Oceanologia (2017) 59, 585—591

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia/

OCEANOLOGIA

ORIGINAL RESEARCH ARTICLE

Acoustical estimation of fish distribution and abundance in two Spitsbergen fjords

Joanna Szczucka [a,*], Łukasz Hoppe [a], Beata Schmidt [b], Dariusz P. Fey [b]

[a] *Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland*
[b] *National Marine Fisheries Research Institute, Gdynia, Poland*

Received 13 July 2016; accepted 11 April 2017
Available online 28 May 2017

KEYWORDS
Arctic fish;
Multifrequency acoustics;
West Spitsbergen

Summary Over recent decades, the Arctic region has been subjected to rapid climate change stemming from global warming. The advance of Atlantic waters to high latitudes is notable. The increased abundance of fish, such as cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), has been reported near the western coast of Spitsbergen and entering fjords together with Atlantic waters. This study used multifrequency acoustics to measure fish distribution and abundance in 2013—2014 in two Arctic fjords, the colder Hornsund, which is typically of Arctic character, and the warmer Kongsfjorden, which is more of Atlantic character. The study revealed a bimodal fish size distribution with larger fish in the deep parts of fjords, and smaller fish distributed in more shallow waters. An evident increase in the abundance of large fish, most probably Atlantic cod, was observed in Hornsund and especially in Kongsfjorden in 2014 in comparison to 2013. The intense inflow of Atlantic water on the shelf in 2014 is suggested as the explanation for this phenomenon.

1. Introduction

Over recent decades, the Arctic region has been subjected to rapid climate change stemming from global warming. Temperature increases have caused decreases in sea ice cover extent and duration (Barber et al., 2015; Falk-Petersen et al., 2015). The warmer Atlantic waters of the West Spitsbergen Current have shifted northward (Walczowski et al., 2012; Walczowski, 2014). Consequently, there has been a shift in ecological zones. The occurrence of increased

* Corresponding author at: Institute of Oceanology, Polish Academy of Sciences, Powstańców Warszawy 55, 81-712 Sopot, Poland. Tel.: +48 587311824; fax: +48 585512130.
E-mail address: szczucka@iopan.gda.pl (J. Szczucka).
Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.oceano.2017.04.007

abundance of fish such as cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Eriksen et al., 2015; Renaud et al., 2012), and most recently Atlantic mackerel (*Scomber scombrus*) (Berge et al., 2015), have been reported near the western coast of Spitsbergen and in fjords. Furthermore, sub-Arctic species such as capelin (*Mollotus villosus*) have extend their distribution further north in warm years (Hop and Gjøsæter, 2013). The increasing temperature in Svalbard fjords supports the survival of fish species that are not typically Arctic during the winter and provides better feeding conditions during summer and autumn. Fossheim et al. (2015) and Haug et al. (2017) recently documented the rapid northward shift in the distribution of boreal fish communities in the Barents Sea because of warming, and concluded that climate warming is inducing structural change over large spatial scales at high latitudes leading to a borealization of fish communities in the Arctic. Similar conclusions can be drawn from a publication by Misund et al. (2016) who analyzed detailed data on fisheries activity in the Svalbard zone since 1980 to show how fisheries for different species have developed as the Arctic ice sheet retreats and new waters open up for boreal fish species. The results clearly indicate a northward trend in landings of many fish species. All of these changes in hydrological conditions and fish community structure are expected to have significant consequences, mostly stemming from increased risk of predation and food competition, for typically Arctic species like the polar cod (*Boreogadus saida*) (Benoit et al., 2014; Berge et al., 2015; Christiansen et al., 2012; Geoffroy et al., 2011; Hop and Gjøsæter, 2013; Renaud et al., 2012).

This study focused on fish as a key component of the marine ecosystem. Fish distribution and abundance were measured in two hydrologically different Arctic fjords, the colder Hornsund and the warmer Kongsfjorden. The main measurement tool was acoustics (3-frequency echo sounder) supported by net catches.

2. Study area

This study was conducted in two West Spitsbergen fjords, Hornsund and Kongsfjorden, during cruises of r/v *Oceania* in the summer seasons of 2013 and 2014, as a part of the GAME (Growing of the Arctic Marine Ecosystem) project. Spitsbergen is the largest island of the Svalbard archipelago located north of Norway. The area is influenced by two water masses. Hornsund is regarded as a cold fjord, under the influence of the South Cape Current, while Kongsfjorden is influenced by warmer Atlantic waters carried by the West Spitsbergen Current. The area of Hornsund is 275 km^2, its volume is 25.7 km^3, and its maximum depth is 260 m. The area of Kongsfjorden is 209 km^2, its volume is 40.5 km^3, and its maximum depth is 394 m. In addition to differences in temperature, significant differences in fish prey species composition and size structure (Węsławski et al., 2006) are also observed between Hornsund and Kongsfjorden.

