risk. It also decreases possibilities for safe schooling behaviour of fish. These processes make these organisms more easily available for surface pecking predators.

   The relatively high food availability - compared to non-glacial shores - may increase the number of surface pecking birds foraging at the glacier fronts. We investigated the distribution of surface pecking birds (the arctic tern (*Sterna paradisaea*) and the kittiwake (*Rissa tridactyla*)) along the coastline in a glacial fjord (Kongsfjorden, Svalbard) in order to assess if these species show preference for foraging at glaciers. We also investigated whether birds prefer foraging close to the coast (0-200m from the coast) or in more deeper water (200-400m from the coast). Prey species occurring in between stones in more shallow water may be more available to surface pecking predators.

2. We sampled the number of foraging Arctic terns and kittiwakes along the coastline in Kongsfjorden. We divided the coastline in two types of coast: (1) glacier and (2) non-glaciated coastline. We numbered the glaciers from 1-5 and divided the non-glaciated coastline into 7 sectors. We selected a line-transect following the coast of the sectors at a distance of 200 m.

3. From June until August 2017 we performed 8 weekly bird counts by boat. Following the line-transect, the boat travelled a distance of 50 km. We counted foraging Arctic terns and kittiwakes between the boat and the coast (starboard side) within a distance of 200 m. We also counted the birds within the same distance at the port side of the boat. The survey thus covered an area of 20 km^2 per day.

4. We found that (1) mean densities of kittiwakes were higher at glaciated coastline compared to non-glaciated coastline; (2) at the non-glaciated coastline, both the arctic tern and the kittiwake showed a higher mean density within 200 m from the coastline, compared to the range of 200-400 m from the coastline; (3) arctic terns tended to show preference for one glacier: the Blomstrandbreen glacier.

5. In Kongsfjorden, glaciers play a major role in foraging patterns of the kittiwake, but to a lesser extent for the arctic tern. Group sizes of kittiwakes were also usually larger than group sizes of arctic terns in front of glaciers. The retreat and possible future disappearance of glaciers and the possible resulting reduced food supply might have a strong influence on the distribution and number of kittiwakes and arctic terns. Temporarily, increasing glacier melt could enlarge foraging hotspots, since increased glacier melt could paralyze or kill more prey. But we expect that in the future, when glaciers have (partially) melted, the number of kittiwakes will decrease. Glacier melt might influence distribution and number of arctic terns to a lesser extent, since they also forage at non-glaciated coastline.

   Suggestions for future research: 1) getting a better view on (distribution and number) of prey species of arctic terns and kittiwakes in Svalbard helps understanding the choice of foraging location of these species; 2) performing more research into number and distribution of arctic terns and kittiwakes in Svalbard; 3) collecting data near glacier fronts is very important to understand the processes underlying the foraging hotspots. Information about the organisms (including prey organisms) and abiotic factors is scarce and needs to be acquired. Research into these suggestions is needed to get a better understanding of the interaction between bird dispersal and glacier melt due to climate change in Svalbard.

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1. Introduction

1.1 Importance of glaciers for food availability

The extent to which glaciers influence bird distribution in Arctic areas is an important question in the light of climate change in the Arctic. Migratory birds flying to the Arctic for breeding profit from a high food availability that is partially mediated by glacier meltwater (Lydersen et al., 2014). Glacier fronts are important foraging hotspots for mammals and birds (Lydersen et al., 2014; Strøm et al., 2012). Several processes at glaciers could explain a high food availability at glacier fronts: 1) Glaciers release sediment that contain nutrients. This promotes primary production, which influences the food web (Apollonio, 1973; Hood & Scott, 2008; Hood et al., 2009) and could eventually promote fish production, thus increasing food availability. 2) The released sediment causes turbidity in the water. This affects vertical migration of zooplankton and fish (Abookire et al., 2002; Frank & Widder, 2002). 3) Safe schooling behaviour of fish could be impeded by turbidity (Partridge & Pitcher, 1980). 4) Tidewater glaciers are a type of glacier where the front part is in contact with a water body, for example a bay or sea. The subsurface release of cold fresh water plumes from tidewater glaciers paralyses and kills zooplankton and fish (Lydersen et al., 2014; Stempniewicz et al., 2017). Processes 2, 3 and 4 increase predation risk and therefore make prey more available for mammals and birds, including surface pecking predators. The processes are visible in Figure 1. A detailed explanation of the figure can be found in the discussion section.

In the process of climate change, glaciers in Svalbard are decreasing in number and size (Kohler et al., 2007) and tidewater glaciers become land-based. This results in a decrease of the number of foraging locations for birds and mammals and could therefore influence their number and distribution (Lydersen et al., 2014). Besides this, the distance from traditional nesting areas to glaciers becomes longer, which results in higher energy costs for flying and might enlarge predation risk of the chicks, since parents are longer absent for foraging, and are not able to protect their young in their absence.

Coastline surrounding glacial fjords may consist of multiple glaciers and non-glaciated coastline. In comparison with glaciers, the absence of these processes at non-glaciated coastline could result in a lower food availability and a resulting lower density of predators. However, along non-glaciated coastline, prey species for birds can be found. These prey organisms, e.g. amphipods and mysids, occur nearby large stones in inshore zones (Hartley & Fisher, 1936). In shallow water these prey might be more available to surface pecking predators, than in deeper water, which could suggest that bird densities are higher close to the coast.

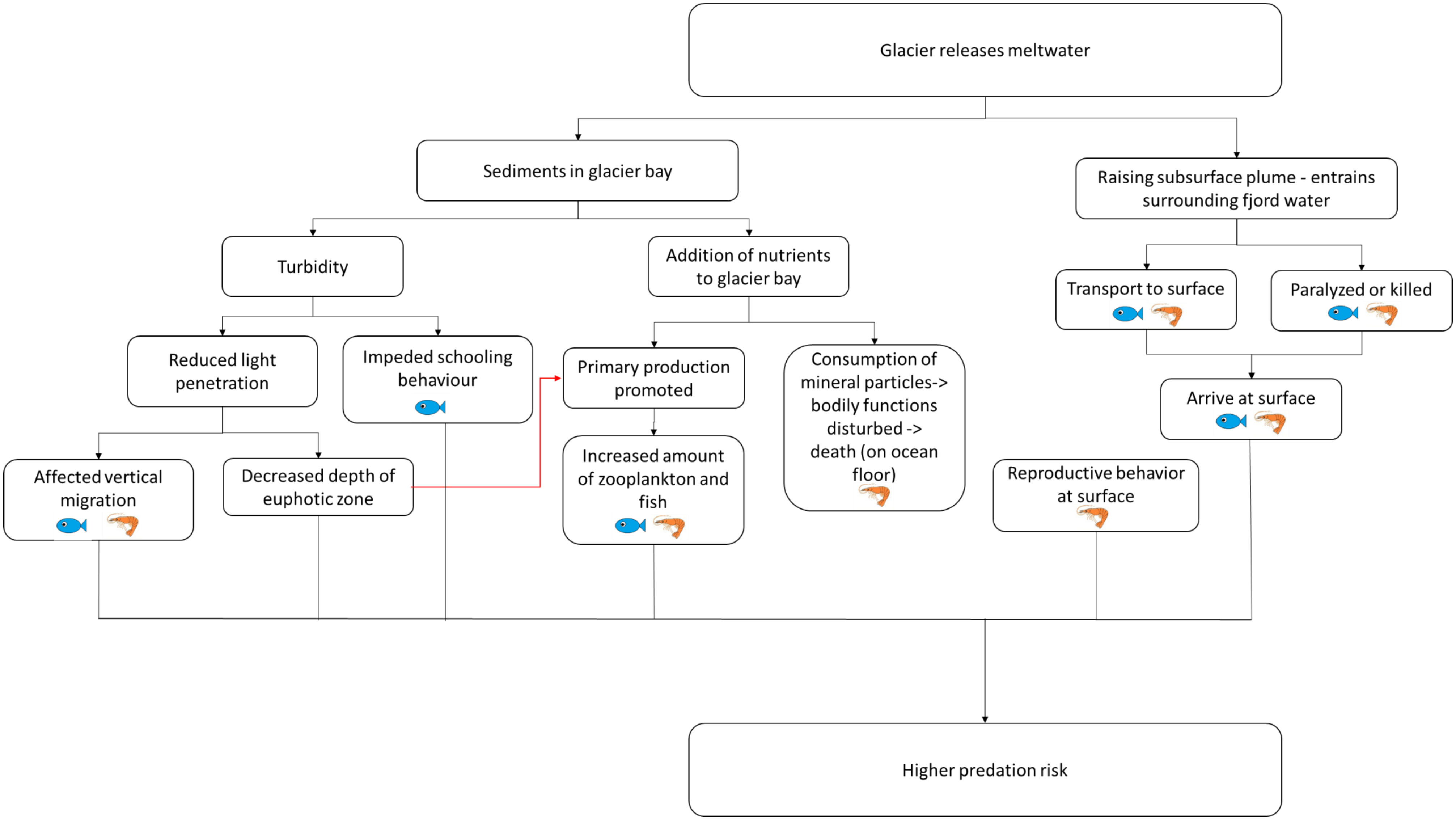

Glacier releases meltwater
Sediments in glacier bay
Raising subsurface plume - entrains surrounding fjord water
Turbidity
Addition of nutrients to glacier bay
Transport to surface
Paralyzed or killed
Reduced light penetration
Impeded schooling behaviour
Primary production promoted
Consumption of mineral particles-> bodily functions disturbed -> death (on ocean floor)
Arrive at surface
Affected vertical migration
Decreased depth of euphotic zone
Increased amount of zooplankton and fish
Reproductive behavior at surface
Higher predation risk

Figure 1: temporal-spatial diagram of processes underlying food availability at glaciers. Group of organisms:  *: Fish.*  *= Zooplankton. If one of these pictures is visible in a box, then the accompanying text relates to this group of organisms. A detailed explanation of the diagram can be found in the discussion section. Promoting (black arrows) and inhibiting (red arrow) factors. Boxes under and including 'Addition of nutrients to glacier bay' are relatively slow processes, but they are constant.*

1.2 Objectives of this study

Since glacier fronts are an important foraging spot, glacier melt could strongly influence foraging patterns of migratory birds in the Arctic.Temperatures in the Arctic are rising two times as fast as global mean temperatures (Richter et al, 2017). In Svalbard, climate change has been causing accelerated glacier melt (Kohler et al., 2007). Kovacs (2011) already described sea ice loss influences number and distribution of Arctic mammals. The decrease of the number and size of glaciers could therefor possibly reduce the number of foraging hotspots, and this might influence bird number and distribution. Therefore we conducted a study about the distribution of two migratory species in a glacial fjord: the arctic tern (*Sterna paradisaea*) and the kittiwake (*Rissa tridactyla*). When kittiwake is mentioned in this report, we mean black-legged kittiwake.

