ARTICLE IN PRESS

Polar Science xxx (2016) 1–11

Contents lists available at ScienceDirect

Polar Science

journal homepage: http://ees.elsevier.com/polar/

Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings

Ole Arve Misund [a, b, c, *], Kristin Heggland [a], Ragnheid Skogseth [a], Eva Falck [a], Harald Gjøsæter [b], Jan Sundet [b], Jens Watne [d], Ole Jørgen Lønne [a]

[a] University Centre in Svalbard, P.O. Box 156, N-9171 Longyearbyen, Norway
[b] Institute of Marine Research, P.O. Box 1870, N-5817 Bergen, Norway
[c] National Institute of Nutrition and Seafood Research, P.O. Box 2029, N-5817 Bergen, Norway
[d] Directorate of Fisheries, P.O. Box 185, N-5804 Bergen, Norway

ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
4 January 2016
Accepted 1 February 2016
Available online xxx

Keywords:
Arctic fisheries
Svalbard
Climate change

ABSTRACT

The Svalbard archipelago in the High Arctic is influenced by cold Arctic water masses from the north-east and the warm West Spitsbergen Current flowing northwards along its western coast. The eastern waters and the fjords are normally frozen during the winter months, while the coastal waters west of the archipelago remain open. Norwegian fishers have been harvesting from Svalbard waters for decades and detailed records of catches exists from 1980 onwards. We analyze the catch records from the Svalbard zone (approximately ICES area IIb). The large fishery for capelin in summer yielding annual catches up to 737 000 tons was closed by a Norwegian fishery regulation in the mid nineteen nineties. Demersal fisheries have been continuous, and the results clearly indicate a northward trend in landings of Northeast Arctic cod, haddock, ling and Atlantic halibut. Fisheries of Northern shrimp have been more variable and shown no clear geographic trends. A "gold rush" fishery for scallops north of Svalbard lasted for about 10 years (1986–1995) only, and ended due to low profitably. These results are discussed in relation to the possibility of further northward extension of fisheries subjected to climate change.

1. Introduction

The area around Svalbard is the world's northernmost waters with regular fisheries and a strict fisheries regulation system. The Svalbard Treaty, signed 1920 in Versailles, France, gave Norway sovereignty over the Svalbard archipelago, and a fisheries protection zone around Svalbard (here termed the Svalbard zone, Fig. 1) was introduced in 1977 when Norway extended its Exclusive Economic Zone to 200 nautical miles. The Svalbard zone was adjusted slightly as a result of the border agreement with Russia in 2010, and is now 715 000 km^2.

Regular commercial fishing is carried out annually from the southern border of the Svalbard zone at 74° North latitude, south of Bjørnøya (Bear Island), and around the Svalbard archipelago all the way up to about 81° 30' North. This is much farther North than in other circumpolar waters. Around Greenland, Canada, Alaska and East Russia most fishing occurs south of 65° North. In the Russian part of the Barents Sea, fishing mainly takes place south of 78° North (Jakobsen and Ozhigin, 2011).

Fishing vessels operating in the fisheries protection zone around Svalbard must follow a suite of technical regulations set to protect juvenile gadoids and redfish. Minimum mesh sizes are regulated for whitefish trawls, and sorting grids are mandatory in both whitefish and shrimp trawls. Moreover, a regulatory system is enforced to open and close areas with high by catch of juvenile cod and redfish (Gullestad et al., 2014). Discarding of unwanted or undersized catch is banned. The Norwegian Coast Guard patrols the area frequently to ensure that these regulations are followed.

