Role of glaciers on zooplankton and ichthyoplankton in West Greenland fjords

Caroline Bouchard, Agathe Charbogne and Lorenz Meire

Technical Report no. 121

Greenland Institute of Natural Resources

3 January 2022

Title:	Role of glaciers on zooplankton and ichthyoplankton in West Greenland fjords
Authors:	Caroline Bouchard Agathe Charbogne Lorenz Meire
Publisher:	Greenland Institute of Natural Resources
Date of publication:	2022
Financial support:	Greenland Institute of Natural Resources Greenland Research Council Swiss Polar Institute
Cover photo:	The sailboat *ATKA* in Greenland in 2019. Copyright: ATKA media
ISSN:	1397-3657
ISBN:	978-87-972977-4-2
EAN:	9788797297742
Web:	http://www.natur.gl/publikationer/tekniske rapporter
Citation:	Bouchard C, Charbogne A, Meire L (2022) Role of glaciers on zooplankton and ichthyoplankton in West Greenland fjords, Technical report no. 121, Greenland Institute of Natural Resources, Greenland. ISBN: 978-87-972977-4-2.

English Summary

The Greenland ice sheet is rapidly melting, and retreating glaciers are transforming fjords ecosystems. A recent study hypothesised that higher primary production in fjords influenced by marine-terminating glaciers compared to fjords influenced by land-terminating glaciers might cascade up to benefit Greenland halibut (*Reinhardtius hippoglossoides*) and its fishery in coastal Greenland. A study designed to document some of the mechanisms underlying this hypothesis was conducted in West Greenland onboard the sailboat *ATKA* between 5 July and 24 August 2019. The survey was designed to compare fjords influenced by land-terminating glacier with fjords influenced by marine-terminating glacier in five regions along a latitudinal gradient from 73° (near Upernavik) to 62°N (near Paamiut). Here, we report surface salinity and temperature, zooplankton biomass, and abundances and sizes of larval fish including polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) at 33 stations distributed in eleven West Greenland fjords. We found some differences between fjords influenced by marine-terminating glaciers and fjords influenced by land-terminating glaciers, but could not conclude whether a type of fjord is more favorable for zooplankton or fish larvae.

Greenlandic Summary - Kalaallisut Naalisarneqarnera

Kalaallisut imaqarniliaq

Kalaallit Nunaanni sermersuaq aakkiartupiloorpoq, sermillu isulerfiisa ilorparaluttuinnarnerisa kangerlunni uumassuseqaqatigiinneq sunniuteqarfigaat. Misissuinerit nutaat pasinarsisippaat sermip isuliffii imaaniikkaangata, sermip isuliffiata nunamiinnerinut sanilliullugit imaani isuliffilinni kangerluit uumaneqarnerusartut, taamaattoqarneralu qaleraleqarneranut (Reinhardtius hippoglossoides) nunattalu kitaani aalisarnermut iluaqutaanerusartoq. Taamaattoqarnersoq uppernarsaatissarsiorniarlugu 2019-imi 5. juulimiit 24. aggustip tungaanut angallat ATKA atorlugu misissuisoqarpoq. Ilumullumi sermit imaani isuliffillit nunami isuliffilinninngarnik uumaneqarnerulersitsisarnersut paasiniarlugu tulluarsakkamik misissuisoqarpoq. Nunap immikkoortuini tallimani tassa 73°N (Upernaviup eqqaaniit) 62°N (Paamiut eqqaa) angullugu misissuisoqarpoq. Immap qaavata tarajoqassusia kissassusia, ippiorannartut planktonit oqimassusinngorlugu peqassusiat, qullugiaaqqallu aalisagaaranngortussat angissusii, eqalukkanik (Boreogadus saida) ammassannillu (Mallotus villosus) peqassuseqarnera misissuiffiusuni katillugit 33-iusuni nunatta kitaani kangerlunni aqqanilinnik amerlassusilinni misissuisoqarpoq. Sermersuup imaanut isuliffigisaani kangerlunni kangerlunnilu sermersuup nunamut isuliffigisaaniittuni assigiinngissuseqartoq takusinnaavarput, inaarutaasumilli oqaatigisinnaanngilarput kangerluit sorleqqissaat imaani plankton'inik aalisagaaranngortussanillu uumaffigissallugit piukkunnarnerunersut.

Danish Summary - Dansk Oversigt

Den grønlandske indlandsis smelter med høj hastighed, og fjordenes økosystemer forandres af de vigende gletsjere. Et studie har for nylig opstillet en teori om, at fjorde, som påvirkes af gletsjere med udløb i havet, har større produktion af plankton (primærproduktion) sammenlignet med fjorde, som påvirkes af gletsjere, der munder ud på land. Den større primærproduktion kan muligvis gavne hellefisk (*Reinhardtius hippoglossoides*) og give bedre fiskeri af hellefisk i disse fjorde.

I perioden fra den 5. juli til den 24. august 2019 blev der fra sejlskibet *ATKA* udført en undersøgelse, som havde til formål at dokumentere nogle af de underliggende mekanismer bag denne teori. Undersøgelsen sammenlignede fjorde, som påvirkes af gletsjere, der munder ud på land, med fjorde, som påvirkes af gletsjere med udløb i havet, i fem områder fra 73°N (nær Upernavik) til 62°N (nær Paamiut). Her rapporterer vi om overfladevandets saltholdighed og temperatur, mængden af dyreplankton (zooplanktonbiomasse) samt mængden af fiskeyngel og ynglens størrelse, herunder polartorsk (*Boreogadus saida*) og lodde (*Mallotus villosus*), på 33 stationer fordelt over 11 vestgrønlandske fjorde. Vi observerede nogle forskelle mellem de to typer fjorde, men var ikke i stand til at konkludere, hvorvidt en bestemt fjordtype er mere gunstig for zooplankton eller fiskelarver.

Table of Contents

List of Figures

1. Introduction

Rapid melting of the Greenland ice sheet leads to glacier retreat and threatens several marine-terminating glaciers to become land-terminating glaciers. Fjords influenced by marine-terminating glaciers show a higher primary production compared to fjords influenced by land-terminating glaciers, and have been hypothesised to support the ecosystem up to Greenland halibut (*Reinhardtius hippoglossoides*), which coastal fishery contributes to a large fraction of the Greenland economy (Meire et al. 2017).