The research questions of our study were:

1) Do arctic terns and black-legged kittiwakes prefer foraging at glaciated coastline or at non-glaciated coastline?
2) Do arctic terns and black-legged kittiwakes prefer foraging close to the coast or further away from the coast?

Our hypotheses were:

1) Arctic terns prefer foraging at glaciated coastline.
2) Arctic terns prefer foraging close to the coast.
3) Black-legged kittiwakes prefer foraging at glaciated coastline.
4) Black-legged kittiwakes prefer foraging close to the coast.

The objective of this study was: investigating the differential use of fishing waters by arctic terns and black-legged kittiwakes, in relation to coast type. Both species are present in Kongsfjorden, Svalbard, which is a fjord that has been researched relatively well. Our study contributes to understanding this ecosystem. Other glacial fjords may have a comparable ecosystem and therefore we could understand the processes occurring there.

The question is: can we measure the supposed temporal-spatial effects of marine food at or without glaciers by researching the relative density and the foraging behaviour of migratory birds? Migratory birds present in summer in Svalbard are the arctic tern (*Sterna paradisaea*) and black-legged kittiwake (*Rissa tridactyla*). Individuals of these species migrate from lower latitudes to the Arctic for breeding, and profit from a high food availability in the Arctic (Bluhm & Gradinger, 2008). Both species are found foraging at glaciers throughout Svalbard, although kittiwakes occur in larger numbers than arctic terns (Stempniewicz et al., 2017; Strøm et al,. 2012). Kittiwakes are regularly observed foraging at 'brown zones' in front of glaciers. These zones are turbid areas containing sediment carried in suspension (Hartley & Dunbar, 1937-1938; Lydersen, 2014; Stott, 1990). Main prey items of arctic terns and kittiwakes in Svalbard are zooplankton and fish (Hartley & Fisher, 1936; Noort, 2016). Arctic terns perform surface-pecking and plunge-diving to a depth of 30-50 cm (McCollough, 2006). Kittiwakes also forage at the surface.

We also investigated the vicinity of foraging arctic terns to the coast. Prey species of arctic terns are the amphipod *Gammarus locusta zaddachi* and the mysid *Mysis oculata*, which can be found in between large stones in shallow water in inshore zones (Hartley & Fisher, 1936). Since arctic terns can dive maximum 30-50 cm, these species are probably less available in water deeper than 50 cm, thus arctic terns are probably more likely to forage close to the shore at non-glaciated coastline. We expected that arctic terns forage close to the coast, where these crustaceans are more available due to shallower water. In our study we observed densities of birds within a distance of 400 m from the coast. Due to safety, we could not drive our boat closer to the coast. It would be dangerous to come to close to calving glaciers. The choice of 400 m is therefore a practical reason. The choice of driving 200 m from the coast gave us the opportunity to observe differences between densities close to and further away from the coast.

Gaining more knowledge about foraging patterns of migratory bird species breeding in the Arctic, will result in a better understanding of the processes in the food webs of the ecosystems in the Arctic. We can use our gained knowledge in protecting the vulnerable Arctic with its species, which are threatened by climate change.

2. Materials and methods

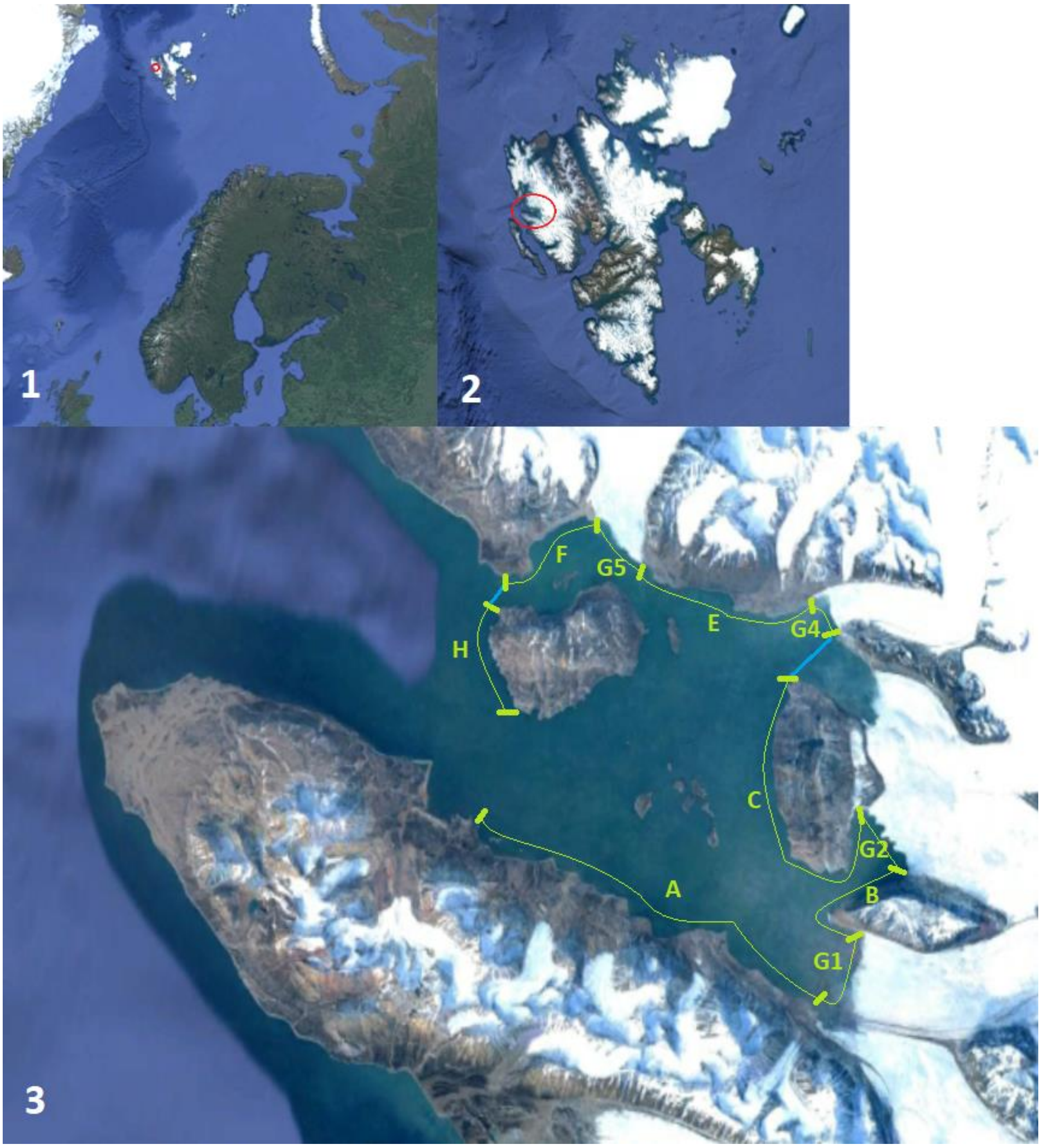
2.1 Boat-based surveys

Our fieldwork methods were based on the study performed by Stempniewicz et al (2017). They performed surveys along the coastline in an Arctic fjord and used the advice of Tasker et al (1984) in counting birds along line-transects. We selected a line-transect of 55 km in Kongsfjorden, Svalbard (Map 1). This transect followed the coast, at a distance of 200 m. From 21 June to 10 August 2017 we performed 8 weekly surveys by boat. During these surveys, we followed the transect counterclockwise. A rangefinder (Leica Geovid 7x42 BD) was used to determine the distance to the coast. Two observers who were skilled in recognizing both bird species counted foraging arctic terns and kittiwakes between the boat and the coast (starboard side) within a distance of 200 m, and also within 200 m at the port side of the boat, thereby covering a width of 400 m. One observer always observed at the port side, the other always observed at the starboard side. The survey thus covered an area of 22 km^2. The surveys started between 10:00 and 12:00 and lasted until between 14:00 and 16:00. The boat drove 15 km/h. The type of boat we used was an aluminum custom built boat with two engines and 60 hp. If ice blocked the line-transect, we temporarily chose a different route and if possible, we returned to the line transect. We continued counting birds within the 200 m on both sides of the boat, even if we temporarily chose another route.

We divided the coastline in two types of coast: (1) glaciated coastline and (2) non-glaciated coastline. The transect was divided into 10 sectors. 6 were non-glaciated sectors (A, B, C, E, F and H) and 4 were glaciers (G1, G2, G4 and G5). We did not count at Kongsbreen North, which is the glacier located between G2 and G4 (Map 1).

A GPS was used to create segments based on coastal factors within sectors. These locations were marked with a waypoint. Each count the waypoints were chosen at the same locations. The number of birds were noted down between two waypoints. We analyzed the number of individuals per species per sector.

Kittiwakes and arctic terns performed different foraging behaviour. While searching for food, arctic terns never floated on the water, while kittiwakes did. Arctic terns observed the water for prey while flying, while kittiwakes seemed not to be foraging while flying in a certain direction. We scored kittiwakes when they were performing the following behaviour: 1) plunge-diving, 2) foraging while sitting on the water surface 3) resting on the water surface. Individuals of arctic terns were counted when performing the following behavior: 1) plunge-diving, 2) flying. We noted down one arctic tern if the boat passed by one arctic tern performing one of the described behaviours. The same accounts for kittiwakes. Flying kittiwakes were ignored.



Map 1: Position of Kongsfjorden (red circle), Svalbard (Image Landsat/Copernicus). Picture 3 shows the transect we followed by boat. Surveys were performed along the green-yellow lines. The transect was divided in 10 sectors. 6 sectors were placed in front of non-glaciated coastline (A-H), and 4 sectors were placed in front of glaciers (G1-G5). Sectors were bordered by the bold lines perpendicular to the coast. We did not count at the blue lines, which are pelagic. We drove counter clockwise from A to H.