Based on historical activity, fishers from Norway and Russia are the main stakeholders to the fish resources in the area, but fishers from "third countries" (the EU and the Faroe Islands) have been allocated quotas of Northeast Arctic cod (*Gadus morhua*) and other demersal species in the Svalbard zone. For Northern shrimp (*Pandalus borealis*), fishers from Iceland and Greenland have access to the area too. The fishing quotas for different species are based on scientific advice from the International Council for the Exploration

* Corresponding author. University Centre in Svalbard, P.O. Box 156, N-9171 Longyearbyen, Norway.
E-mail address: ole.arve.misund@unis.no (O.A. Misund).

http://dx.doi.org/10.1016/j.polar.2016.02.001
1873-9652/

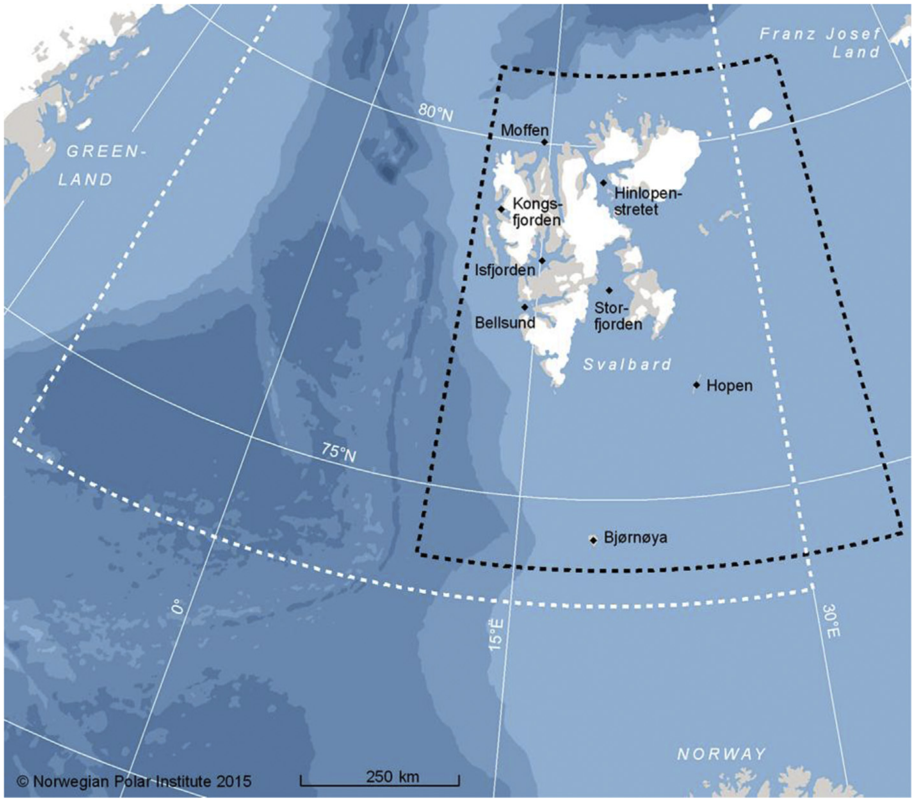

Fig. 1. The Svalbard zone (stippled black line) and ICES area IIb (stippled white line).

of the Sea (ICES), and are negotiated and decided upon by the joint Norwegian–Russian Fishery Commission, which has been active since 1976 (Hammer and Hoel, 2012). These fishing quotas are set for each individual species, and are normally valid for ICES areas I, IIb (approximately the Svalbard zone), and IIa. Specific regulations can apply for the Svalbard zone, however, for instance regarding the redfish fishery by third countries (the EU and the Faroe Islands).

Norwegian fishers have been harvesting the Svalbard waters for about 140 years. On the northernmost leg of the famous Norwegian North Sea Expedition in 1878, a vessel with fishers jigging Northeast Arctic cod from dories was encountered west of the northernmost islands along the west coast of the Svalbard archipelago (Sars, 1878). The first catch records for Northeast Arctic cod from Svalbard waters date back to 1874 (Iversen, 1934). Norwegian vessels caught 37 000 cod in 1874 and the fishing continued up to 1882 when 249 400 cod were caught in the Svalbard waters. In 1883 altogether 18 Norwegian fishing vessels went to Svalbard waters, but the cod was no longer present (Iversen, 1934).