3. Material and methods

3.1. Survey design

Since Arctic expeditions are multidisciplinary, their scientific programs are very extensive and time-consuming, which means that the time planned for specific tasks is severely limited. The typical acoustic survey design for fish distribution and abundance estimation (e.g., systematic zig-zag) could not, therefore, be implemented, and it was necessary to reduce the cruise track to a few sections. Acoustic surveys were carried out together with continuous CTD measurements. The main transect was planned along the fjord axis extending from the mouth of the fjord to the easternmost glacier, with two or three additional transverse transects (Fig. 1a and b). A total of 66.7 nautical miles of acoustic transects were sampled in Hornsund (40.6 nmi in 2013 and 26.1 nmi in 2014), while in Kongsfjorden the measurements covered 53.7 nmi (27 nmi in 2013 and 26.7 nmi in 2014).

The technical specifications of concurrent CTD and acoustic surveys limited the ship speed to 3—4 knots. The speed was further reduced to 1—2 knots when ice floes appeared in the fjords.

3.2. Data acquisition

Acoustic data were collected with a Simrad EK60 split-beam echo sounder operating at frequencies of 70, 120, and 200 kHz, and all three transducers with 7 degrees beam angle at −3 dB. Acoustic transducers were mounted on a rigid frame attached to the broadside of the vessel, approximately 1 m below the sea surface. All three echo sounders used a 256 μs pulse length, with 525, 200, and 120 W of power, respectively. The ping rate was set to 2 s^{-1} and pulse transmission was synchronized for each transmitter. Calibration was performed before the first season (2013) using the standard target method (Foote et al., 1987). Acoustic signals were collected with dedicated Simrad ER60 software and stored digitally in raw format for later analysis in Echoview and Matlab.

Fish were collected at two stations in Kongsfjorden (at depths of 134 m and 52 m) between September 29 and October 4, 2013 during a cruise of the r/v *Helmer Hanssen* using a bottom Campelen 1800 shrimp trawl (Fey and Węsławski, in this issue). The horizontal and vertical openings were 17 m and 4—5 m, respectively, and the door spread was about 45—50 m. The mesh size was 80 mm in the front and 22 mm in the cod end. The gear was towed at the bottom for approximately 10—15 min, at 3 knots. More than 600 specimens of polar cod in the size range 6.1—24.3 cm and several individuals of other small pelagic species were measured (±1 cm) and weighed (±1 g). The only fish collected in Hornsund were small demersal species and larvae caught in a Tucker Trawl and several epibenthic sledge hauls in August 2015.

3.3. Data pre-processing

Acoustic data were pre-processed in Echoview software (Sonardata Pty Ltd.), which automatically delivered the values of S_V (volume backscattering strength) integrated into selected cells (distance by depth). Fish biomass calculations were based on 70 and 120 kHz records, while 200 kHz echoes were contaminated by the interfering ADCP signals and had to be neglected. Multi-frequency analysis required all frequency data to be unbiased from any noise (Korneliussen, 2000). A special algorithm for noise removal was developed

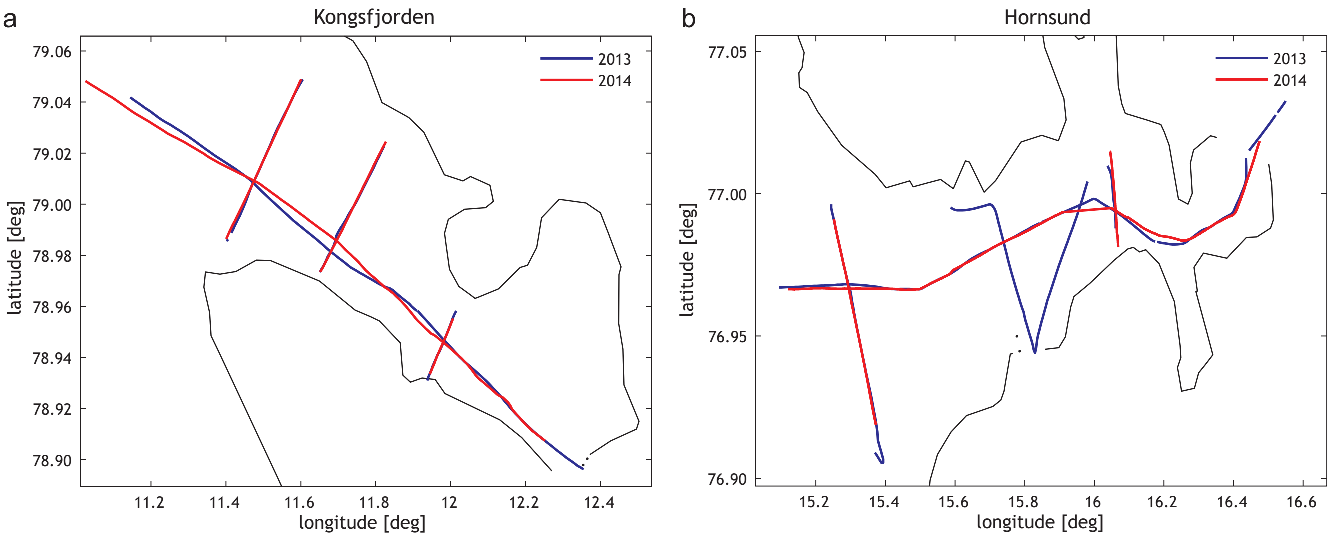

Figure 1 Acoustic transects in West Spitsbergen fjords: (a) Kongsfjorden (north) and (b) Hornsund (south).