2.2 Coding localities

A code was assigned to each sector (Table 1). Each code starts with a letter of the sector and is then followed by C or O which means 'coast side' and 'open water side' subsequently. The port side of the boat was the open water side and the starboard side was the coast side. These sector codes are visible in the graphs and the accompanying subscripts in the results. The meaning of these codes can be found in Table 1.

Table 1: Overview of sector codes along the line-transect in Kongsfjorden, Svalbard. The port side of the boat was the open water side and the starboard side was the coast side.

Name of sector	**Sector**	**Sector code**	
		Coast side	**Open water side**
A	A	AC	AO
B	B	BC	BO
C	C	CC	CO
E	E	EC	EO
F	F	FC	FO
H	H	HC	HO
Kronebreen	G1	G1C	G1O
Kongsbreen South	G2	G2C	G2O
Conwaybreen	G4	G4C	G4O
Blomstrandbreen	G5	G5C	G5O
Glaciated coastline combined	GX	GXC	GXO
Non-glaciated coastline combined	X	XC	XO

The front part of glacier 1 (Kronebreen) consists of two glaciers. The southern glacier is Kongsvegen, and the northern part is Kronebreen. We call glacier 1 Kronebreen because the largest part of the glacier front is part of the Kronebreen glacier.

2.3 Statistical analyses

In order to compare the densities of the species per sector, we transformed the counted numbers of each species to density (n/km^2) per sector per observation day. These densities were ln transformed prior to analysis in IBM SPSS Statistics 25.

When comparing the densities at the coast side of the sectors, an ANOVA and the Tukey HSD *post hoc* test were performed. The same tests were used for comparing the densities at the open water side of the sectors.

The ln transformed densities of the sectors were aggregated in two groups: non-glaciated coastline and glaciated coastline. The t-test was used to compare the coast side of the non-glaciated coastline with the coast side of the glaciated coastline. The same procedure was repeated for the open water side.

A paired t-test was used for comparing the coast side with the open water side of glaciated coastline. We repeated the same procedure for non-glaciated coastline.

In the graphs of the results section, we created boxplots. Horizontal black bars in the boxplots are the medians.

3. Results

3.1 Distribution of kittiwakes

The mean density of kittiwakes near the coast was much higher at the glaciated sites (ANOVA, $p = <0.001$, $F_{9,55}=5.470$; Tukey HSD *post hoc* test, Appendix C1, Table 10 and 11). Mean densities of kittiwakes tended to be higher at all four glaciers compared to non-glaciated coastline at the coast side, with means varying from 41.68/km^2 - 159.17/km^2 at the coast side of glaciers, and means varying from 0/km^2 - 6.23/km^2 at the coast side of non-glaciated coastline (Fig. 2 and Table 2). Appendix B, Fig.11, shows the densities before ln transformation.

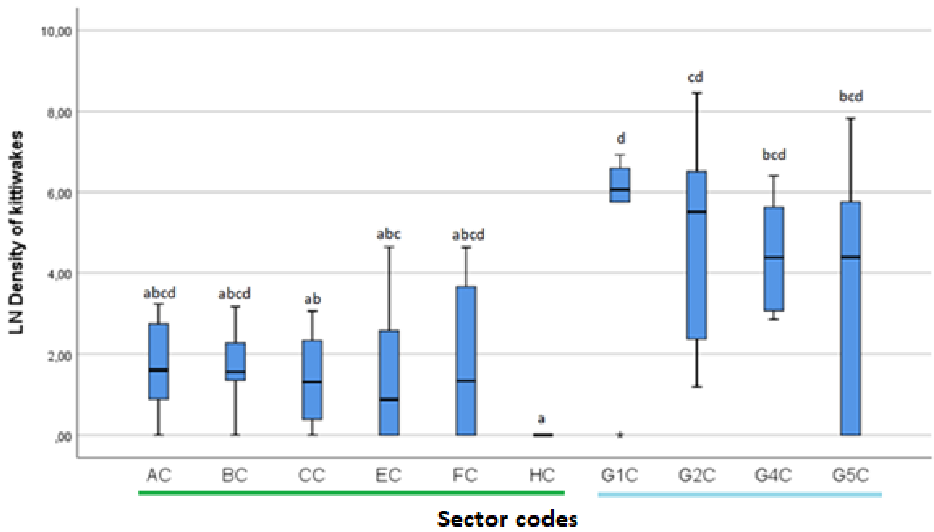


Figure 2. *Natural logarithm of observed density of kittiwakes (n/km^2) at the sector codes. AC to HC (above green line) = sector codes at non-glaciated coastline. G1C to G5C (above light blue line) = sector codes at glaciers (Map 1, Table 1). Horizontal black bars in boxes are the medians. The letters above the boxes represent the homogeneous subsets which are based on the means (Tukey HSD post hoc test, Appendix C1, Table 10 and 11; Table 2). Number of observations per sector code: A: 8, B: 7, C: 8, E: 8, F: 4, H: 7, G1: 5, G2: 6, G4: 6 G5: 6.*

Table 2. *The number of observations, mean, median, lowest value and highest value of the density of kittiwakes at the coast side of the sectors. The mean, median, lowest value and highest value are back transformed.*

Sector code	**Nr of observations**	**Mean**	**Median**	**Lowest value**	**Highest value**
AC	8	5.58	5.00	0.00	25.53
BC	7	5.53	4.76	0.00	23.57
CC	8	4.01	3.71	0.00	21.33
EC	8	4.22	2.41	0.00	104.58
FC	4	6.23	3.82	0.00	103.54
HC	7	0.00	0.00	0.00	0.00
G1C	5	159.17	428.38	0.00	1012.32
G2C	6	138.38	247.15	3.29	4675.07
G4C	6	85.63	79.84	17.46	601.85
G5C	6	41.68	81.45	0.00	2489.91

The mean densities of kittiwakes at the sector codes on the open water side were similar (ANOVA, $F_{9,57}$=1.336; p=0.239; Fig. 3 and Table 3)

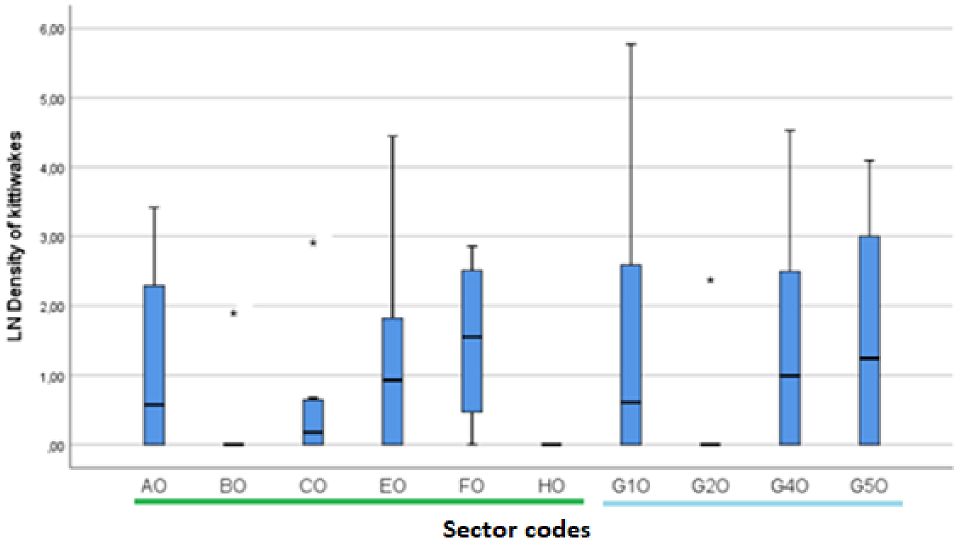


Figure 3. *Natural logarithm of observed density of kittiwakes (n/km²) at the sector codes. AO to HO (above green line) = sector codes at non-glaciated coastline. G1O to G5O (above light blue line) = sector codes at glaciers (Map 1, Table 1). Horizontal black bars in boxes are the medians. The letters above the boxes represent the homogeneous subsets which are based on the means (Tukey HSD post hoc test, Appendix C1, Table 9; table 3). Number of observations per sector code: A: 8, B: 7, C: 8, E: 8, F: 4, H: 7, G1: 5, G2: 6, G4: 6, G5: 8.*

Table 3. *The number of observations, mean, median, lowest value and highest value of the density of kittiwakes at the open water side of the sectors. The mean, median, lowest value and highest value are back transformed.*

Sector code	**Nr of observations**	**Mean**	**Median**	**Lowest value**	**Highest value**
AO	8	3.13	1.77	0.00	30.57
BO	7	1.31	0.00	0.00	6.69
CO	8	1.77	1.20	0.00	18.36
EO	8	3.46	2.53	0.00	85.63
FO	4	4.44	4.71	0.00	17.46
HO	7	0.00	0.00	0.00	0.00
G1O	5	5.99	1.84	0.00	320.54
G2O	6	1.49	0.00	0.00	10.70
G4O	6	4.48	2.69	0.00	92.76
G5O	8	4.81	3.46	0.00	60.34

The mean density of kittiwakes at the coast side of the glaciated coastline (91.84/km²) was higher than the coast side of non-glaciated coastline (3.53/km²) (independent samples t-test, df=29.040, p<0.001; Appendix C2, Table 16). The mean density of kittiwakes at the open water side of the glaciated coastline (3.74/km²) and non-glaciated coastline was similar (2.05/km²; independent samples t-test, df=35.902, p=0.131; Appendix C2, Table 15; Fig. 4, Table 4).