Since 1980, the Directorate of Fisheries in Norway (www.fiskeridir.no) has collected detailed information on landings from Norwegian fishers, including data about the Svalbard zone. Weight and monetary value, broken down by species, is available from the database of statistics at the Directorate of Fisheries. Data for the years from 2000 to the present are available on line. To combat illegal fishing, a regulation was introduced in 2003 requiring Norwegian fishing vessels larger than 15 m to carry a satellite transmitter sending information about vessel position and speed on an hourly basis to the Fisheries Monitoring Centre at the Norwegian Directorate of Fisheries.

In a circumpolar context, the waters along the western and northern coast of Svalbard (about 76° 30' – 81° North, see Fig. 1), are the northernmost waters that are usually ice free. This is because the Svalbard archipelago is warmed by the West Spitsbergen Current (Fig. 2), the northernmost branch of the North Atlantic Current, which flows along the western coast and turns northeastwards into the Polar Basin north of the archipelago. The eastern coast of the Svalbard archipelago is chilled by a cold Arctic current flowing from northeast. This cold current rounds the southern tip of Svalbard and flows as a cold, coastal current northwards along the western coast of Svalbard (see Fig. 2). The Svalbard fjords are therefore normally frozen during winter, but during the past decade this has not been the case on the western coast of Svalbard.

In recent decades, global warming has become more evident. For example, sea ice extent in the Arctic at its minimum in September has been reduced by 13% per decade in the period 1979–2012 (NSIDC, 2013). Likewise, the volume of the Arctic sea ice has been reduced by 3100 km^3 per decade since 1979 (psc.apl.washington.edu). This indicates quite dramatic changes in the sea ice volume and extent over the last three decades. Winter ice extent in the waters north of Svalbard has declined by about 10% per decade, and the Atlantic Water entering the Arctic Ocean has warmed by about 0.3 °C per decade (Onarheim et al., 2014). The maximum temperatures of Isfjorden and Grønfjorden on the west coast of Svalbard have increased by about 2 °C during the last hundred years (Pavlov et al., 2013).

Warming of the Svalbard waters in the last decades has enabled northward expansion of boreal marine species. In 2005 blue mussels (*Mytulis edulis*) were back in the fjords of Western Svalbard for the first time in 1000 years (Berge et al., 2005). Species like Northeast Arctic cod, Northeast Arctic haddock (*Melanogrammus aeglefinus*), and herring (*Clupea harengus*) have become successively more common in the fjords of Western Svalbard (Berge et al., 2015). In 2013, Atlantic mackerel (*Scomber scombrus*) were caught

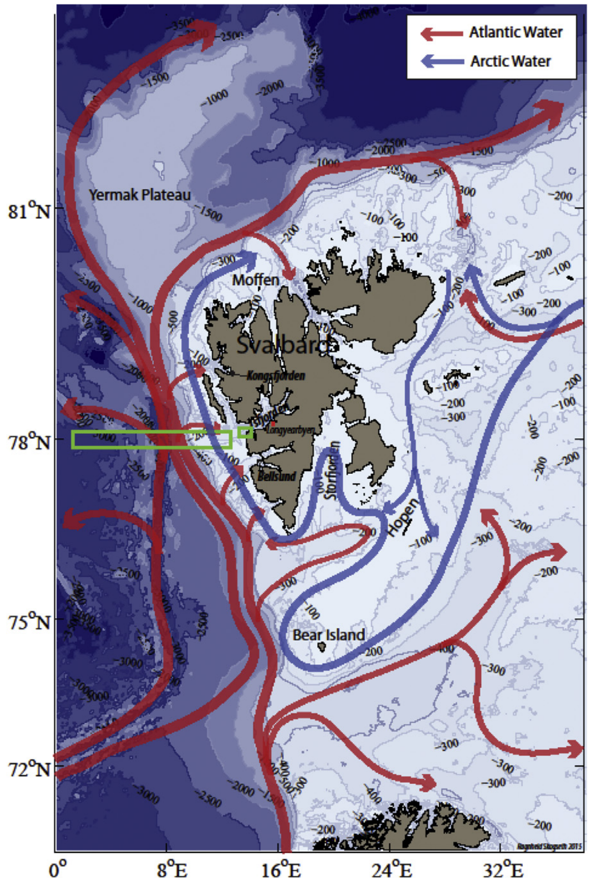

Fig. 2. The main current systems in the area around Svalbard, where blue arrows designate Arctic Water and red arrows Atlantic Water. The West Spitsbergen Current is shown by the thick red lines west of Svalbard. The two sections used to produce the temperature time series are indicated by green boxes.

near Longyearbyen in September (Berge et al., 2015), most probably an episodic event due to a larger stock than ever at that time in combination with warm waters.