Greenland halibut is a predatory fish feeding notably on polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*), two planktivorous fish highly abundant and playing a key role in West Greenland ecosystems. At the larval stage, both polar cod and capelin rely heavily on Calanoid copepods as source of energy (Bouchard and Fortier 2020, Malanski et al. 2020). A likely mechanism underlying the link between increased primary production in West Greenland fjord influenced by marine-terminating glaciers and increased Greenland halibut production in the nearby regions suggested by Meire et al. (2017) is hence that high productivity benefit the zooplankton, which in turn increase the feeding success of polar cod and capelin at the larval and adult stages, increasing recruitment and population sizes of these two species. Larger populations of polar cod and capelin would then constitute an increased in food availability for Greenland halibut, leading to larger populations of this fish.

In this study, we documented the surface salinity, surface temperature, mesozooplankton biomass, macrozooplankton biomass, and the abundance and size of larval fish including polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) in eleven West Greenland fjords. The study design include at least one fjord influenced by marine-terminating glaciers and one fjord influenced by land-terminating glaciers in each of the five study regions. The physical environment, zooplankton biomass and larval fish abundances and size are compared among fjord types in all regions, within a same region, and also within individual fjord along a three-stations transect. Northern fjords (Upernavik, Uummannaq and Ilulissat regions) are aslo compared with southern fjords (Sisimiut and Paamiut regions).

2. Materials and Methods

2.1. Study area

The waters of west Greenland are characterized by the deep basins of Baffin Bay, Davis Strait and the Labrador Sea. The continental shelf is between 40 km to 250 km wide and characterized by numerous coastal areas of shallow depth crossed by deep channels. The coast is also characterized by many fjords where fresh water from the ice sheet flow into the ocean. The northern part of the shelf is generally covered with sea ice from November to December. The ice breakup begins in early spring in the south and moves northwards in the summer until the entire area becomes ice free by the end of July. The southern portion of the shelf (latitude below 68 °N) generally remains ice-free throughout the year.

2.2. Field sampling

The study area covered eleven fjords along the west coast of Greenland between 73 and 62 °N. Five fjords were influenced by at least one land-terminating glacier and six fjords were influenced by at least one marine-terminating glacier. This two types of fjords are hereafer refered to as ″fjord with land-terminating glaciers″ and ″fjord with marine-terminating glaciers″ regardless of the number of glaciers influencing a specific fjord (Figure 1). In each fjord, a transect of three stations located in the outer fjord (station A), mid-fjord (station B) and inner fjord (station C) was sampled. The study area was divided into five regions, from North to South: Upernavik, Uummannaq, Ilulissat, Sisimiut and Paamiut.

The sampling was carried out in West Greenland in July and August 2019 during the expedition of the sailboat *ATKA* (Aebischer 2020). At each station, a temperature and salinity profile was obtained with an RBR Concerto® CTD. Zooplankton and ichthyoplankton were sampled using a bongo sampler carrying two nets of 0.6 m in diameter with a mesh size of 335 µm and 500 µm. A 10 cm opening, 50-µm mesh net was attached to the bongo frame to sample the microzooplankton. A KC Denmark® flowmeter was installed in front of each net. The bongo was towed obliquely from the surface to a maximum sampling depth of 100 m at a vessel speed of 1-3 knots. The target depth of 100 m was estimated and adjusted during each deployment using the length of the cable and its angle to the horizon, and a Star-Oddi® mini-CTD attached to the sampler provided the actual sampling depth a posteriori.

Onboard, whole samples containing zooplankton and ichthyoplankton were stored in 96% ethanol. The microzooplakton samples from the 50-µm mesh net were preserved in 4% borax-buffered formaldehyde seawater solution. Due to the limited storage space onboard the sailboat, some samples were split using a Folsom Wilko® cylindrical zooplankton splitter and only half or a quarter of the sample was retained. For other logistical reasons (time constraint, limited expertise onboard, unstable platform), the larvae were not sorted from the zooplankton samples before being divided. These fractionations were taken into account in the calculation of larval fish abundances.