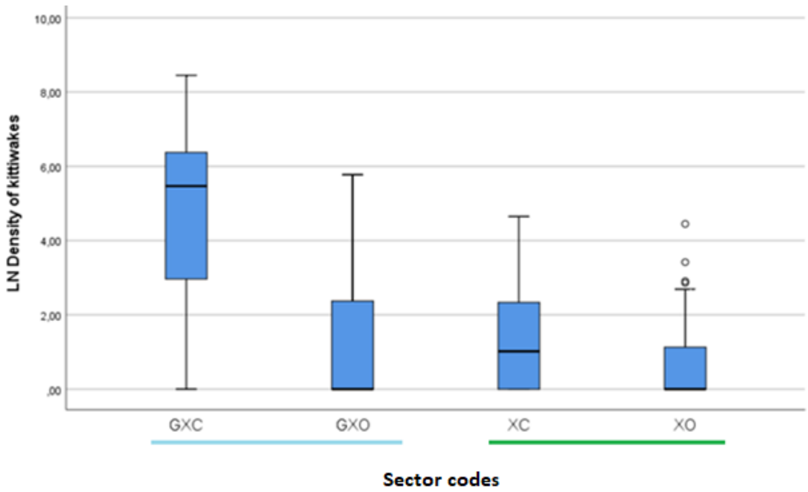


Figure 4. *Natural logarithm of observed density of kittiwakes (n/km^2) at an aggregation of the sector codes. GXC and GXO (above light blue line) = sector codes at glaciers. XC and XO (above green line) = sector codes at non-glaciated coast line (Map 1, Table 1). Horizontal black bars in boxes are the medians (Table 4). Number of observations per sector codes: GXC: 23, GXO: 25, XC: 42, XO: 42.*

Table 4. *The number of observations, mean, median, lowest value and highest value of the density of kittiwakes at the coast side and the open water side of the glaciated coastline and the non-glaciated coastline. The mean, median, lowest value and highest value are back transformed.*

Sector codes	**Nr of observations**	**Mean**	**Median**	**Lowest value**	**Highest value**
GXO	25	3.74	0.00	0.00	320.54
XO	42	2.05	0.00	0.00	85.63
GXC	23	91.84	237.46	0.00	4675.07
XC	42	3.53	2.77	0.00	104.58

At the aggregated coast sides of the glaciated coastline, the mean density of the kittiwakes was higher (91.84/km^2) than at the open water side (3.74/km^2; paired samples test, df=22, p<0.001; Appendix C3, Table 19). This was also the case for the aggregated coast sides of the non-glaciated coastline, where the mean density of kittiwakes was higher (3.53/km^2) than at the open water side (2.05/km^2; paired samples test, df=43, p=0.006; Appendix C3, Table 20).

3.2 Distribution of arctic terns

For the arctic tern, the mean densities at the various near-coast sites sector codes were rather similar at about 10/km^2, except for one site (G5C, mean density 113.30/km^2; ANOVA, $F_{9,55}$ = 5.363, p<0.001; Tukey HSD *post hoc*, Appendix C1, Table 14; Fig. 5 and Table 5). The densities at the near-coast side were not significantly different. Appendix B, Fig. 10, shows the densities before ln transformation.

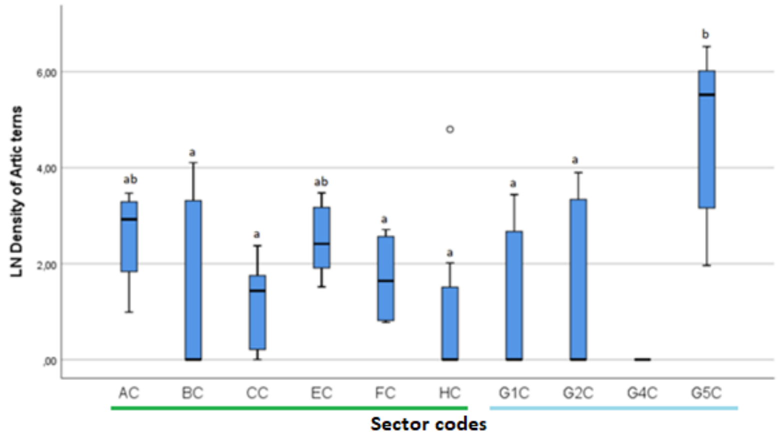


Figure 5. *Natural logarithm of observed density of arctic terns (n/km²) at the sector codes. AC to HC (above green line) = sector codes at non-glaciated coastline. G1C to G5C (above light blue line) = sector codes at glaciers (Map 1, Table 1). Horizontal black bars in boxes are the medians. The letters above the boxes represent the homogeneous subsets which are based on the means (Tukey HSD post hoc test, Appendix C1, Table 14; Table 5). Number of observations per sector code: A: 8, B: 7, C: 8, E: 8, F: 4, H: 7, G1: 5, G2: 6, G4: 6, G5: 6.*

Table 5. *The number of observations, mean, median, lowest value and highest value of the density of arctic terns at the coast side of the sectors. The mean, median, lowest value and highest value are back transformed.*

Sector code	**Nr of observations**	**Mean**	**Median**	**Lowest value**	**Highest value**
AC	8	13.07	18.54	2.69	32.14
BC	7	4.62	0.00	0.00	60.34
CC	8	3.16	4.18	0.00	10.70
EC	8	12.18	11.13	4.57	32.14
FC	4	5.42	5.16	2.16	15.03
HC	7	3.06	0.00	0.00	5.53
G1C	5	3.39	0.00	0.00	31.19
G2C	6	3.35	0.00	0.00	49.40
G4C	6	0.00	0.00	0.00	0.00
G5C	6	113.30	249.64	7.10	678.58

The mean densities at the open water sides of the sectors showed a bit more variation and local absences (HO, G4O) than at the near-coast locations (ANOVA, $F_{9,57} = 4.763$, $p<0.001$; Tukey HSD *post hoc* test, Appendix C1, Table 13). The density at G5O (21.76/km²) surpassed that of most others again (Fig. 6 and Table 6).

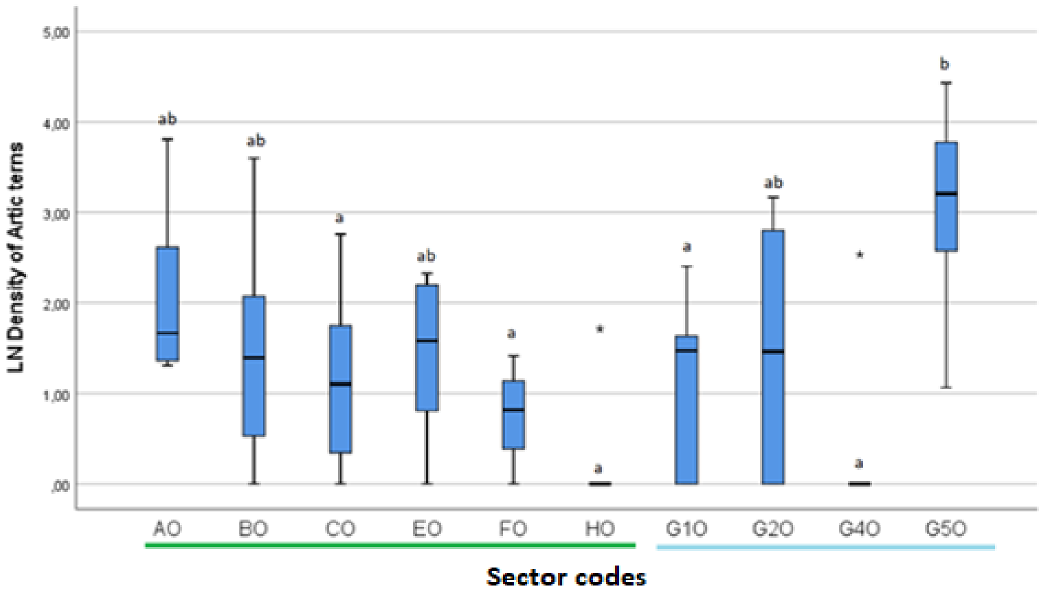


Figure 6. *Natural logarithm of observed density of arctic terns (n/km²) at the sector codes. AC to HC (above green line) = sector codes at non-glaciated coastline. G1C to G5C (above light blue line) = sector codes at glaciers (Map 1, Table 1). Horizontal black bars in boxes are the medians. The letters above the boxes represent the homogeneous subsets which are based on the means (Tukey HSD post hoc test, Appendix C1, Table 13; Table 6). Number of observations per sector code: A: 8, B: 7, C: 8, E: 8, F: 4, H: 7, G1: 5, G2: 6, G4: 6, G5: 8.*

Table 6. *The number of observations, mean, median, lowest value and highest value of the density of arctic terns at the open water side of the sectors. The mean, median, lowest value and highest value are back transformed.*

Sector code	**Nr of observations**	**Mean**	**Median**	**Lowest value**	**Highest value**
AO	8	7.77	5.31	3.71	45.15
BO	7	4.31	4.01	0.00	36.60
CO	8	3.13	3.00	0.00	15.80
EO	8	4.22	4.85	0.00	10.28
FO	4	2.14	2.27	0.00	4.14
HO	7	1.27	0.00	0.00	5.53
G1O	5	3.00	4.35	0.00	11.02
G2O	6	4.39	4.31	0.00	23.81
G4O	6	1.52	0.00	0.00	12.55
G5O	8	21.76	24.78	2.89	83.93

The mean density of arctic terns at the coast side of the glaciated coastline (6.23/km²) and non-glaciated coastline (6.11/km²) was similar (independent samples t-test, df=29.866, p=0.974; Appendix C2, Table 18; Fig. 7 and Table 7).
Similarly, the mean density of arctic terns at the open water side of the glaciated coastline (5.26/km²) and non-glaciated coastline (3.46/km²) was similar (independent samples t-test df=37.080, p=0.223; Appendix C2, Table 17; Fig. 7 and Table 7).