and applied. To remove spike noise, the samples in each ping were compared to the same-range samples in the previous and following pings. If the ping-to-ping difference was greater than 10 dB, the value of the sample was replaced with the value of the previous sample. The threshold of 10 dB was determined after visual inspection of echograms before and after spike removal. "Second bottom reflections" were removed. Finally, the difference between volume backscattering strength recorded at 120 and 70 kHz, $S_{V,120} - S_{V,70}$, was used to discern fish from other scatterers, mainly zooplankton. Based on the fact that in the range of 70—120 kHz fish with swim bladder scatter more sound at a lower frequency than at a higher one (Pedersen and Korneliussen, 2009) and that scattering on zooplankton shows a reverse tendency, all the samples with the difference $S_{V,120} - S_{V,70} > 0$ were classified as "no fish" and were removed from the 70 kHz echogram.

The effectiveness of the algorithm for removing noise and zooplankton contributions was tested by calculating the differences in ΔS_V between backscattering strength before and after correction. This was performed at 0.1 nmi intervals for all longitudinal and transverse transects in both fjords and seasons. An example is presented in Fig. 2 showing the histogram of ΔS_V for Kongsfjorden in the 2014 season. The median of this distribution is 1.69 dB. Considerably higher median values of ΔS_V were obtained for the three other

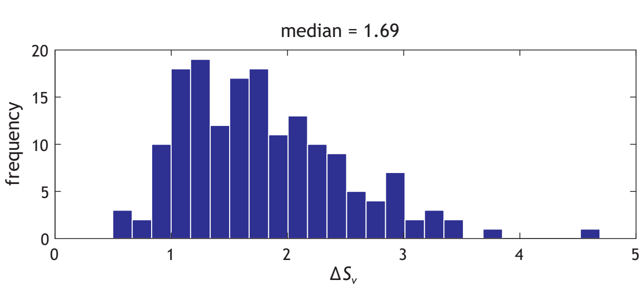

Figure 2 Histogram of differences between raw and corrected values of backscattering strength $S_{V,0} - S_{V,1}$ obtained in Kongsfjorden in 2014.

cases: 6.37 for Kongsfjorden'2013, 3.79 for Hornsund'2013, and 2.76 for Hornsund'2014. This was probably the result of the more serious contamination (mainly electrical) of the echo signals obtained.

3.4. Computational algorithms for fish abundance, biomass concentration, total fish biomass

The volume backscattering strength is the logarithmic measure of the volume backscattering coefficient. They are related as follows (Medwin and Clay, 1998):

$$\langle S_V \rangle = 10 \log \langle s_V \rangle. \tag{1}$$

In the case of bimodal fish size distribution, the backscattering coefficient can be expressed as (Simmonds and MacLennan, 2005):

$$s_V = s_{V,1} + s_{V,2} = (f_1 + f_2) s_V, \tag{2}$$

where f_1 and f_2 — weighting coefficients; $f_1 + f_2 = 1$ and numerical concentration of the ith fish size class (Nakken and Dommasnes, 1977):

$$N_{fish,i} = \frac{\langle s_{V,1} \rangle}{\langle \sigma_{bs,i} \rangle} = f_i \frac{\langle s_V \rangle}{\langle \sigma_{bs,i} \rangle}, \tag{3}$$

where σ_{bs} is the backscattering cross section of individual fish.

Biomass concentration estimates were derived by multiplying numerical concentration by the mean weight of acoustically detected fish of the ith size class:

$$M_i = N_{fish,i} W_i. \tag{4}$$

The weight-length dependence for fish was adopted as:

$$W(L) = AL^B, \tag{5}$$

where W is fish weight in g, L is fish length in cm. $A = 0.008$, $B = 3.05$ for Atlantic cod was taken from the literature (Wigley et al., 2003). These values for polar cod were based on our own trawl catch and were calculated with linear regression at $A = 0.005$, $B = 3.04$, $R = 0.98$. The length of the analyzed fish was in the range of 6.1—24.3 cm.

Calculating fish target strength *TS* was done with Echoview single echo detection and the fish tracking tool. The fish tracking criteria were as follows: minimum number of single targets in a track — 3; minimum number of pings in track — 3; maximum gap between single targets — 2. This delivered the *TS* distribution, and its depth dependence. When there was bimodal *TS* distribution, weighting coefficients f_1 and f_2 (expression (2)) were determined.