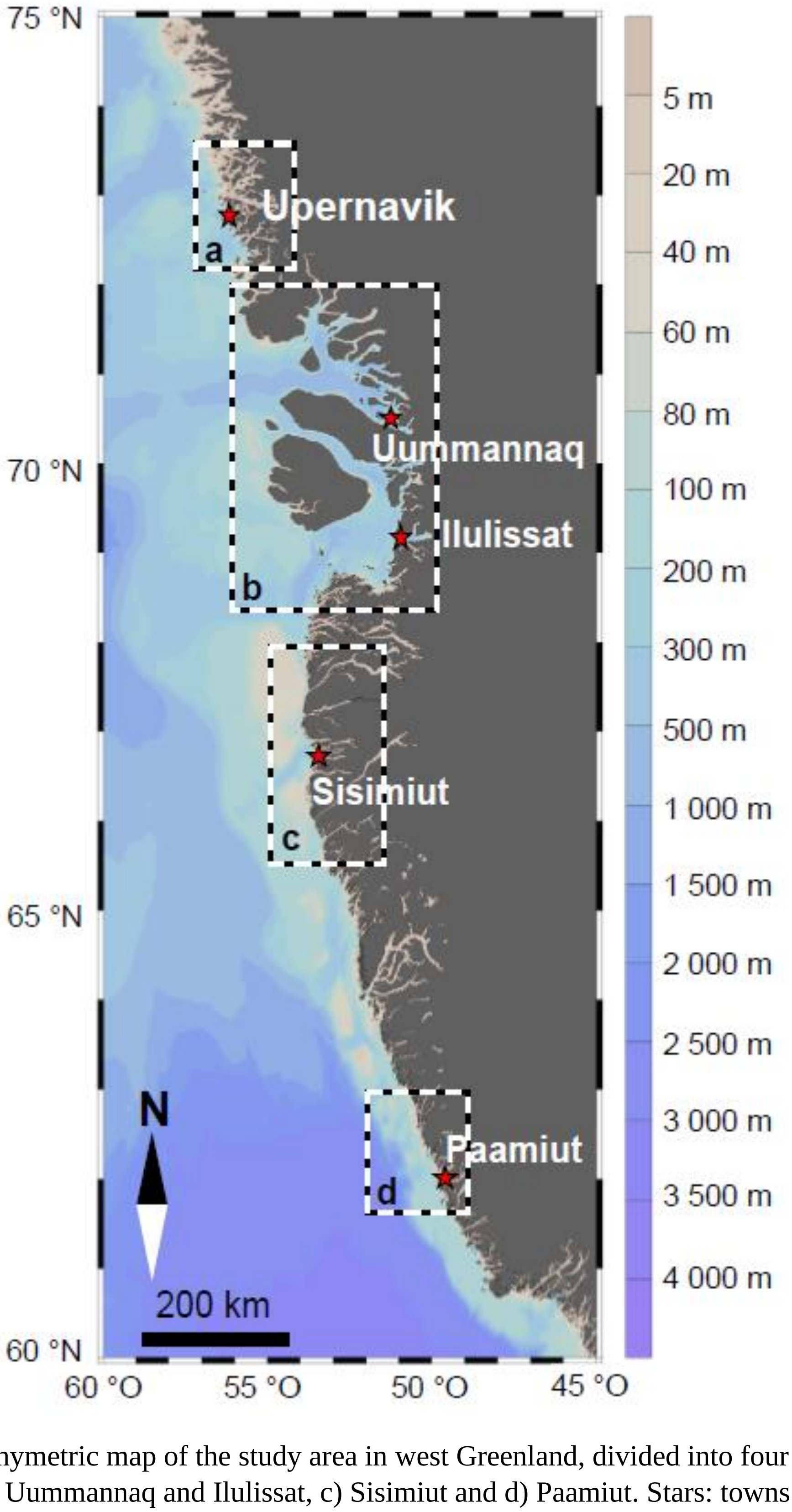

Figure 1. Bathymetric map of the study area in west Greenland, divided into four regions: a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut. Stars: towns.

2.3. Laboratory analyses

In the laboratory at the Greenland Institute of Natural Resources, all larval and juvenile fish (age-0 fish) were sorted out of the zooplankton, enumerated and identified at the lowest taxonomic level possible. Up to 25 individuals per station and species were measured for preserved standard length (SLp) and body depth at the anus (BDp), then individually preserved in 96% ethanol. Larval fish abundances were calculated for each taxon by dividing the number of larvae collected in a net by the volume of water filtered during deployment (data from the flowmeter) and averaged between the two nets for each station. Age-0 Gadidae were identified genetically using the method described in Bouchard et al. (2021).

The larvae were measured ca. 6 months after storage in ethanol. To account for shrinkage after preservation in ethanol, the fresh standard length, SLf, of *B. saida* larva were calculated from their SLp using a regression built from data of larval *B. saida* collected in the Beaufort Sea in 2008 (SLf = 1.025 × SLp + 1.097; n = 290, r^2 = 0.957 for SLp between 5 and 20 mm). The SLf of other larval species were calculated using linear regressions found in the literature. For *M. villosus*: SLf = 0.94 + 1.036 × SLp, n = 105, r^2 = 0.97 (Kruse and Dalley 1990); for *G. morhua*: SLf = 1.009 × SLp - 0.819, n = 283, r^2 = 0.998 (Fey 2012); for *A. glacialis*: SLf = 1.073 × SLp + 0.253, n = 663, r^2 = 0.995 (Bouchard et al. 2016).

Zooplankton samples collected with the 335 µm net were divided into two equal parts using a Folsom Wildco® plankton splitter. Half of each sample was retained for future taxonomic identification and half was used to estimate the dry mass of mesozooplankton (300 - 1000 µm) and macrozooplankton (>1000 µm). Each sample was filtered by wet sieving through 1000 µm and 300 µm WS Tyler® sieves. The sample was poured through the sieves and washed by swirling and shaking in a pan filled with about 2 L of fresh water. The water that has passed through the sieve with the largest mesh was then poured into the next sieve and the process was repeated several times. The zooplankton contained in the two sieves were rinsed with fresh water and transferred with a flat spoon to pre-weighed aluminum trays. The samples were then dried at 60 °C for a minimum of 24 h and weighed to an accuracy of 0.001 mg. The samples from the 50-µm and 500 µm-mesh nets remained unprocessed to this date, and are available for future studies.

2.4. Data analysis

Sea surface salinities and temperatures (SST and SSS) were obtained by averaging the CTD data between 0 and 20 m. Statistical analyzes were performed using RStudio software (RStudio Team 2015). Normality of data were verified using Shapiro-Wilk tests and equality of variances were tested with Fisher tests. In cases of unequal variances, Student's tests and Welch tests were used. In cases of non-normal data, non-parametric Wilcoxon tests were performed. Maps were produced with the software ODV (Schlitzer 2020).

3. Results

3.1. Physical environment

Sea surface temperature (SST) was significantly different between fjord types (Wilcoxon test, p-value = 0.008), being higher in fjords with land-terminating glaciers than in fjords with marine-terminating glaciers (Figure 2). SST generally differed between the two types of fjords within a region. For example in Upernavik, SST was higher in the fjord with land-terminating glaciers (LT1), than in the fjord with marine-terminating glaciers (MT1). This pattern was also observed in Ilulissat and Paamiut. In Uummannaq and Sisimiut, the pattern was reversed: SST was higher in the fjords with marine-terminating glaciers than in the fjords with land-terminating glaciers (Figure 2). SST along all fjords with marine-terminating glaciers decreased from the outer fjord to the inner fjord, whereas in fjords with land-terminating glaciers SST generally increased from the outer fjord to the inner fjord, with the exception of the LT3 fjord. The LT3 fjord was removed from the statistical analyses because of extreme SST compared to the other fjords (Figure 2). As expected, SST was significantly higher in the southern fjords (Sisimiut and Paamiut) than in the northern fjords (Student's test, p-value = 0.0016).

In general, fjords with marine-terminating glaciers had higher sea surface salinity (SSS) than fjords with land-terminating glaciers (Figure 3). The general pattern for both fjord types was that SSS decrease from the outer fjord to the inner fjord. In Ilulissat, SSS remained constant along the fjord for both types of fjords. SSS were on average higher in the northern fjords (Upernavik, Uummannaq and Ilulissat) than in the southern ones (Wilcoxon test, p-value = 0.0006).