Table 7. *The number of observations, mean, median, lowest value and highest value of the density of arctic terns at the coast side and the open water side of the glaciated coastline and the non-glaciated coastline. The mean, median, lowest value and highest value are back transformed.*

Sector code	Nr of observations	Mean	Median	Lowest value	Highest value
GXO	25	5.26	5.10	0.00	83.93
XO	42	3.46	3.71	0.00	45.15
GXC	23	6.23	0.00	0.00	678.58
XC	42	6.11	6.36	0.00	60.34

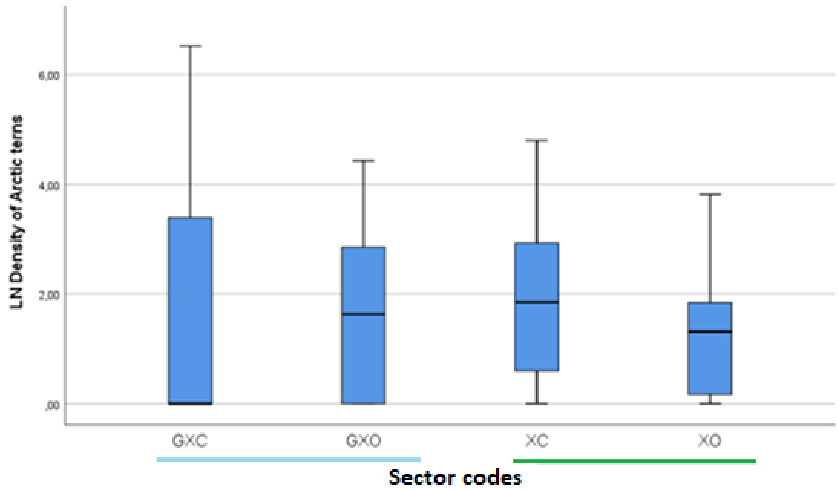


Figure 7. *Natural logarithm of observed density of arctic terns (n/km²) at an aggregation of the sector codes. GXC and GXO (above light blue line) = sector codes at glaciers. XC and XO (above green line) = sector codes at non-glaciated coast line (Map 1, Table 1). Horizontal black bars in boxes are the medians. Number of observations per sector codes: GXC: 23, GXO: 25, XC: 42, XO: 42.*

There was no difference in mean density of arctic terns between the coast side (6.23/km^2) and the open water side (5.26/km^2) of all glacier sector codes combined (paired samples test, df=22, p=0.441; Appendix C3, Table 21). At the coast side of all sector codes of the non-glaciated coast (6.11/km^2), the mean density of arctic terns was higher than at the open water side (3.46/km^2) of all non-glaciated coast (paired samples test, df=43, p=0.001; Appendix C3, Table 22).

4. Discussion

4.1 Summary of results

During this study we analyzed whether kittiwakes and arctic terns showed a preference for foraging at glaciated coastlines or non-glaciated coastlines in a glacial fjord. Additionally we analyzed whether kittiwakes and arctic terns showed a preference for foraging close to the coast (0-200m from the coast line) versus further away from the coast (200-400m from the coastline, the open water side).

We observed high numbers of kittiwakes in front of glaciers. They were mostly present in large groups, gathered in a food frenzy. The mean density of kittiwakes at the coast side of the glaciated coastline was higher than the coast side of non-glaciated coastline. At both glaciated and non-glaciated coastline, kittiwakes showed preference for foraging close to the coast (0-200m from the coast).

The mean density of arctic terns at the glaciated coastline and non-glaciated coastline was similar, although they tended to show preference for G5, Blomstrandbreen. Nearby the coast (0-200m from the coast) of non-glaciated coast, the mean density of arctic terns was higher than further away from the coast (200-400m).

4.2 Comparison of results with literature

4.2.1 Kittiwake

Stempniewicz et al. (2017) performed line-transect surveys by boat in Burgerbukta, in Hornsund, Svalbard. The size of Burgerbukta was 34,4 km^2. The transect area was 8.86 km^2. They counted foraging individuals and excluded birds that were floating on the water or that were flying. The average number of kittiwakes in the transect area varied from 371 in 2014 to 2069 in 2015. This number was significantly larger than the average number of arctic terns (4 in 2014 and 11 in 2015). The following percentages show the percentage of kittiwakes present at different coast types: 77.0% in 2014 and 75.3% in 2015 in glaciated sectors (this included tidewater glaciers and coastline terminating glaciers); 73.9% in 2014 and 75.1% in 2015 at tidewater glaciers; 3.1% in 2014 and 0.2% in 2015 at coastline terminating glaciers and 23.0% in 2014 and 24.7% in 2015 at non-glaciated coastline.

After statistical analysis, they found that the largest share of kittiwakes was present at glaciers. Of the glaciated sectors tidewater glaciers were clearly the most attractive to the kittiwakes: the kittiwake preferred tidewater glaciers over non-glaciated coastline. The 4 glaciers we observed in Kongsfjorden were tidewater glaciers. We did not observe at coast line terminating glaciers.

We counted the kittiwakes floating on the water or performing plunge-diving. In our study, an average of 769 kittiwakes was present in the fjord (Appendix A, table 8). 85.66% of the kittiwakes was present at glaciers. 14.34% was present at non-glaciated coastline. We calculated an average of 35 kittiwakes per km^2 in our study*. Stempniewicz et al. (2017) did not mention density, but by calculating their data we found a density of 42 kittiwakes per km^2 in 2014 and 233 kittiwakes per km^2 in 2015 in Burgerbukta**.

In our study, our densities were lower than in Burgerbukta. As described in 'improvements of our our study for future research' in the discussion section, we were unable to count the number of kittiwakes that was present behind blocks of ice or were foraging outside the 200 m width at the starboard side. Therefore, the number of kittiwakes could have been higher in reality. But Stempniewicz et al. (2017) did not count kittiwakes resting on the water, so their number would have increased if they would have counted those individuals too.

Our study shows similar results to what Stempniewicz et al. (2017) describe: kittiwakes prefer tidewater glaciers over non-glaciated coastline.

Besides this, Stempniewicz et al. (2017) observed at two coastline terminating glaciers and described that glacier rivers coming from these glaciers entered shallow bays. These bays seemed less interesting for birds. They also observed a strong interannual difference in number of kittiwakes in the fjord (the number of kittiwakes was 4 times higher in 2015 compared to 2014), this difference did not affect their distribution or habitat choice.

Strøm et al. (2012) performed aerial surveys throughout Svalbard in August and September of

2010/11 and reported 70000 kittiwakes in the area. The majority of these birds was foraging at glacier fronts.

Hartley and Fisher (1936) observed a large group of kittiwakes at a cave that was part of the glacier. Water was streaming down from the cave. Kittiwakes flew to the opening of the cave, rested on the water, and were then transported with the stream further away from the cave. After having floated away for several meters, they flew back to the opening of the cave. We observed similar behavior at glaciers where streams departed. This behaviour might suggest that a subsurface freshwater plume was released from the glacier and raised to the surface in front of the glacier (Fig. 8) (Lydersen et al., 2014). The freshwater discharge may have paralyzed or killed zooplankton and fish. Kittiwakes consumed the prey that reached the surface. Further away from the opening, most prey items were consumed by kittiwakes close to the glacier. Therefore flying back to the glacier front could increase consumption rates. More information about his process can be found at 'processes at glaciers' in the discussion section. More detailed information about other processes taking place at tidewater glaciers including the resulting circulation in the fjord can be found in the report by Lydersen et al. (2014).

* 769 (average number of kittiwakes) / 22 (transect area is 22 km^2) = 35
** 371 (average number of kittiwakes) / 8,86 (transect area is 8,86 km^2) = 42; 2069 (number of kittiwakes)/8,86 (transect area is 8,86 km^2) = 233

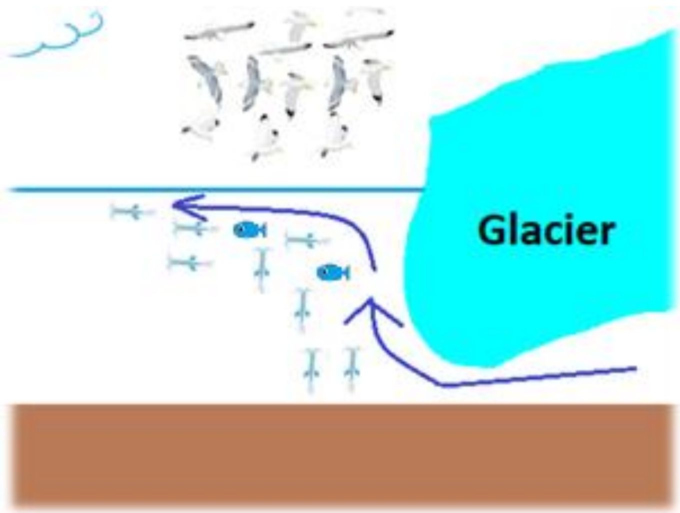


Fig. 8: Kittiwakes forage at a glacier front and the tidewater glacier releases subsurface meltwater. The purple arrows visualize the rising plume that entrains fjord water and transports zooplankton and fish to the surface. Brown area: the floor of the fjord. This figure is adapted from Lydersen et al. (2014).

4.2.2 Arctic tern

Stempniewicz et al. (2017) also counted arctic terns in Burgerbukta, the way that is described at 'kittiwake' in the discussion section. They counted foraging individuals, and did not count arctic terns in flight. An average of approximately 8 foraging arctic terns was present in 2014 and 2015. This number was significantly smaller than the number of kittiwakes present in Burgerbukta.

Stempniewicz et al. (2017) drew two conclusions: 1) the largest share of Arctic terns was present at non-glaciated coastline; 2) the highest density of arctic terns was observed at coastline terminating glaciers. This information is contradictory: arctic terns prefer non-glaciated coastline, but the highest density was observed at coastline terminating glaciers. Based on their supplementary material, we expect that they mean that the arctic terns were foraging most often at non-glaciated coastline. In their study, the percentage of arctic terns foraging at tidewater glaciers varied from 2.6% 2014 to 14.3% in 2015. The percentage foraging at non-glaciated coastline was 58% in 2014 and 61% in 2015. The remaining percentages (39.4% in 2014 and 24.7% 2015) were foraging at coastline terminating glaciers.

In our study, we counted foraging arctic terns and arctic terns in flight. We counted an average of 270 arctic terns in Kongsfjorden. 44.42% of the arctic terns was present at glaciers; 55.58% was present at non-glaciated coastline (Appendix A, Table 8). After statistical analysis we concluded that densities at non-glaciated and glaciated coastline were similar. We observed 12 arctic terns per km^2 ***. Stempniewicz et al. (2017) observed a density of approximately 1/km^2 in 2014 and 2015. Note that we also counted flying arctic terns. In our study, the majority of arctic terns was flying without actively foraging (Schumacher, J.E., personal observation). Comparison with Stempniewicz et al. (2017) is therefore difficult.

In their report, they call the arctic tern a pelagic feeder, but do not describe why they chose this word. In our study, the arctic terns were foraging more nearby the coast (0-200m) instead of further away from the coast (200-400m). Therefore we would call it a 'coastal feeder', which is another foraging strategy used in their paper. We did not analyze densities of arctic terns in pelagic areas, but during our survey we crossed pelagic waters and the number of arctic terns appeared to be lower in these areas compared to coastal areas (Schumacher, J.E., personal observation).