The fish target strength dependence on fish length was adopted as:

$$TS(L) = m\log(L) + b, \tag{6}$$

where *L* is fish length in cm, $m = 21.8$, $b = -72.7$ dB for polar cod (Benoit et al., 2008) and $m = 20$, $b = -68.9$ dB for Atlantic cod (Simmonds and MacLennan, 2005), which were the two most abundant species occurring in the study area.

Because target strength is equivalent to fish length, the size of individuals or the dominant size of the fish could be determined.

The fish biomass for each integration interval was determined using the relationship between the weight of fish and its length (5) and between *TS* and fish length (6).

Volume backscattering strength values S_V extracted from the cleaned 70 kHz data, integrated horizontally over 0.5 nmi and vertically by 5 m depth layers, were used to visualize the depth distribution of fish biomass along each transect.

S_V values obtained for the entire water column were integrated horizontally over 0.1 nmi to determine fish concentration, abundance, and total biomass. Sampled volume was also calculated in each interval, so the product of biomass concentration and sampled volume resulted in the total mass of fish. Finally, the sum of biomass calculated for all transects of the fjord and the knowledge of the total fjord volume permitted approximating the total tonnage of fish in the fjord.

4. Results and discussion

Target strength distribution determined for each fjord and each year using the fish tracking tool combined with target strength dependence on fish length permitted finding the dominant fish size in any specific situation. In the first research season (2013), in Hornsund, unimodal *TS* distribution was obtained (Fig. 3a), while in Kongsfjorden analogous distribution was bimodal, with a relatively high number of small fish in comparison to large ones (Fig. 4a).

Hornsund was dominated by fish with a *TS* mean = −54.12 dB (fish length ≅ 7.1 cm) occurring to a depth of 200 m (Fig. 3b). In Kongsfjorden, the *TS* mean of small fish = −54.87 dB, which corresponded to a $L \cong 6.6$ cm, while the *TS* mean for large fish = −32.89 dB, which corresponded to $L = 80$ cm. Small fish, most likely polar cod, with $TS < -45$ dB, occurred in shallow layers to a depth of 200 m, while large Atlantic cod with $TS > -40$ dB occupied the lower part of the water column below 200 m.

This situation changed radically in summer 2014, when very large Atlantic cod with $TS > -40$ dB (up to 1 m in length) appeared in Hornsund (Fig. 5a), and the proportions of the *TS* bimodal distribution in Kongsfjorden changed with large fish predominating in number over small ones (Fig. 6a). Large fish also appeared in more shallow water than they had a year earlier (Fig. 6b).

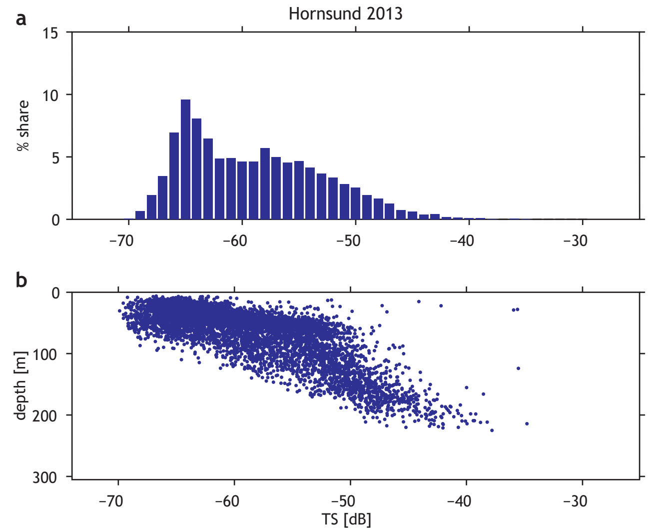

Figure 3 (a) *TS* distribution obtained for Hornsund in 2013. (b) Depth distribution of *TS* values measured in Hornsund in 2013.

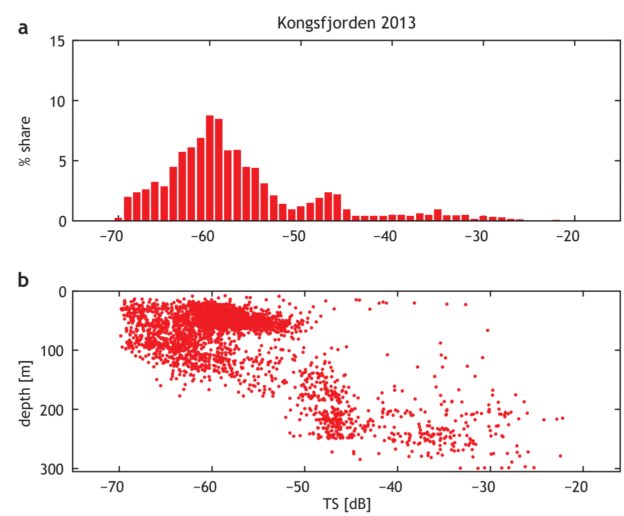

Figure 4 (a) *TS* distribution obtained for Kongsfjorden in 2013. (b) Depth distribution of *TS* values measured in Kongsfjorden in 2013.