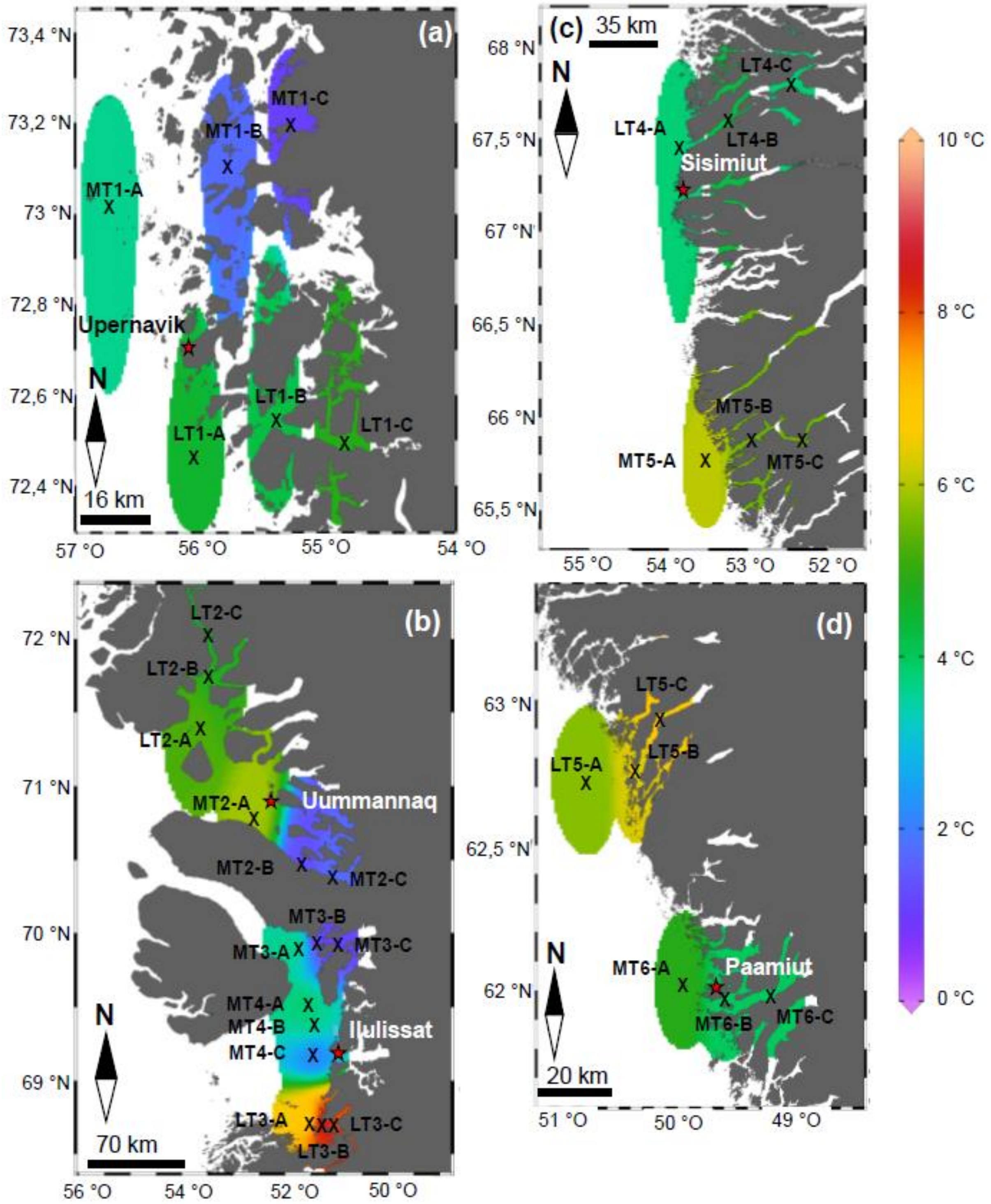

Figure 2. SST in fjords influenced by marine-terminating glacier (MT) and fjords influenced by land-terminating glacier (LT) in the regions of a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut.