In this study we use detailed data on fisheries activity in the Svalbard zone available since 1980 to analyze how fisheries for different species have developed as the Arctic ice sheet retreats and new waters open up for boreal fish species and their quota licensees. To substantiate the development of the oceanographic conditions in the area since 1980, we analyze oceanographic data from a relevant transect in the West Spitsbergen Current and in the fjords of western Svalbard.

2. Material and methods

Detailed data on landings by the Norwegian fishing fleet are available from a digital bank of statistics run by the Directorate of Fisheries in Norway since 1980. This applies to Norwegian vessels operating in areas under Norwegian jurisdiction, including the fisheries protection zone around Svalbard. From this data source, data on total catch and monetary value per year from vessels operating in the Svalbard zone have been collected. Data sets covering the periods 1980–1999, 2000–2004, and 2005 to the present were combined in the R software (R Core Team, 2012). Due to slight differences in the naming of species in the genera *Sebastes* and *Anarhichas* in the three datasets, species from these genera have been grouped into redfishes and wolf fishes, respectively. One dataset covering the whole period was constructed for each species.

Data on Iceland scallop (*Chlamys islandica*) landings and vessels were also retrieved from the Norwegian Fishermen's Sales Organization (www.rafisklaget.no).

For the years 2000–2004 no data were available on the monetary value of the landings of fish. The values for these years were estimated using a simple linear regression model, estimating price per kg and then multiplying by the total live weight per year.

The data were processed in R-statistical software (R Core Team, 2012). To study the trends in the time series, a smoother was applied to the data using the scatter.smooth function in R. No statistical trend analysis was performed due to lack of independence and normality of the data.

The Svalbard zone is a large ocean area, and until recently, the fishers did not have to report specifically where they had conducted the catching operations. Therefore the fisheries statistics do not contain information on where in the Svalbard zone the catches have been taken. Since 2003 the position and speed of Norwegian fishing vessels larger than 15 m have been tracked through the VMS system by the Fisheries Monitoring Centre (FMC) at the Directorate of Fisheries in Bergen (http://www.fiskeridir.no/English/Fisheries/Fisheries-Monitoring-Centre). Norwegian legislation does not permit release of data on the position and speed of individual vessels to the public. However, for the purpose of our study, maps of annually aggregated positions of the Norwegian fishing vessels larger than 15 m moving between 1 and 5 knots have been made by FMC. Using these maps, it is possible to describe where the fishing activities have been carried out on an annual basis.

Standard hydrographical data (temperature, salinity, and pressure) were used to produce time series of temperature for the area west of Spitsbergen from 1980 to 2014. The data comprised hydrographical data from the Norwegian Marine Data Centre (NMD), ICES, and the University Centre in Svalbard (UNIS, since 1995). Two representative sections with good data availability were chosen to cover the temperature of the Atlantic Water in the West Spitsbergen Current, one along 78°N (an area between 1° and 13°E, and 77.8°N and 78.2°N) and one on the southern side of the mouth of Isfjorden (between 13.5° and 14.3°E, and 78.08° and 78.21°N. The latter area covers the inflow of Atlantic Water into Isfjorden (see Fig. 2). Only data taken between June and October have been used because this is the main period for commercial fishing activities in the Svalbard zone.