Generally, except for the first season (2013) with hardly any large fish in Hornsund, bimodal *TS* distributions were the most common, with distinct local maximums of small and large fish.

The mean values of *TS* for one or both modes are presented in Table 1. They were used in fish abundance computations (formulae 2 and 3).

Because of fish mobility, we decided to apply the general *TS* distribution, which was universal for the entire fjord in each season, in the final computations instead of separate *TS* distributions for individual transects.

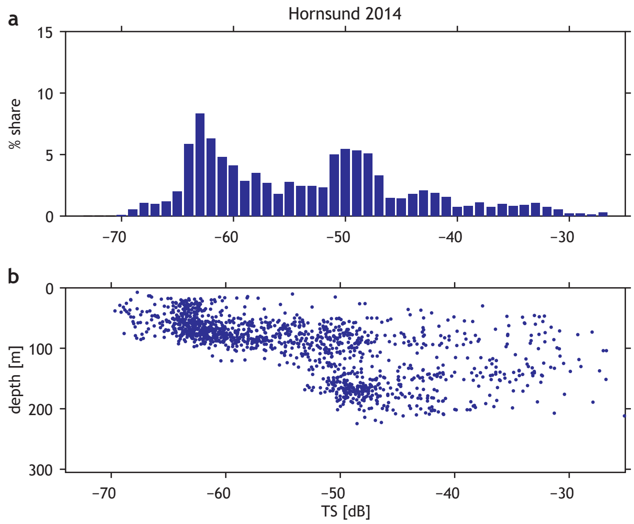

Figure 5 (a) *TS* distribution obtained for Hornsund in 2014. (b) Depth distribution of *TS* values measured in Hornsund in 2014.

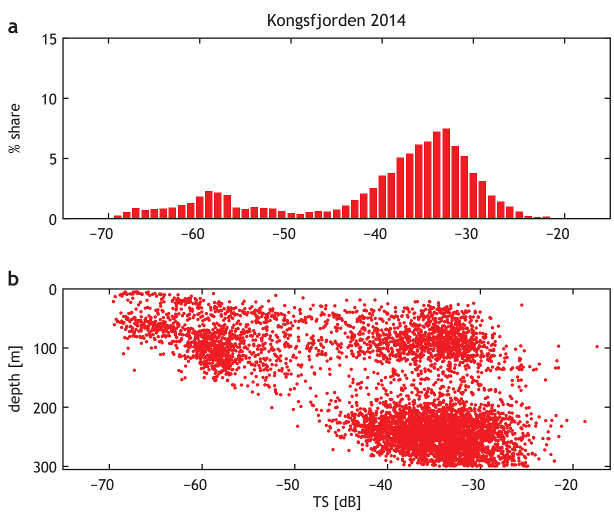

Figure 6 (a) *TS* distribution obtained for Kongsfjorden in 2014. (b) Depth distribution of *TS* values measured in Kongsfjorden in 2014.

Fig. 7a presents an example of fish biomass distribution in the external transverse transect of Kongsfjorden in 2014. The maximum biomass is concentrated in the deep water of the fjord, and a distinct fish layer exists at a depth of 100 m. The dependence of fish target strength on depth for the same transect is presented in Fig. 7b. Deep-water fish are probably large Atlantic cod grazing close to the bottom. Comparisons with trawl catch data indicate that the small fish are mainly polar cod with an admixture of capelin, while the large fish are Atlantic cod with an admixture of haddock.

TS means calculated for the individual modes can be attributed to the dominant size of fish in clusters. According to formula (6), small fish *TS* values correspond to a fish length of 7—8 cm. Minimum *TS* values (−70 dB) correspond to a fish length of 1 cm. The polar cod in the current study measured to determine the relationship *TS*(*L*) were caught in September 2013, and they were all longer than 6.1 cm. Nevertheless, during the polar expedition of 2015, polar cods as short as 13—23 mm were caught in the upper 20 m water layer.

The combination of acoustic methods and net-captured fish analysis suggests that the dominant species observed during this study was polar cod. Although significant differences in polar cod vertical distribution can occur depending on time of year, area, and environmental conditions such as food availability, the presence of predators, or light intensity (Benoit et al., 2010), the general pattern of smaller specimens occurring in shallow waters and large ones distributed in deeper layers is the most common for this species (Benoit et al., 2010, 2014; Falk-Petersen et al., 1986). This pattern of size-dependent vertical distribution was found in the present work in both 2013 and 2014. However, fish size differences among different depths are related not only to the behaviour (e.g., migrations) of polar cod, the most common species in Svalbard fjords, but also to the presence of other species in the same water masses. The large fish measuring up to 1 m observed in the present research must have been Atlantic cod. Although its presence in Svalbard fjords is not surprising (Renaud et al., 2012), especially in Kongsfjorden which is under strong Atlantic water influence, this is still not an ordinary situation.