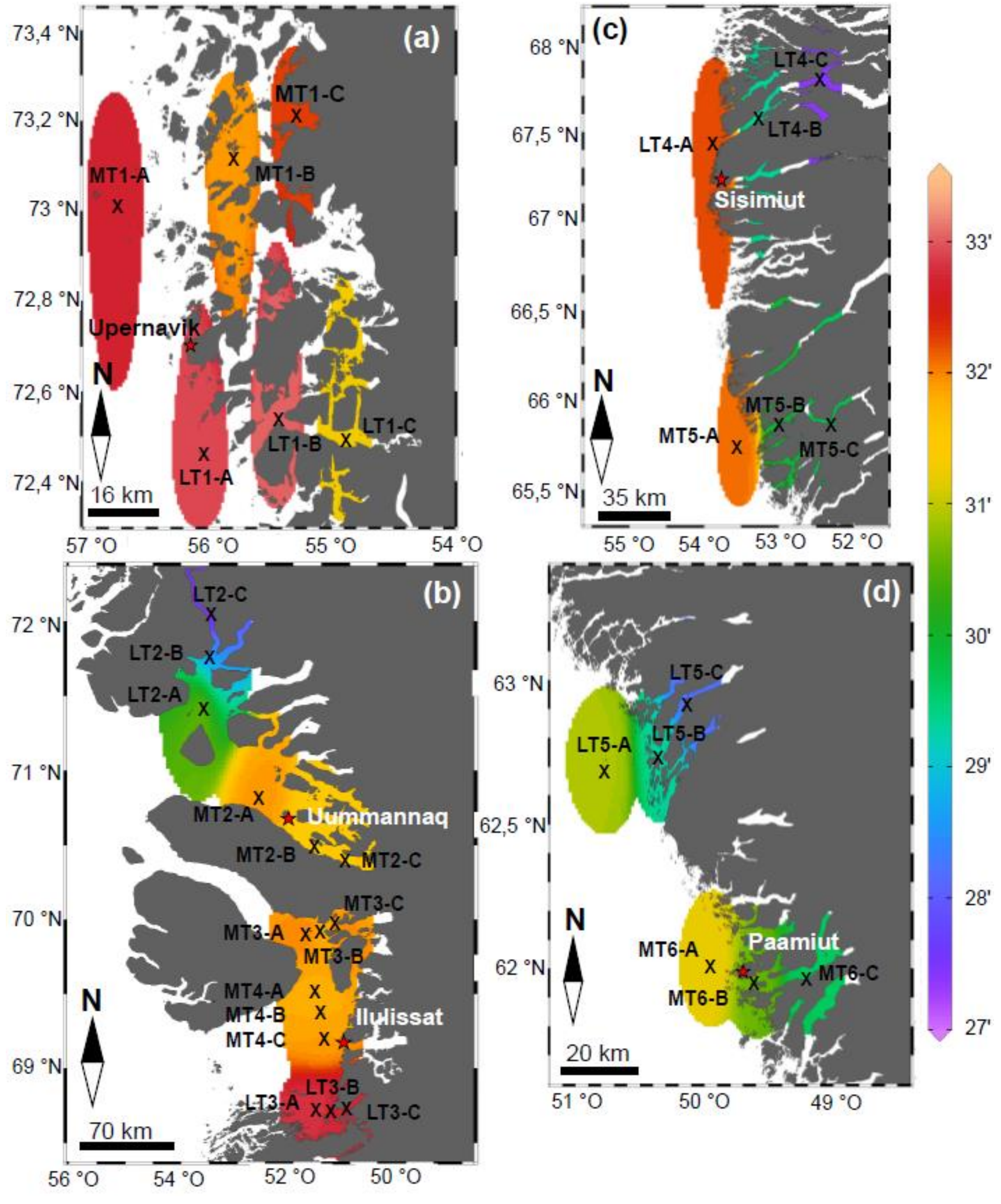

Figure 3. SSS in fjords influenced by marine-terminating glacier (MT) and fjords influenced by land-terminating glacier (LT) in the regions of a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut.

3.2. Mesozooplankton and macrozooplankton

The biomass (dry weight) of mesozooplankton and macrozooplankton (Figure 4) were not statistically different between the two types of fjords (Wilcoxon test, p-value = 0.22 and 0.36, respectively).

In fjords with land-terminating glaciers, the biomass of mesozooplankton seems to decrease from the outer fjord to the inner fjord, while the biomass of macrozooplankton does not seem to follow any particular pattern (Figure 4). In fjords with marine-terminating glaciers, the biomass of mesozooplankton does not seem to follow any particular pattern, while the biomass of macrozooplankton seems to decrease from the outer fjord to the inner fjord.

The biomass of mesozooplankton and macrozooplankton differed between fjords type in some regions. In Upernavik, the mesozooplankton biomass was similar between LT1 and MT1, while macrozooplankton biomass was greater in the fjord with land-terminating glaciers. In Uummannaq, Ilulissat and Paamiut, the biomass of mesozooplankton and macrozooplankton were similar for the two types of fjords. In Sisimiut, the biomass of mesozooplankton and macrozooplankton were higher in the fjord with land-terminating glaciers (LT4) than in fjord with marine-terminating glaciers (MT5).

The biomass of mesozooplankton and macrozooplankton were higher in the northern fjords (Upernavik, Uummannaq and Ilulissat) than in the southern ones (Wilcoxon test, p-value = 0.014 and 0.018, respectively).