For the 78°N section only temperatures above 3 °C and salinities above 34.9 have been included, as these temperature and salinity criteria are characteristic of Atlantic Water in the West Spitsbergen Current. For the section from the mouth of Isfjorden, where the Atlantic Water has been mixed to some degree with Arctic Water, the temperature and salinity criteria were above 1 °C and 34.7, respectively. To avoid the effect of seasonal warming of the surface, measurements from the upper 50 m have also been excluded. For each of the sections, two different time series were made: the yearly temperature at maximum salinity, to represent the core temperature of the West Spitsbergen Current; and the yearly mean temperature and its standard deviation. Trends were identified from linear regression with 95% uncertainties.

3. Results

3.1. Oceanographic conditions

The time series of maximum (T_{Smax}) and mean (T_{mean}) temperature for the sections 78°N and at the mouth of Isfjorden for the period 1980–2014 showed a trend of increasing temperatures in all the time series (Figs. 3 and 4). A trend toward increasing temperatures is clearly seen in all the time series. In the West Spitsbergen Current the temperature of the core of the Atlantic Water (T_{Smax}, Fig. 3) shows interannual variability with lowest temperature (3.5 °C) in 1996 and highest (7.5 °C) in 2006, while the mean temperature (T_{mean}, Fig. 3) of the Atlantic Water in the 78°N section fluctuates mainly between 3.5 °C and 4.5 °C. Periods of inflow of warmer Atlantic water in the sections 78°N seem to have occurred 1982–1983, 1990–1994, and then varying inflow from 1998. The Atlantic Water temperature at the mouth of Isfjorden (Fig. 4) shows a variation in T_{Smax} between 2 °C (in 1989) and 5.5 °C (in 2013), while T_{mean} fluctuates between 1.5 °C and nearly 5 °C.

3.2. Fisheries

Maps produced from the AIS positions of Norwegian vessels show that rather limited areas of the Svalbard zone are used for fishing (Fig. 5). We have only been allowed to investigate data from 2006 to 2012, and the material is inadequate to reveal annual variations and trends in the areas of fishing activity. Shrimp trawling is carried out in the depths west and north of Svalbard, in Isfjorden, outside Kongsfjorden, in the strait Hinlopen, and in the deep waters east of Hopen (Figs. 1 and 5). Along the slope of the west coast of Svalbard, gadoids are taken by bottom trawl. On the grounds near Bjørnøya (Figs. 1 and 5), bottom trawling, Danish seining and long lining are carried out for gadoid species. A purse seine fishery for capelin (*Mallotus villosus*) was carried out in the Svalbard zone, mainly in the waters east of Hopen in the autumn months (August–November) until the beginning of the 1990s. Dredging for Iceland scallops was carried out north of Bjørnøya, and Moffen north of Svalbard during 1986–94 (Fig. 1).

The total value of the landings (4.84 million tons) of the 13 most valuable species recorded from the Svalbard zone amounts to 27.55 billion NOK (adjusted to the present value of the Norwegian krone) for the 34 years 1980–2013 (Table 1). Landings of these species from the Svalbard zone declined during the period 1980–2013 (Fig. 6). This is because the purse seine fishery for "summer" capelin dominated the landings from the Svalbard zone in the early 1980s, and was roughly ten times larger than the other fisheries. The capelin fishery was carried out by about 150 vessels carrying catches of about 300–1500 tons. The fishery started in late August, often over a large area east of Hopen, and ended when capelin schools scattered at the onset of the dark season in November. The capelin stock was drastically reduced in the mid-1980s; the "summer" capelin fishery in the Svalbard zone was closed 1986–1990, and opened up again in 1991–1992 when the stock had recovered. Since then, Norwegian fishery regulations have not opened for a "summer" capelin fishery. The "summer" capelin fishery varied from 434 000 tons worth 256 million NOK in 1980, up to the peak landing of 737 000 tons worth 405 million NOK in 1983, but fell to 120 000 tons worth 67 million NOK in 1985. The two seasons in the early 1990s (1991–1992) gave total landings of about 80 000 tons worth about 40 million NOK. The prices for capelin were low, and fell from 0.59 NOK per kg in 1980 to 0.45 NOK per kg in 1992.