Lydersen et al. (2014) also observed arctic terns at glacier fronts, but kittiwakes outnumbered arctic terns.

*** 270 (average number of arctic terns) / 22 (transect area is 22 km2) = 12

4.3 Foraging locations

In our study, important foraging spots for kittiwakes and sometimes arctic terns were locations where glacier meltwater was visibly discharged: 1) at some locations amounts of fresh water were discharged above the water surface, streaming down at high speed as glacier rivers; 2) another location was a turbid water current departing from G1 (name of glacier: Kronebreen). Compared to Kongsvegen (the southern part of the glacier front at G1), Kronebreen (the northern part of the glacier front at G1) has the largest amount of freshwater discharge (Loonen, M.L., personal communication). This freshwater contains a lot of sediment, which gives the fjord water a brown color, thus creating a 'brown zone'. While this brown zone was clearly present in front of Kronebreen (Appendix, Fig. 14), it was absent in front of Blomstrandbreen (G5). This might suggest that the amount of sediment released by Kronebreen is large, and small at Blomstrandbreen. The absence of a 'brown zone' at Blomstrandbreen could explain why arctic terns where foraging there in large numbers. Observing prey is important in their hunting strategy and sediment in water could decrease visibility of prey. Brown zones were visible at several glaciers in the fjord (Appendix H, Fig. 13 and 14), sometimes large parts in front of the glaciers were brown zones, and sometimes the origin of brown zones was local along a glacier front. Several authors describe that kittiwakes forage in brown zones (Hartley & Dunbar, 1937-1938; Lydersen, 2014; Stott, 1990). In Appendix H, figure 13, a picture of brown zones in front of glaciers 1 and 2 can be found.

Besides this, arctic terns and kittiwakes preferred foraging close to the coast at non-glaciated coastline. Non-glaciated shorelines were shallower than shorelines at glaciated coastline. The shoreline in front of a glacier was relatively deep. Non-glaciated coastline mostly looked like beaches with shallow water along the coast. Prey living in between stones in shallow water at non-glaciated coastline were therefore probably more available.

4.4 Processes at glaciers

Several processes might explain why kittiwakes and arctic terns forage at glaciers (Fig. 1).

1) Tidewater glaciers release subsurface freshwater plumes with a low density, due to the absence of salt. As a result these plumes rise to the surface, thereby entraining surrounding fjord water. These waters may contain organisms like zooplankton and fish, which can be transported to the surface, making them easily available for surface pecking predators (Fig. 8). The freshwater plume can also paralyze or kill these organisms by means of osmotic shock, which increases their predation risk (Lydersen et al., 2014; Stempniewicz, et al., 2017*).* Although researchers suspect that this process plays an important role in the formation of foraging hotspots, important data is missing to underpin this process and to evaluate how much this process influences food availability. Dangerous glacier calving avoids researchers from collecting data near glacier fronts. However, Weslawski and Legezynska (1998) investigated the sea floor of Kongsfjorden, several hundreds of meters from Kronebreen, and they found 500 dead copepod

individuals and 130 dead *Themisto* sp. per square meter. This phenomenon could be the result of the osmotic shock of the freshwater plume. Another explanation could be the consumption of fine mineral particles, disturbing bodily functions, possibly resulting in death.

2) Glaciers release sediment that contain nutrients, which are consumed by phytoplankton (Apollonio, 1973) and heterotrophs (Hood & Scott, 2008; Hood et al., 2009), thus promoting primary production. This influences the food web, and could therefore promote fish production, resulting in an increased food supply for the birds. However, when larger amounts of sediment enter the glacier bay, light penetration is strongly reduced. As a result, the depth of the euphotic zone is reduced (Svendsen et al., 2002). In euphotic zones primary production takes place. Therefore turbidity is a limiting factor for primary production in zones close to the glacier front. Sediment can thus promote and inhibit primary production. In Appendix H, figure 13, 'brown zones' are visible, which is fjord water that contains sediment.
3) Glaciers release large amounts of sediments. This sediment laden water reduces light penetration and can therefore affect the diurnal vertical migration of zooplankton and fish. This migration is driven by predator avoidance and feeding. Due to the lower light conditions they occur higher in the water column, making them more available for predators foraging in the upper water layers (Abookire et al., 2002; Frank & Widder, 2002).
4) During daytime euphausiids may be present at the surface for reproductive behavior (Arimitsu et al., 2012; Hanamura et al., 1989). This increases their risk for predation and increases food availability for surface pecking predators.
5) Fish use the lateral line of their sensory system and their vision to be able to swim in schools. Reduced light penetration by sediment in the water may decrease their vision and therefor may impede their schooling behavior (Partridge & Pitcher, 1980). As a result the schools may be less dense, increasing the chance being caught by a predatory bird.

Besides these processes, another reason might partially explain the choice for foraging at glaciers. At Gerdøya, which is a small island in the fjord that is located close to Blomstrandbreen, there was a breeding location for arctic terns. This could partly explain the large numbers of arctic tern foraging at Blomstrandbreen.

Apart from birds, tracking studies in Svalbard uncovered that ringed seals and white whales frequently dive at glacier fronts. Researchers expect that these animals forage at these locations (Lydersen et al., 2014). These mammals may profit from the same foraging hotspots as arctic terns and kittiwakes.

4.5 Prey species

We performed a literature research about prey species found in the stomachs of arctic terns and kittiwakes. Understanding the distribution of these prey species could explain the observed foraging patterns of the bird species. Information about prey species is located in the Appendix of this report (Appendix G). If useful information about distribution of important prey species was available, we put it in this section.

In the last century, zooplankton and fish have been found in stomachs of arctic terns and kittiwakes in Svalbard (Hartley and Fisher, 1936; Mehlum, 1984). These prey might be abundant in foraging hotspots at glaciers, as described in 'processes at glaciers' in the discussion section. Hartley and Fisher (1936) performed research in Billefjorden, Svalbard. They examined the content of stomachs of kittiwakes and arctic terns. Among several species, they found *Themisto libellula* and *Thysanoessa inermis.* Mehlum (1984) performed research in Kongsfjorden, Svalbard, and found *Themisto libellula* in the stomachs of kittiwakes. *Themisto libellula* was also found in the stomach of polar cod present in the stomach of the kittiwakes. From 2006 to 2011, Dalpadado et al. (2016) analyzed the distribution of amphipods and euphausiids in Kongsfjorden. They used a net and pulled it up vertically from a depth of approximately 20 meters. At the entrance of the fjord, they found low numbers of the amphipod *Themisto libellula* (mean: 14 individuals per m^2). As they progressed into the fjord, they found more individuals of *Thermisto libellula*. In front of Kronebreen (G1 in our study), a density of 500 individuals per m^2 was found. Their research could suggest that *Themisto libellula* is more available in front of Kronebreen. Therefore *Themisto libellula* could be an important prey species in the foraging hotspots at glacier fronts. The euphausiid *Thysanoessa inermis* was found in highest numbers (mean: 754 individuals per m^2), several hundred meters south from the island Blomstrand (this is the large island visible south of Blomstrandbreen (G5 in our study), Map 1), and in lower numbers in front of Kronebreen (mean: 183 individuals per m^2). An average of 183 per m^2 could contribute to foraging hotspots at Kronebreen. Although higher numbers of *Thysanoessa inermis* are found nearby the island Blomstrand, an average of

183 m^2 nearby Kronebreen can contribute to foraging hotspots. It must be noted that the sampling location was located several hundred of meters away from the glacier front of Kronebreen. Information about densities of these species directly in front of the glacier was missing in their report.

In August 2017 we temporarily observed parent arctic terns bringing food to their chicks at a nest site at Ny-Ålesund, a village on the south coastline of Kongsfjorden. We observed fish and crustaceans being delivered (Schumacher, J.E., unpublished data). We also observed arctic terns foraging in a freshwater lake at Ny-Ålesund, Kongsfjorden. *Lepidurus arcticus* occurred in this freshwater lake (Solvatnet) in Ny-Ålesund (Sanne Moedt, personal communication, August 1, 2017). Since the only other relatively large organism living there was the water flea, which would probably be too small as a prey species, we expect that the terns were consuming *Lepidurus arcticus*. Hartley and Fisher (1936) found this species in the stomachs of arctic terns. This shows that arctic terns are not fully dependent on fjord water for prey.

During our study, we observed a higher density of arctic terns at the coast side compared to the open water side. We also observed arctic terns successfully foraging in between large stones at the coastline of Ny-Ålesund. At close inspection of the coast we found *Gammarus* sp. and unidentified fish (Schumacher, J.E., unpublished data), possibly being their food. In the stomach content of arctic terns Hartley and Fisher (1936) found prey species (*Gammarus locusta zaddachi* and *Mysis oculata*) that occur close to large stones in inshore zones. *Gammarus* was found in shallow waters. This suggests that arctic terns in Kongsfjorden can obtain their food from non-glaciated foraging waters. Arctic terns are surface pecking predators and can only dive to a depth of 30 cm. In shallower water these prey could possibly be caught by the terns.

4.6 Significance of this study

Investigating the distribution of arctic terns and kittiwakes in Svalbard gives a better understanding of what locations these birds prefer and what biotic and abiotic factors may influence their foraging behaviour. Many researchers, including us, have observed the importance of tidewater glaciers for arctic terns and especially kittiwakes (Hartley & Fisher, 1936; Lydersen et al., 2014; Stempniewicz et al., 2017). Since we know that through climate change glaciers retreat and may eventually disappear (Kohler et al., 2007), we can expect that this will influence the distribution and will affect the number of individuals of these species in the Arctic. We expect that climate change has mostly negative effects, but there could temporary be a positive effect.

Since the release of meltwater at glacier fronts creates foraging hotspots for predators, we think that in theory there is a possibility that an increase of meltwater discharge due to climate change could temporarily result in more food for predators. Stott (1990) suggests that high temperatures result in more melting and this may create a stronger upwelling at glacier fronts. Increased glacier melt can therefor paralyze or kill more zooplankton. This process could be temporary during summer, but when climate changes and rising temperatures increase melt, temporarily more prey items could be available.