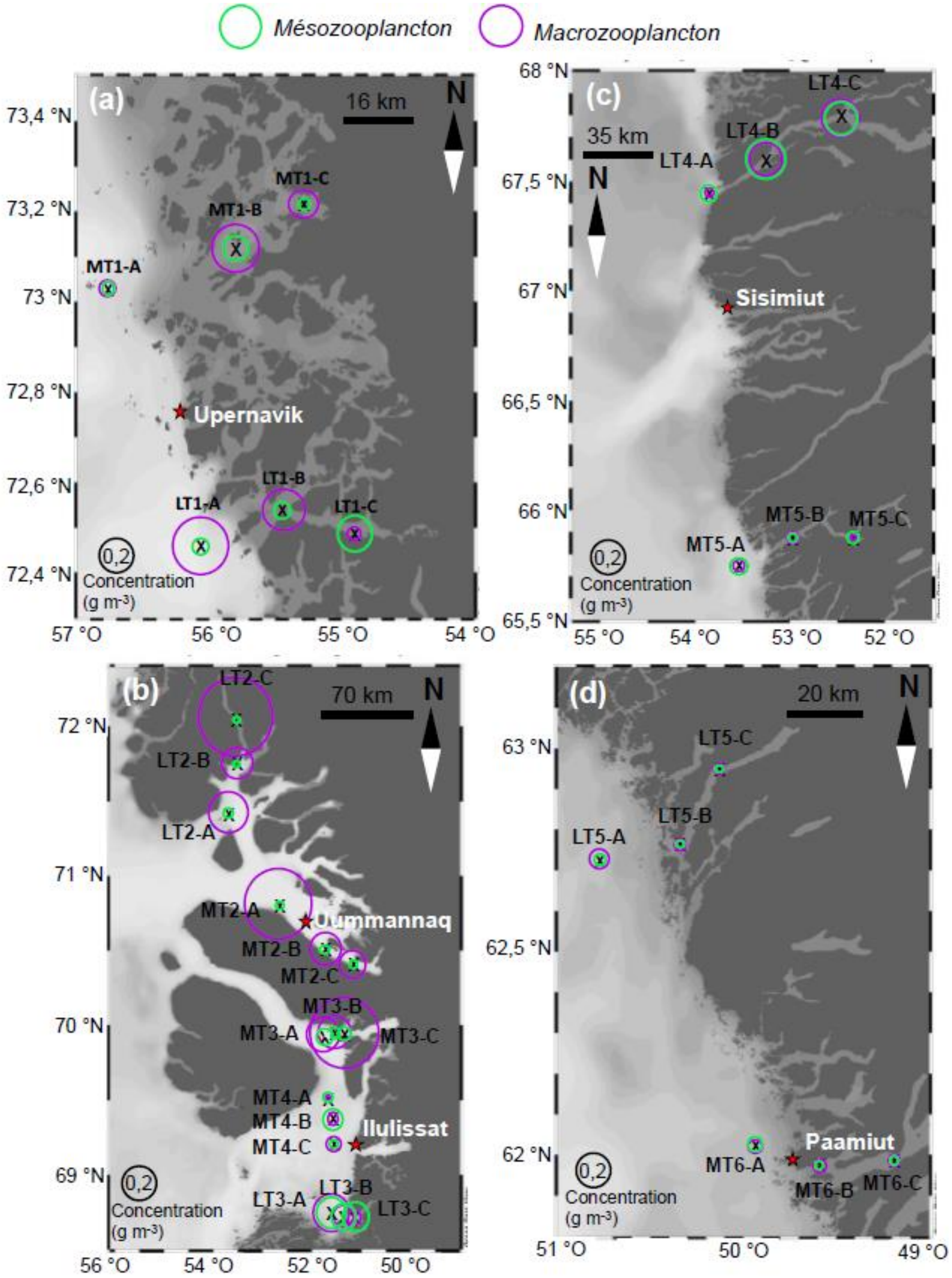

Figure 4. Biomass (Concentration, in g m^{-3}) of mesozooplankton and macrozooplankton in fjords influenced by marine-terminating glacier (MT) and fjords influenced by land-terminating glacier (LT) in the regions of a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut.

3.3. Ichthyoplankton

A total of 699 age-0 fish were collected during the survey. The distribution of the most abundant species and the maximum density of each species by region, is presented in Bouchard et al. (2021).

Boreogadus saida and *M. villosus* were the most abundant species (Figure 5). In general, *M. villosus* was more present in fjords with land-terminating glaciers than in fjords with marine-terminating glaciers, with abundances generally increasing from the outer fjord to the inner fjord. *Gadus morhua* and *A. glacialis* were present only in fjords with land-terminating glaciers whereas *Boreogadus saida* was present in both types of fjords.

In some cases, ichthyoplankton assemblages differed importantly between fjords within a region (Figure 5). For example in Upernavik, the assemblages of LT1 and MT1 were strikingly different. In Uummannaq, *M. villosus* was present in LT2 but absent in MT2. In Ilulissat, *M. villosus* was present in both types of fjords. In Sisimiut, *M. villosus* was present in both types of fjords but much more abundant in MT5 than in LT4. However in Paamiut, the opposite was observed with higher abundances in the fjord with land-terminating glaciers (LT5) than in the fjord with marine-terminating glaciers (MT6).

In general, *M. villosus* larvae were larger in the inner fjord than at the mid-fjord and outer fjord stations (Figure 6). *Boreogadus saida* was of similar size at stations. *Gadus morhua* were larger in the south (LT5-A) than in the north (LT1-C). The size of *B. saida* and *M. villosus* were similar regardless of the type of fjords in which they were found (Figure 6).

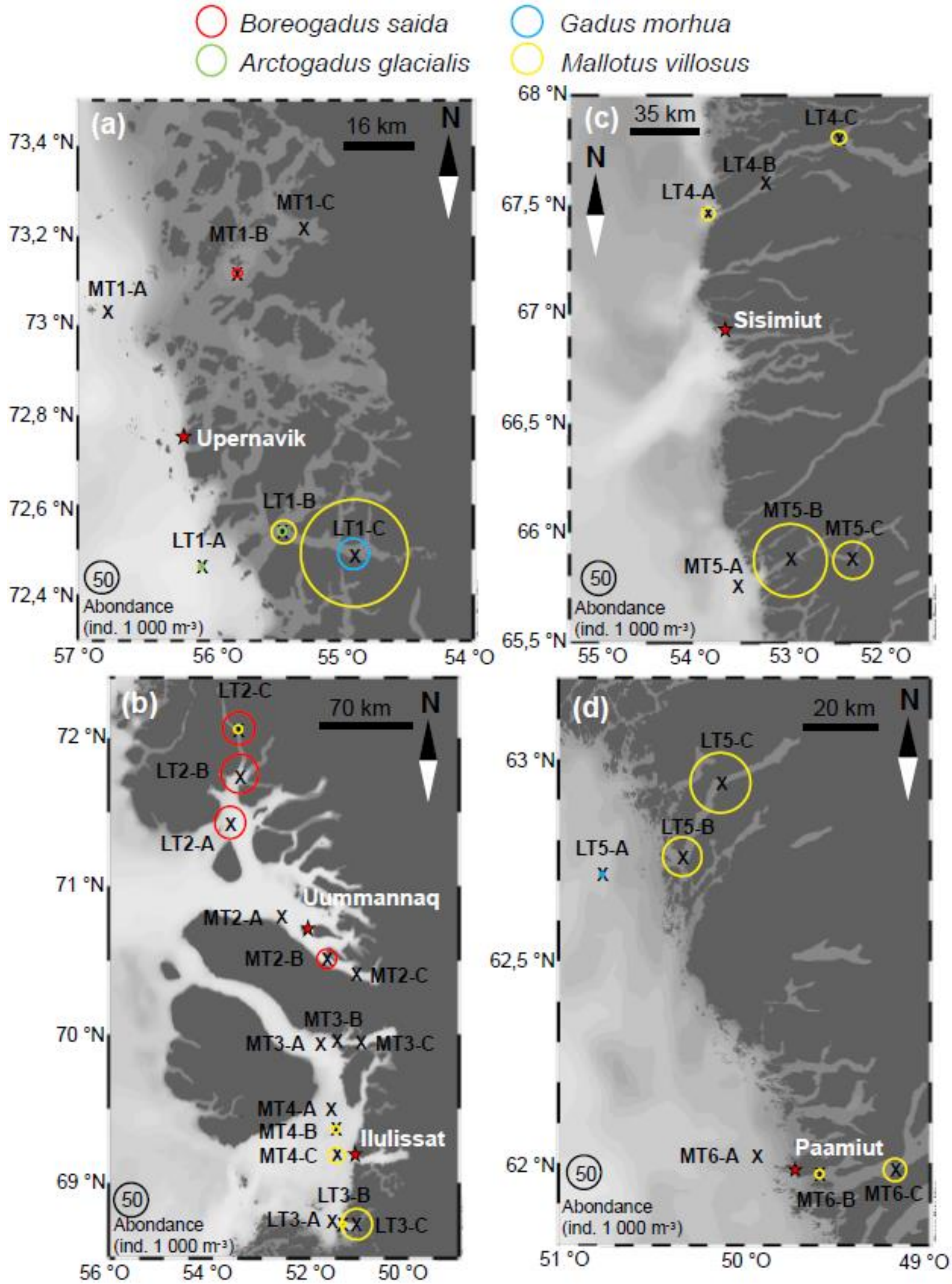

Figure 5. Abundances (Abondance, in ind. 1000 m^{-3}) of larval *B. saida, A. glacialis, G. morhua* and *M. villosus* in fjords influenced by marine-terminating glacier (MT) and fjords influenced by land-terminating glacier (LT) in the regions of a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut.