The demersal fisheries developed gradually from 9009 tons in 1980 to about 112 258 tons in 2013 (Fig. 6). Total landings were highest in 2012 with 136 583 tons, closely followed by 1987 with 132 864 tons. The mean annual total demersal catch throughout the period was 54 331 tons. However, an increase in demersal landings is evident (Fig. 6). Demersal species such as Northeast Arctic cod, Northeast Arctic haddock, saithe (*Pollachius virens*), redfishes, and Greenland halibut (*Reinhardtius hippoglossoides*) are mainly caught by 60–70 m freezer and factory trawlers operating around Bjørnøya and northwards along the continental shelf of western Svalbard (Figs. 1 and 5). These species are also caught by long line, gill-net and Danish seine vessels around Bjørnøya. Wolf fishes, tusk (*Bromse brosme*), ling (*Molva molva*) and Atlantic halibut (*Hippoglossus hippoglossus*) are mainly caught by long liners.

Northeast Arctic cod is the most important species in terms of both weight and value (Table 1). The fishery of Northeast Arctic cod has continued throughout the time series (Fig. 7). The general trend shows an increase in landings with time, in particular since the late 1990s. In addition, landings peaked in 1986 and 1995, with 14 687 tons and 60 917 tons, respectively. The year with the highest catch was 2013 with 83 182 tons and the lowest catch was in 1981 with a mere 11.4 tons.

Fishery for Northern shrimp has been extensive in the Svalbard

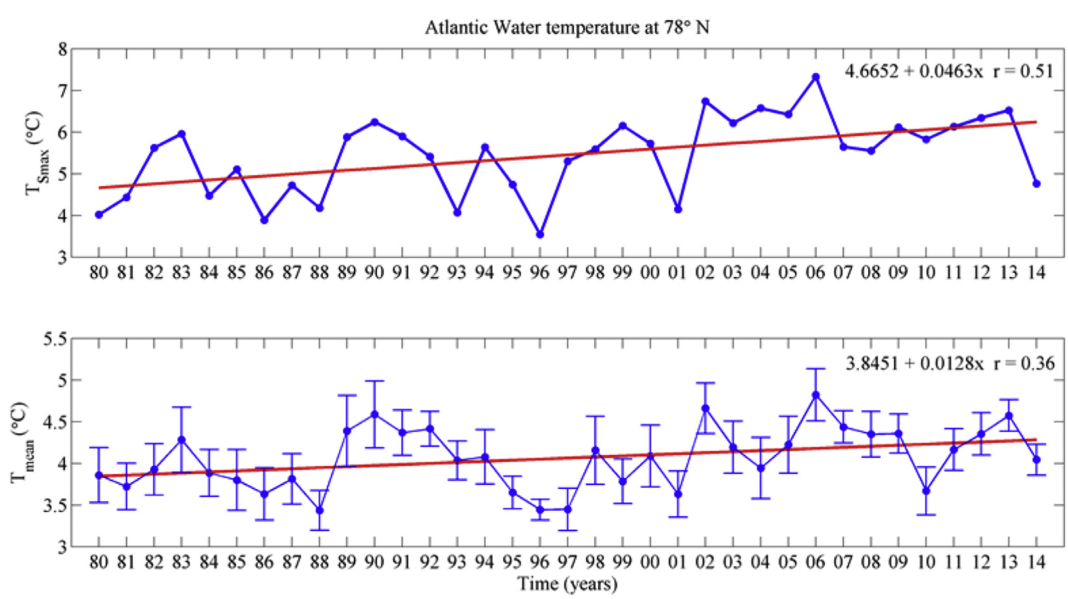

Fig. 3. Time series of Atlantic Water temperature for the section along 78°N. Upper panel: yearly temperature at maximum salinity (T_{Smax}) in the core of the West Spitsbergen Current. Lower panel: yearly mean temperature (T_{mean}) of Atlantic Water (error bars ± one standard deviation of the mean). The equation for the regression line is shown in the upper left corner of each time series, where r is the correlation between the regression line and the data points.