The total fish biomass estimated for 2014 was 35 tonnes in Hornsund and 241 tonnes in Kongsfjorden, and the fish density was 1.4×10^{-3} g m^{-3} and 6×10^{-3} g m^{-3}, respectively. The abundance of Atlantic cod in Spitsbergen fjords in 2014 compared to that in 2013 was related to the intense influx of Atlantic water on the shelf in that year. The water temperature in both fjords was higher than the long-term average (2001—2015) by almost 1.5 degrees, and Atlantic water had the greatest reach in this period. It filled almost the entire water column in Kongsfjorden, from 20 m down to 250 m (Promińska et al., 2017). The northward expansion of the distribution of large predatory species such as Atlantic cod is a consequence of the warming observed in the Arctic

Table 1 Weighting coefficients *f* and mean *TS* for small and large fish in both fjords in both years.

Area/year	Small fish		Large fish	
	f_1	TS_1	f_2	TS_2
Hornsund'2013	1	−54.12	0	
Hornsund'2014	0.823	−52.66	0.177	−35.69
Kongsfjorden'2013	0.914	−54.87	0.086	−32.89
Kongsfjorden'2014	0.237	−53.79	0.763	−32.51

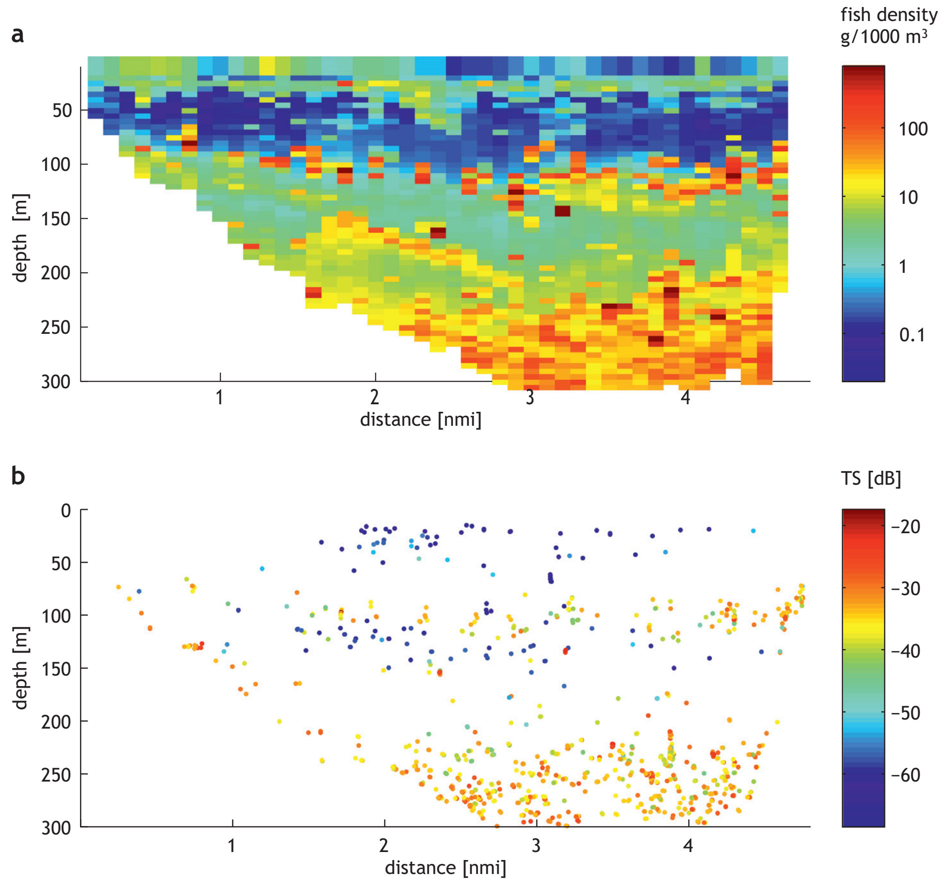

Figure 7 (a) Fish biomass along the external transverse transect of Kongsfjorden in 2014. S_V integrated horizontally over 0.5 nmi and vertically by 5 m depths. (b) Fish target strength vs depth for the same transect.

that is leading to structural changes in and the borealization of fish communities (Fossheim et al., 2015). The consequences of these changes are difficult to predict because of the complexity of the processes such as increasing food competition and predation (Hop and Gjøsæter, 2013; Renaud et al., 2012) among typical Arctic species like polar cod and incoming species like Atlantic cod, haddock, mackerel, and capelin. The intensity and mechanisms of competition and predation will vary significantly not only among fjords, but also at different times of the year. It should be remembered that these mechanisms also involve higher level predators such as birds and mammals, and polar cod is an important, valuable food source in this food chain component (Crawford and Jorgenson, 1996; Harter et al., 2013; Weslawski et al., 1994).