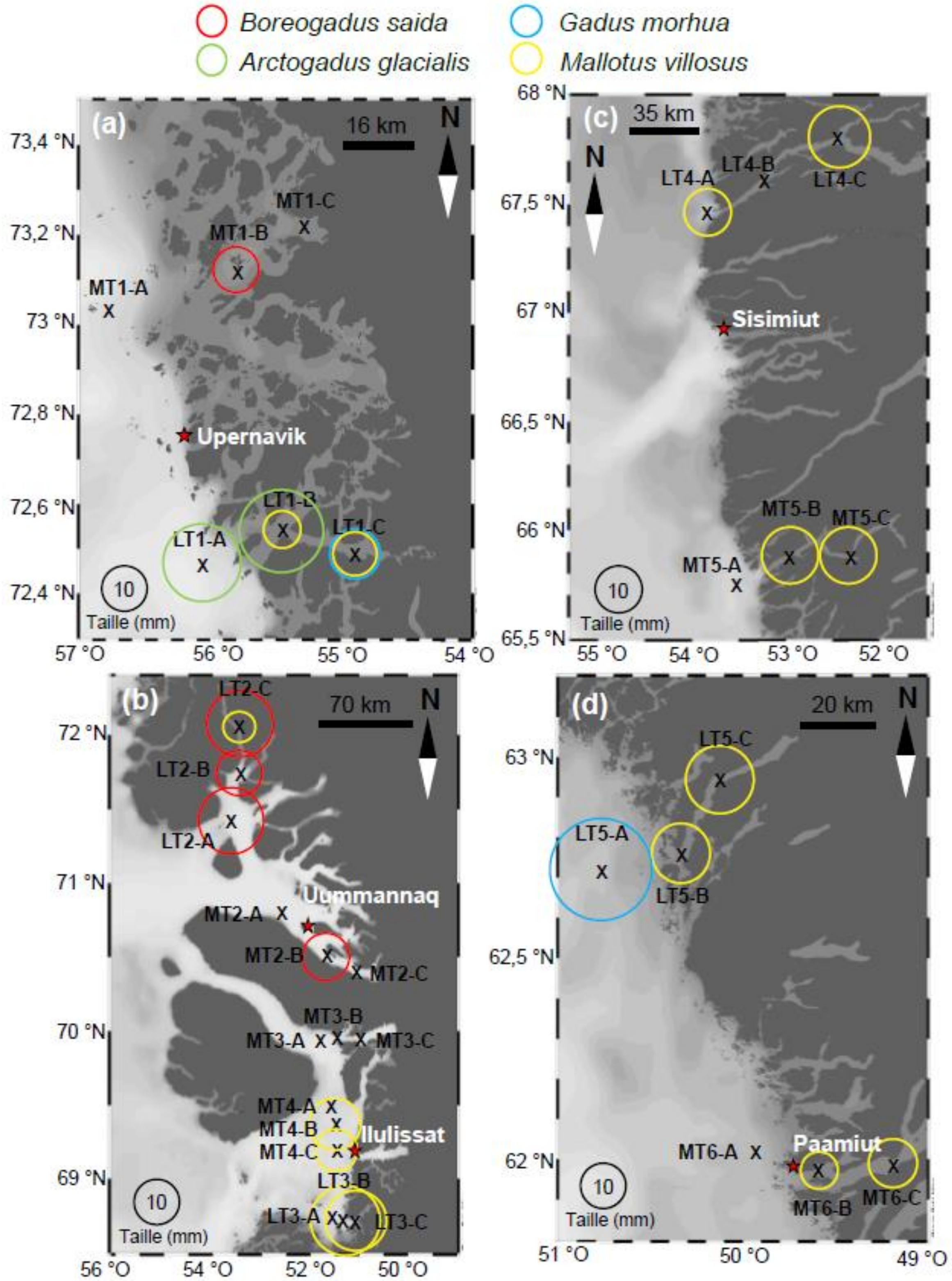

Figure 6. Standard length (Taille, in mm) of larval *B. saida, A. glacialis, G. morhua* and *M. villosus* in fjords influenced by marine-terminating glacier (MT) and fjords influenced by land-terminating glacier (LT) in the regions of a) Upernavik, b) Uummannaq and Ilulissat, c) Sisimiut and d) Paamiut.

4. Discussion

Greenland is strongly impacted by climate change. Global warming induces the melting of the Greenland ice sheet potentially leading to the retreat of marine-terminating glaciers and transformation into land-terminating glaciers. This transformation could potentially lead to changes in Greenland fjord ecosystems with cascading effects up to higher trophic levels including Greenland halibut (*Reinhardtius hippoglossoides*), a commercially important species (Meire et al. 2017). In this study we compared mesozooplankton biomass, macrozooplankton biomass, ichthyoplankton assemblages and size structure, in fjords influenced by marine-terminating glacier and fjords influenced by land-terminating glaciers along the West Greenland coast.

We observed a high level of heterogeneity in the habitats of zooplankton and ichthyoplankton in West Greenland fjords along a latitudinal gradient, between types of fjords, and along a transect within each fjord. Differences in SST and SSS between the northern and the southern regions most likely reflect differential heating along the latitudinal gradient, differences in heat absorption due to turbidity and presence of different water masses and circulation. In fjords with land-terminating glaciers, SST increased from the outer fjord to the inner fjord, while in fjords with marine-terminating glaciers, the opposite was observed. In general, SST and SSS were lower in the inner fjords than in the outer fjords, due to melting of the ice and the runoff of water contributing to cold and fresh water inside the fjords (e.g. Meire et al. 2017, Rignot et al. 2010).