But if glaciers reduce in size, the amount of meltwater will also decrease. If the observed acceleration of the thinning of glaciers proceeds and glacier retreat continues (Kohler et al., 2007), the number and the size of glaciers will reduce.

Besides this, when tidewater glaciers have retreated so much that the front part is positioned on the land, then subsurface meltwater discharge is absent. Organisms that are usually brought upwards in the freshwater plume at tidewater glacier fronts, will stay at lower depth, avoiding them from being caught by surface pecking birds (Lydersen et al., 2014). This reduces food availability for arctic terns and kittiwakes.

Due to glacier retreat, the distance of a breeding location to a foraging hotspot at a glacier, might also increase (Fig. 9). A larger flying distance results in higher energy costs and might enlarge predation risk of the chicks, since parents are longer absent for foraging, and are not able to protect their young in their absence.

In Figure 9, one can see the retreat of Blomstrandbreen (G5) in the past century (Kohler, 2017). A breeding location has been present since 1956 (Strijbos, 1956) on the small island Gerdøya with the red circle. The flying distance between the glacier and the breeding location has increased over the previous decades.

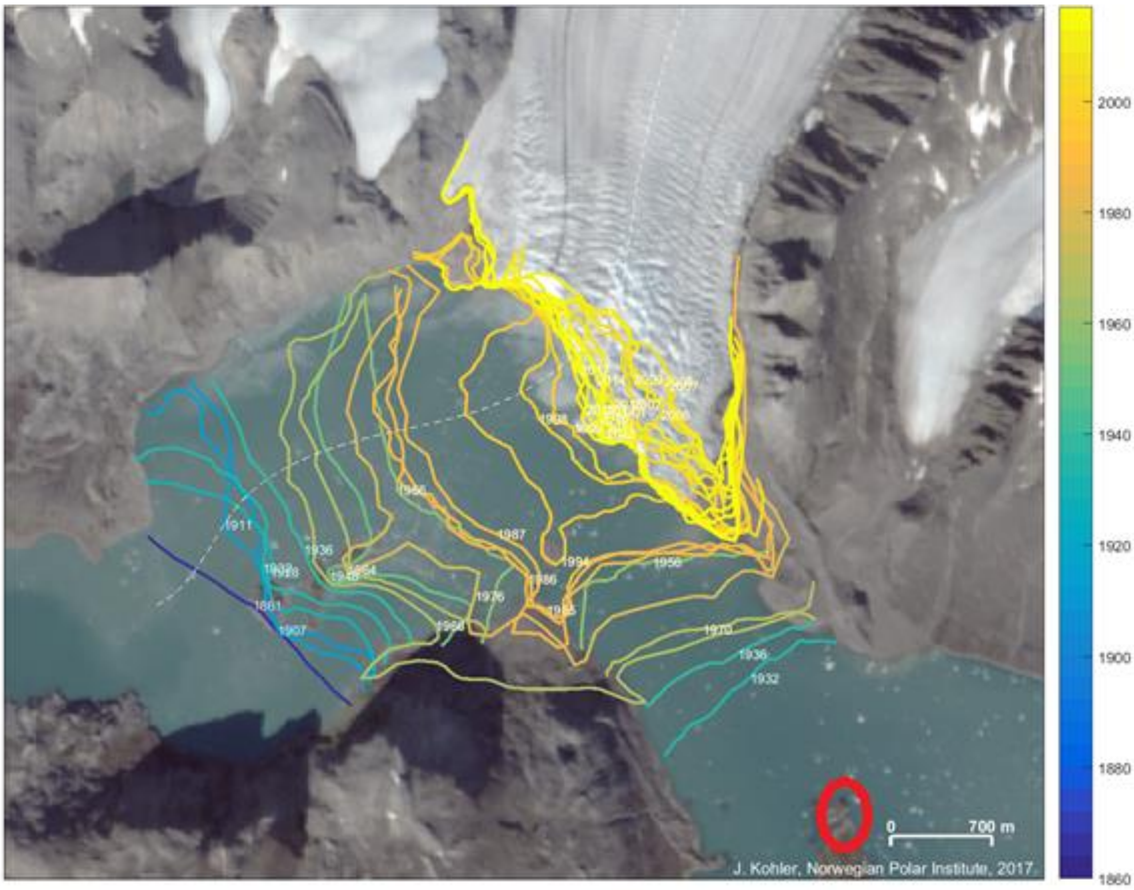


Figure 9: Retreat of Blomstrandbreen in Kongsfjorden, Svalbard, in the last century (Kohler, 2017). Lines show locations of the glacier front during the several years. Breeding location of arctic terns at the small island Gerdøya (red circle).

The decrease of glacier size will eventually probably result in less, less dense and smaller foraging hotspots for arctic terns and kittiwakes (Lydersen et al., 2014). This could influence number and distribution of these species foraging in glacial fjords. Kovacs (2011) already described that the number of individuals of certain endemic Arctic mammals has declined due to the reduction of sea ice. He also observed shifts in distribution.

In the process of climate change and glacier melt, the distribution of migratory birds in Svalbard could also shift. Birds profiting from a high food availability at glaciers, could move to locations in Svalbard where glaciers with foraging hotspots would still be present. In the future, space and the availability of food, will possibly be limiting factors. This could affect the body condition and reproduction success of individuals and could result in lower population numbers.

Our study shows that kittiwakes clearly profit from foraging at tidewater glaciers, so we expect that what we stated above might apply to kittiwakes. We expect that there will be a strong decrease in the number of kittiwakes in the future.

A large part of the arctic terns also foraged at non-glaciated coastline, so we expect a slight decrease in the number of arctic terns in the course of climate change. The distribution might also change since they will move to non-glaciated shorelines.

4.7 Improvements of our study for future research

4.7.1 Fieldwork

What affected our conclusions most were 1) the small sample size. Sample size has to be larger to get a realistic view on distribution in the fjord and in order to be able to show more significant differences. We sometimes were not able to show significant differences between sectors in our study and we expect that if sample size was larger, we could have found more significant differences. 2) Sometimes it was difficult to boat 200 m from the coast. Our route was regularly blocked due to floating pieces of ice, and being too close to some glaciers was dangerous due to glacier calving. Therefore, we sometimes had to keep a distance of at least 300 meters from the glacier. In our study, we only counted within 200 m from our boat. If a large flock of kittiwakes was present very close to the glacier, and therefore further away than 200 m, we did not count them. This means that the numbers of kittiwakes at glaciers were higher than we counted. If we could have counted all kittiwakes, numbers sometimes would have increased significantly. 3) Sometimes a lot of ice blocked our view. This means that we missed individuals floating or flying behind it. Using a drone or observing from a higher point on the ship could give a better view on what is behind the parts of ice.

Besides these three circumstances, other situations could have influenced our study, these are mentioned in order of importance. In our study one observer always observed at the starboard side of the boat and the other always at the port side. Possible differences in skills and sight could have influenced the numbers that were counted. Changing position every survey could prevent this from happening.

In our study we counted kittiwakes performing the following behavior: 1) plunge-diving, 2) foraging while sitting on the water surface 3) resting on the water surface. We counted arctic terns in a different way. Only birds performing the following behaviour, were counted: 1) plunge diving, 2) flying. This way of counting is different from the kittiwake. We chose this, because during flight arctic terns seemed to be actively observing for prey items. they usually flew with their beaks pointed in the direction of the water. Kittiwakes seemed to be flying in a straight direction to their location of arrival, and rarely stopped to perform foraging behavior. It would have been better to only count foraging individuals. In the case of arctic terns, we suggest that individuals are counted when performing the following behavior: 1) plunge-diving. Exclude the flying individuals and the individuals resting on ice or land. In the case of kittiwakes: 1) plunge-diving, 2) foraging while sitting on the water. Exclude birds resting on ice or land, birds that fly and birds that rest on the water.

Due to floating blocks of ice, we sometimes had to change the route we drove by boat. Sometimes the distance to the coast was therefore slightly larger. Besides this, sometimes we were not able to reach glacier fronts, so then we missed data of some glacier fronts. This was unavoidable, but reduced the amount of data we wanted to gain.

4.7.2 Statistics

We looked at whether the density of birds was higher at the coast side or the open water side at specific locations. I used paired t-tests for this, but the (repeated) t-tests cause a higher chance on type 2 errors, because the sample size was very small per location (maximum 8 samples per sector). If during 6 surveys a higher density at the coast side was observed, and in 2 surveys a higher density on the open water side, usually no significant difference between the coast side and open water side could be found. If sample size would have been larger and in 75% of the surveys the density at the coast side was higher, we could probably have found a significant difference. Thus sample size should have been larger.

T-tests assume that the values of the dependent variable (the densities) are independent. Since we followed the same line transect 8 times, the values are not independent. We repeated observations at the same sector 8 times. Therefore a t-test was not very suitable. The same situation applies to a Generalized Linear Model (GzLM).

A better option for statistics would have been the Linear Mixed Model (LMM), with taking the sectors as a random factor. In this analysis one can also put all variables in one analysis, which is preferred. Possible interactions can then also be found. In the Appendix the output of the LMM can be found (Appendix E). In the appendix (Table D), the output of a Generalized Linear Model is present. But a LMM is preferred. Results of both tests can also be found in the Appendix, but due to a lack of time we did not put those results in our results section.

Besides this, placing transects randomly in het entire fjord could offer a better view on what the distribution of these species in the entire fjord is.

Although these circumstances (described in discussion section 4.7) may have affected the results, the results are still similar to what we observed. Namely, kittiwakes prefer to forage at glacier fronts, probably because of a high food availability. This did not necessarily apply to Artic terns, because they seemed to prefer foraging at only one glacier.

4.8 Recommendations for future research

Getting a better view on the diet of arctic terns and kittiwakes, helps understanding the choice of foraging location of these species. Options for investigating food choice are: 1) performing research on stomach content of arctic terns and kittiwakes can provide information about prey choice. This has been performed in the 1936 and 1984 but has not been repeated; 2) performing DNA analysis on fecal samples, can offer information about prey choice; 3) stable isotope analysis of muscle tissue of birds could reveal their diet too. If we know their diet, we could investigate fish and crustacean abundance in fjords and at glacier fronts. At a later stage, one should also focus on how this differs throughout the season and how this changes interannually.