To sum up, the results presented here provide another example of size-related differences in the vertical distribution of polar cod, and the northern migration of typical Atlantic species such as Atlantic cod into Svalbard fjords as a consequence of environmental warming and the inflow of warm Atlantic waters into fjords.

Acknowledgements

This work was supported by the GAME project of the National Science Centre no. DEC-2012/04/A/NZ8/00661 and the GLAERE project of the Norwegian Funding Mechanism no. DZP/POL-Nor/1876/2013.

References

Barber, D.G., Hop, H., Mundy, C.J., Else, B., Dmitrenko, I.A., Tremblay, J.E., Ehn, J.K., Assmy, P., Daase, M., Candlish, L.M., Rysgaard, S., 2015. Selected physical, biological and biogeochemical implications of a rapidly changing Arctic Marginal Ice Zone. Prog. Oceanogr. 139, 122—150, http://dx.doi.org/10.1016/j.pocean.2015.09.003.

Benoit, D., Simard, Y., Fortier, L., 2008. Hydroacoustic detection of large winter aggregations of Arctic cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea). J. Geophys. Res. 113 (6), 1—9, http://dx.doi.org/10.1029/2007JC004276.

Benoit, D., Simard, Y., Fortier, L., 2014. Pre-winter distribution and habitat characteristics of polar cod (*Boreogadus saida*) in southeastern Beaufort Sea. Polar Biol. 37 (2), 149—163, http://dx.doi.org/10.1007/s00300-013-1419-0.

Benoit, D., Simard, Y., Gagne, J., Geoffroy, M., Fortier, L., 2010. From polar night to midnight sun: photoperiod, seal predation, and the diel vertical migrations of polar cod (*Boreogadus saida*) under landfast ice in the Arctic Ocean. Polar Biol. 33 (11), 1505—1520, http://dx.doi.org/10.1007/s00300-010-0840-x.

Berge, J., Heggland, K., Lønne, O.J., Cottier, F., Hop, H., Gabrielsen, G.W., Nottestad, L., Misund, O.A., 2015. First records of Atlantic Mackerel (*Scomber scombrus*) from the Svalbard Archipelago, Norway, with possible explanations for the extension of its distribution. Arctic 68 (1), 4—61, http://dx.doi.org/10.14430/arctic4455.

Christiansen, J.S., Hop, H., Nilssen, E.M., Joensen, J., 2012. Trophic ecology of sympatric Arctic gadoids, *Arctogadus glacialis* (Peters, 1872) and *Boreogadus saida* (Lepechin, 1774), in NE Greenland.

Polar Biol. 35 (8), 1247—1257, http://dx.doi.org/10.1007/s00300-012-1170-y.

Crawford, R.E., Jorgenson, J.K., 1996. Quantitative studies of Arctic Cod (*Boreogadus saida*) schools: important energy stores in the arctic food web. Arctic 49 (2), 181—193, http://dx.doi.org/10.14430/arctic1196.

Eriksen, E., Ingvaldsen, R.B., Nedreaas, K., Prozorkevich, D., 2015. The effect of recent warming on polar cod and beaked redfish juveniles in the Barents Sea. Reg. Stud. Mar. Sci. 2, 105—112.

Falk-Petersen, I.B., Frivoll, V., Gulliksen, B., Haug, T., 1986. Occurrence and size/age relations of polar cod, *Boreogadus saida* (Lepechin), in Spitsbergen coastal waters. Sarsia 71 (3—4), 235—245, http://dx.doi.org/10.1080/00364827.1986.10419693.

Falk-Petersen, S., Pavlov, V., Berge, J., Cottier, F., Kovacs, K.M., Lydersen, Ch., 2015. At the rainbow's end: high productivity fueled by winter upwelling along an Arctic shelf. Polar Biol. 38 (1), 5—11, http://dx.doi.org/10.1007/s00300-014-1482-1.

Fey, D.P., Węsławski, J.M., 2017. Age, growth rate, and otolith growth of polar cod (*Boreogadus saida*) in two fjords of Svalbard, Kongsfjorden and Rijpfjorden. Oceanologia 59 (4), 576—584, http://dx.doi.org/10.1016/j.oceano.2017.03.011.

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., Simmonds, E.J., 1987. Calibration of Acoustic Instruments for Fish Density Estimation: A Practical Guide. ICES Coop. Res. Rep., 144, 69 pp.

Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R.B., Aschan, M.M., Dolgov, A.V., 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nat. Clim. Change 5, 673—677, http://dx.doi.org/10.1038/nclimate2647.