The biomass of mesozooplankton and macrozooplankton were higher in the northern fjords (Upernavik, Uummannq and Ilulissat) than in the southern ones (Pedersen and Smidt 2000) and could potentially explain the higher abundance of age-0 fish in these regions. However, the biomass of mesozooplankton and macrozooplankton did not differ between fjords with land-terminating glaciers and fjords with marine-terminating glaciers. We can hypothesise that the higher primary production observed in fjords influenced by marine-terminating glaciers compared to fjords with land-terminating glaciers (Kanna et al. 2018, Meire et al. 2017) is either: 1) not directly transferred to secondary producers, 2) transferred mostly to small zooplankton (< 335 µm), not quantified in the current study, or 3) transferred only to certain zooplankton taxa within the mesozooplankton or macrozooplankton. Taxonomic analyses of the microzooplankton, mesozooplankton and macrozooplankton collected during the study is needed to address this hypothesis. Another possibility is that the contribution of marine-terminating glaciers to secondary production occurs on a relatively large scale (e.g. Disko Bay, Uummannaq Bay) rather than at the scale of individual fjord. As age-0 fish were neither more abundant nor larger in fjords with marine-terminating glaciers (*M. villosus* was in fact more abundant in fjords with land-terminating glaciers), we could not conclude whether a type of fjord is more favourable for larval fish recruitment. Local environment, in terms of SST and SSS for the larvae, but also in terms of habitats for the adult stage of each species, may be more important than the type of fjord. For polar cod larvae, which are highly sensitive to temperature above 5°C, some fjords with marine-terminating glaciers may constitute a refuge against warm summer SST (Bouchard et al. 2021). The individual features of each fjord seems indeed an important factor, as a linear relationship was found between the amount of meltwater runoff originating from the marine-terminating glaciers in a fjord and Greenland halibut catches in the region close to that fjord (Meire et al. 2017). Our study design includes fjords receiving a wide range of meltwater runoff in both fjord types, but this parameter was not considered in data analyses. More in-depth analyses of our dataset with detailed runoff information could lead to different conclusions. Our results are not supporting the hypothesis that increased primary production in fjords influenced by marine-terminated glaciers cascade up the food webs to benefit secondary production, larval fish recruitment and biomass of a Greenland halibut, but they are not contradicting it either. The present study clearly shows a greater need for studies further testing this hypothesis.

5. Contributions

Contributed to conception and design: CB, LM
Contributed to acquisition of data: CB, AC
Contributed to analysis and interpretation of data: CB, AC, LM
Drafted and/or revised the report: CB, AC, LM
Approved published version: CB, LM

This report is based on the internship report entitled *"Zooplancton et ichtyoplancton dans deux types de fiords sur la côte ouest du Groenland"* prepared by Agathe Charbogne as a requirement for the completion of a Master's degree in Marine Sciences - concentration Biological Oceanography and Marine Ecology at *Observatoire des sciences de l'Univers - Institut Pythéas, Aix-Marseille Université*, 2019-2020, 41 pp., available upon request (in French).

6. References

Aebischer S. 2020. ATKA 2019, Expedition report West Greenland. ATKA média, 52 pp. https://atka.fr/wp-content/uploads/2020/09/ATKA_RapportScience_Edition_VF.pdf

Bouchard, C., Mollard, S., Suzuki, K., Robert, D. and Fortier, L. 2016. Contrasting the early life histories of sympatric Arctic gadids Boreogadus saida and Arctogadus glacialis in the Canadian Beaufort Sea. Polar Biol. 39: 1005-1022. doi: http://dx.doi.org/10.1007/s00300-014-1617-4.

Bouchard, C. and Fortier, L. 2020. The importance of *Calanus glacialis* for the feeding success of young polar cod: a circumpolar synthesis. Polar Biol. 43: 1095-1107. doi: https://doi.org/10.1007/s00300-020-02643-0.

Bouchard, C., Charbogne, A., Baumgartner, F. and Maes, S.M. 2021. West Greenland ichthyoplankton and how melting glaciers could allow Arctic cod larvae to survive extreme summer temperatures. Arctic Science 7: 217-239. doi: https://doi.org/10.1139/as-2020-0019.

Fey, D. P. 2012. Length adjustment of larval and early-juvenile cod (*Gadus morhua*) after up to 3 years of preservation in alcohol: preservation of larval and juvenile cod. J. Appl. Ichthyol. 28: 665-666. https://doi.org/10.1111/j.1439-0426.2011.01929.x.

Kanna, N., Sugiyama, S., Ohashi, Y., Sakakibara, D., Fukamachi, Y., & Nomura, D. 2018. Upwelling of macronutrients and dissolved inorganic carbon by a subglacial freshwater driven plume in Bowdoin Fjord, northwestern Greenland. J. Geophys. Res. Biogeosci. 123: 1666-1682. https://doi.org/10.1029/2017JG004248.

Kruse, G. H., and Dalley, E. L. 1990. Length changes in capelin, *Mallotus villosus* (Muller), larvae due to preservation in formalin and anhydrous alcohol. J. Fish Biol. 36: 619-621. https://doi.org/10.1111/j.1095-8649.1990.tb03564.x.

Malanski, E., Munk, P., Swalethorp, R. and Nielsen, T. 2020. Early life characteristics of capelin (*Mallotus villosus*) in the subarctic-arctic transition zone. Estuar. Coast. Shelf Sci. 106787. doi: https://doi.org/10.1016/j.ecss.2020.106787.

Meire, L., Mortensen, J., Meire, P., Juul-Pedersen, T., Sejr, M.K., Rysgaard, S., Nygaard, R., Huybrechts, P. and Meysman, F.J.R. 2017. Marine-terminating glaciers sustain high productivity in Greenland fjords. Global Change Biol. 23: 5344-5357. doi: https://doi.org/10.1111/gcb.13801.

Pedersen, S.A. and Smidt, E.L.B. 2000. Zooplankton distribution and abundance in West Greenland waters, 1950–1984. J. Northwest Atl. Fish. Sci. 26: 45-102. doi: https://doi.org/10.2960/J.v26.a4.

Rignot, E., Koppes, M., & Velicogna, I. (2010). Rapid submarine melting of the calving faces of West Greenland glaciers. Nat. Geosci. 3: 187-191. doi: https://doi.org/10.1038/ngeo765.

RStudio Team. 2015. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA (Computer Software v0.98.1074). http://www.rstudio.com/.

Schlitzer, R. 2009. Ocean Data View software, http://odv.awi.de.