Besides this, arctic terns might feed different prey to their chicks than what they use for own consumption. More research needs to be performed here.

Collecting data near glacier fronts is very important to understand the processes underlying the foraging hotspots. Due to glacier calving, collecting data from near glacier fronts is dangerous. Therefore, not much research has been performed close to the fronts. Information about the organisms (including prey organisms) and abiotic factors is scarce and needs to be acquired. Diving or flying instruments, like a submarine device or a drone, provided with a camera, catching device or net, could offer more information about the processes occurring at the fronts (Lydersen et al., 2014).

If we can understand the local ecosystem with its biotic and abiotic factors we can understand the choice of foraging location and we could create future scenarios regarding foraging birds in the Arctic in the course of climate change.

5. Conclusion

Our aim was to study the distribution of foraging arctic terns and kittiwakes along the coastline of a glacial fjord. We wanted to analyze whether these species prefer foraging at glaciated or non-glaciated coastline, and whether they prefer foraging close to the coast (0-200m) or further away from the coast (200-400m).

We observed high numbers of kittiwakes in front of glaciers. They were mostly present in large groups, gathered in a food frenzy. The mean density of kittiwakes at the coast side of the glaciated coastline was higher than the density at the coast side of non-glaciated coastline. Besides this, kittiwakes showed preference for foraging close to the coast (0-200m).

The mean density of arctic terns at the glaciated coastline and non-glaciated coastline was similar, although they tended to show preference for G5, Blomstrandbreen. Besides this, arctic terns showed preference for foraging close to the coast (0-200m).

In the case of kittiwakes, we draw the same conclusions as Stempniewicz et al. (2017), who also performed boat-based line-transect surveys in Svalbard. Kittiwakes prefer foraging at glaciated coastline and strongly prefer one type of glacier: tidewater glaciers.

In our study densities of arctic terns were similar at glaciated and non-glaciated coastline, but they tended to prefer foraging at one tidewater glacier. In their study arctic terns did not show preference for tidewater glaciers, but showed preference for non-glaciated coastline. Our study agrees with theirs that a significant part of arctic terns forages at non-glaciated coastline, which shows that they are not largely dependent on foraging at glaciers.

Therefore the influence of climate change and increasing glacier melt might influence them to a lesser extent than the influence these processes might have on kittiwakes. Although a small part of the kittiwakes were found foraging at non-glaciated coastline in both studies, kittiwakes showed a strong preference for foraging at glaciers. Climate change, increasing glacier melt and a therefore possibly reduced food supply might thus strongly influence their number and distribution in the future. Population sizes could decrease, and they could move to locations where glaciers would still be present, or search for other foraging locations.

This study has shown the importance of glaciers and brought us a step closer to understanding foraging patterns of artic terns and kittiwakes in Svalbard.

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7. References

Abookire, A.A., Piatt, J.F. and Speckman, S.G. (2002). A near surface, daytime occurrence of two mesopelagic fish species (Stenobrachius leucopsarus and Leuroglossus schmidti) in a glacial fjord. *Fishery Bulletin*. Vol. 100, pp. 376–380.

Apollonio, S. (1973). Glaciers and nutrients in Arctic seas. *Science*. Vol. 180, pp. 491–493.

Arimitsu, M. L., Piatt, J. F., Madison, E. N., Conaway, J. S. and Hillgruber, N. (2012). Oceanographic gradients and seabird prey community dynamics in glacial fjords. *Fisheries Oceanography*. Vol. 21, No. 2-3, pp. 148-169.

Bluhm, B.A. and Gradinger, R. (2008). Regional variability in food availability for Arctic marine mammals. *Ecological applications*, vol 18(2) Supplement, pp. S77-S96.

Dalpadado, P., Hop, H., Rønning, J., Pavlov, V., Sperfeld, E., Buchholz, F., Rey, A. and Wold, A. (2016). Distribution and abundance of euphausiids and pelagic amphipods in Kongsfjorden, Isfjorden and Rijpfjorden (Svalbard) and changes in their relative importance as key prey in a warming marine ecosystem. *Polar Biology*. Vol 39:1765-1784.

Eriksen, E., Dalpadado, P. and Dolgov, A. (2015). Ecosystem survey of the Barents sea autumn 2015. *Biomass indices and distribution of krill and amphipods.* Retrieved at (4-9-2018): *https://www.imr.no/filarkiv/2015/12/4_3_3_biomass_indices_and_distribution_of_krill_and_amphipods.pdf/nb-no*

Fey, D.P. and Weslawski, J.M. (2017). Age, growth rate, and otolith growth of polar cod (Boreogadus saida) in two fjords of Svalbard, Kongsfjorden and Rijpfjorden. *Oceanologia*. Vol. 59, issue 4, pp. 576-584.

Frank, T.M. and Widder, E.A. (2002). Effects of a decrease in downwelling irradiance on the daytime vertical distribution patterns of zooplankton and micronekton. *Marine Biology*. Vol. 140, pp. 1181–1193.

Habiter le monde- Svalbard, Ny-Ålesund, un village scientifique (2018) TV5. https://tv5.ca/habiter-le-monde/?e=b8et9lnyrzyl4

Hanamura, Y., Kotori, M. and Hamaoka, S. (1989). Daytime surface swarms of the euphausiid Thysanoessa inermis off the west coast of Hokkaido, northern Japan. *Marine Biology*. Vol. 102, pp. 369-376.

Hartley, C.H. and Dunbar, M.J. (1937-1938). On the hydrographic mechanisms of the so-called brown zones associated with tidal glaciers. *Journal of Marine Research*. Vol. 1, pp. 305-311.

Hartley, C. H. and Fisher, J. (1936). The marine foods of birds in an inland fjord region in West Spitsbergen. Part 2. Birds. *Journal of Animal Ecology*. Vol. 5, pp. 370-389.

Hood, E. and Scott, D. (2008). Riverine organic matter and nutrients in southeast Alaska affected by glacial coverage. *Nature Geoscience*. Vol. 1, pp. 583-587.

Hood, E., Fellman, J., Spencer, R.G.M., Hernes, P.J., Edwards, R., D'Amore, D. and Scott, D. (2009). Glaciers as a source of ancient and labile organic matter to the marine environment. *Nature.* Vol. 462, pp. 1044-1047.

Image Landsat/Copernicus. Image IBCAO. Google Earth Pro. Visited on 11-9-2018.

Kohler, J., James, T.D., Murray, T., Nuth, C., Brandt, O., Barrand, N.E., Aas, H.F. and Luckman, A. (2007). Acceleration in thinning rate on western Svalbard glaciers*. Geophyical research letters*. Vol. 34.

Kohler, J. (2017). Norwegian Polar institute. *In press*.

Kovacs, K.M., Lydersen, C., Overland, J.E. and Moore, S.E. (2011). Impacts of changing sea-ice conditions on Arctic marine mammals. *Marine Biodiversity*. Vol. 41, pp. 181-194.

Lewis, A. G. and Syvitsky. J. P. M. (1983). The interaction of plankton and suspended sediment in fjords. *Sedimentary Geology*. Vol. 36, pp. 81-92.

Lydersen, C., Assmy, P., Falk-Petersen, S., Kohler, J., Kovacs, K. M., Reigstad, M., Steen, H., Strøm, H., Sundfjord, A., Varpe, Ø., Walczowski, W., Węsławski, J. M. and Zajaczkowski, M. (2014). The importance of tidewater glaciers for marine mammals and seabirds in Svalbard, Norway. *Journal of Marine Systems.* Vol. 129, pp. 452–471.

McCollough, M. (2006). Island-nesting terns assessment. Maine department of inland fisheries and wildlife, *wildlife division*, resource assessment section.

Mehlum, F. and Giertz, I. (1984). Feeding ecology of seabirds in the Svalbard area – a preliminary report. *Norsk Polarinstitut Rapport*. Vol. 16, pp. 1-20.

Montague, F. A. (1926). Further notes from Spitsbergen. *Ibis*. Vol. 2, pp. 136-151.

Noort, H.I. van (2016). Variation in parental food provisioning of arctic tern chicks in the high Arctic. Report Master project. University of Groningen. pp. 14

Partridge, B.L. and Pitcher, T.J. (1980). The sensory basis of fish schools: Relative roles of lateral line and vision. *Journal of Comparative Physiology*. Vol. 135, pp. 315-325.

Piwosz, K., Walkusz, W., Hapter, R., Wieczorek, P., Hop, H. and Wiktor, J. (2009). Comparison of productivity and phytoplankton in a warm (Kongsfjorden) and a cold (Hornsund) Spitsbergen fjord in mid-summer 2002. *Polar Biology*. Vol. 32, pp. 549-559.

Richter-Menge, J., Overland, J. E., Mathis, J.T., and Osborne, E., Eds., 2017: Arctic Report Card 2017, http://www.arctic.noaa.gov/report-Card.

Stempniewicz, L., Goc, M., Kidawa, D., Urbański, J., Hadwiczak, M., and Zwolicki, A. (2017). Marine birds and mammals foraging in the rapidly deglaciating Arctic fjord – numbers, distribution and habitat preferences. *Climatic Change*. Vol. 140, pp. 533-548.

Stott, F.C. (1990). Feeding of birds near a glacier in Svalbard*.* *Polar Rec*. Vol. 26, pp. 243.

Strijbos, J. P. (1957). Svalbard zwerftocht langs de koele stranden van Spitsbergen. L. J. *Veen's uitgeversmaatschappij NV*, Amsterdam.

Strøm, H., Bakken, V. and Skogland, A. (2012). Kartlegging av myte- og høstbestander av sjøfugl på Svalbard august-september 2010 og 2011. *Sluttrapport til* Svalbard Miljøfond. pp. 33.

Svendsen H., Beszczynska-Møller, A., Hagen, J.O., Lefauconnier, B., Tverberg, V., Gerland, S., Ørbæk, J. B., Bischof, K., Papucci, K., Zajaczkowski, M., Azzolini, R., Bruland, O., Wiencke, C., Winther, J. and Dallmann, W. (2002). The physical environment of Kongsfjorden-Krossfjorden, an Arctic fjord system in Svalbard. *Polar Research*. Vol. 21, No. 1, pp. 133-166.

Tasker M.L., Jones P.H., Dixon T, and Blake B.F. (1984). Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. Vol. 101, pp. 567–577.