Geoffroy, M., Robert, D., Darnis, G., Fortier, L., 2011. The aggregation of polar cod (*Boreogadus saida*) in the deep Atlantic layer of ice-covered Amundsen Gulf (Beaufort Sea) in winter. Polar Biol. 34, 1959—1971, http://dx.doi.org/10.1007/s00300-011-1019-9.

Harter, B.B., Elliott, K.H., Divoky, G.J., Davoren, G.K., 2013. Arctic cod (*Boreogadus saida*) as prey: fish length-energetics relationships in the Beaufort Sea and Hudson Bay. Arctic 66 (2), 191—196, http://dx.doi.org/10.14430/arctic4290.

Haug, T., Bogstad, B., Chierici, M., Gjøsæter, H., Hallfredsson, E.H., Høines, Å.S., Hoel, A.H., Ingvaldsen, R.B., Jørgensen, L.L., Knutsen, T., Loeng, H., Naustvoll, L.J., Røttingen, I., Sunnanå, K., 2017. Future harvest of living resources in the Arctic Ocean north of the Nordic and Barents Seas: a review of possibilities and constraints. Fish. Res 188, 38—57, http://dx.doi.org/10.1016/j.fishres.2016.12.002.

Hop, H., Gjøsæter, H., 2013. Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. Mar. Biol. 9 (9), 878—894, http://dx.doi.org/10.1080/17451000.2013.775458.

Korneliussen, R.J., 2000. Measurement and removal of echo integration noise. ICES J. Mar. Sci. 57 (4), 1204—1217, http://dx.doi.org/10.1006/jmsc.2000.0806.

Medwin, H., Clay, C.S., 1998. Fundamentals of Acoustical Oceanography. Acad. Press, Boston, 712 pp.

Misund, O.A., Heggland, K., Skogseth, R., Falck, E., Gjøsæter, H., Sundet, J., Watne, J., Lønne, O.J., 2016. Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings. Polar Sci. 10 (3), 312—322, http://dx.doi.org/10.1016/j.polar.2016.02.001.

Nakken, O., Dommasnes, A., 1977. Acoustic estimates of the Barents Sea capelin stock 1971—1976. Meet. Int. Explor. Sea (H:35) 1—6.

Pedersen, G., Korneliussen, R.J., 2009. The relative frequency response derived from individually separated targets of northeast Arctic cod (*Gadus morhua*), saithe (*Pollachius virens*), and Norway pout (*Trisopterus esmarkii*). ICES J. Mar. Sci. 66 (6), 1149—1154, http://dx.doi.org/10.1093/icesjms/fsp070.

Promińska, A., Cisek, M., Walczowski, W., 2017. Kongsfjorden and Hornsund hydrography - comparative study based on a multiyear survey in fjords of west Spitsbergen. Oceanologia 59 (4), 397—412, http://dx.doi.org/10.1016/j.oceano.2017.07.003.

Renaud, P.E., Berge, J., Varpe, Ø., Lønne, O.J., Nahrgang, J., Ottesen, C., Hallanger, I., 2012. Is the poleward expansion by Atlantic cod and haddock threatening native polar cod, *Boreogadus saida*? Polar Biol. 35 (3), 401—412, http://dx.doi.org/10.1007/s00300-011-1085-z.

Simmonds, J., MacLennan, D., 2005. Fisheries Acoustics. Theory and Practice, 2nd edn. Blackwell Publ., Oxford, http://dx.doi.org/10.1002/9780470995303, 437 pp.

Walczowski, W., 2014. Atlantic Water in the Nordic Seas. Properties, Variability, Climatic Importance, GeoPlanet: Earth and Planetary Sciences. Springer Int. Publ., London, 174 pp., http://dx.doi.org/10.1007/978-3-319-01279-7.

Walczowski, W., Piechura, J., Goszczko, I., Wieczorek, P., 2012. Changes of the Atlantic Water properties as an important factor of the European Arctic marine climate. ICES J. Mar. Sci. 69 (5), 864—869, http://dx.doi.org/10.1093/icesjms/fss068.

Weslawski, J.M., Ryg, M.S., Smith, T.G., Oritsland, N.A., 1994. Diet of ringed seals (Phoca Hispida) in a fjord of West Svalbard. Arctic 47 (2), 109—114, http://dx.doi.org/10.14430/arctic1279.

Węsławski, J.M., Kwaśniewski, S., Stempniewicz, L., Błachowiak-Samołyk, K., 2006. Biodiversity and energy transfer to top trophic levels in two contrasting Arctic fjords. Pol. Polar Res. 27 (3), 259—278.

Wigley, S.E., McBride, H.M., McHugh, N.J., 2003. Length-Weight Relationships for 74 Fish Species Collected during NEFSC Research Vessel Bottom Trawl Surveys, 1992—99. NOAA Tech. Memo. NMFS-NE-171, 26 pp.