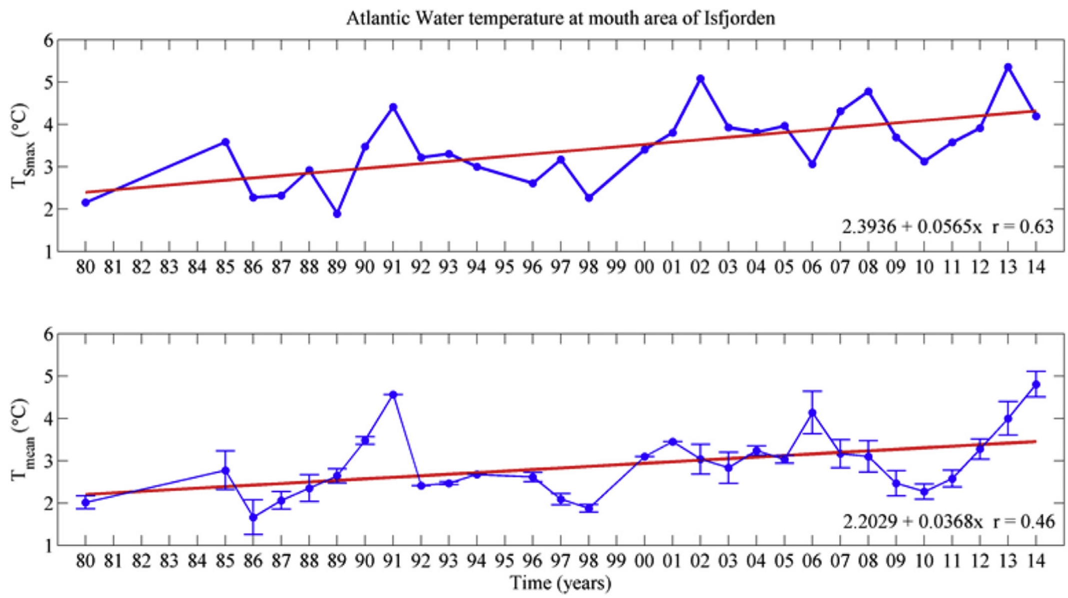

Fig. 4. Time series of Atlantic Water temperature for the mouth of Isfjorden. Upper panel: yearly temperature at maximum salinity (T_{Smax}). Lower panel: yearly mean temperature (T_{mean}) of Atlantic Water (error bars ± one standard deviation of the mean). The equation for the regression line is shown in the upper left corner of each time series, where r is the correlation between the regression line and the data points.

zone (Table 1). There seems to be a cyclical pattern in the landings, with peaks in 1985, 1992, 1998, 2005 and 2010, and lows in 1980, 1988, 1995, 2001, 2008 and 2013 (Fig. 8). The data also show a general decrease over time: the largest landing (52 222 tons) was in 1985 and the lowest (4335 tons) was in 2013. In the early 1980s, most shrimp trawlers were small, converted vessels of about 30 m length, though there were a few larger (40–50 m long) purpose-built, ice-strengthened freezer trawlers. Since the mid 1990s, the shrimp fishery fleet has been comprised of such freezer trawlers of about 60 m length (Fig. 9). Shrimp trawling is carried out on flat, deep, soft bottom areas northeast of Hopen, in Storfjorden, Bellsund, Isfjorden, off Kongsfjorden, in Hinlopen and along the continental shelf northeastwards of Svalbard (Figs. 1 and 5). This is a year-round fishery, ongoing even in the dark season and in fairly icy waters. The lights of shrimp vessels can be seen from Longyearbyen when they are operating in Isfjorden in winter darkness.

The catch of Northeast Arctic haddock has been relatively stable in the period 1980–2003, with annual catches mostly around 1000 tons (Fig. 10). In 2004 the landings started to increase with a peak catch of 49 278 tons in 2011. The lowest catch of Northeast Arctic haddock was in 1981 with 4099 tons.

Greenland halibut was harvested in the Svalbard zone in all 34 years of the survey. The fishery has been relatively stable, with mean landings of 937 tons, except in the peak year of 1991. The minimum catch was in 1981 with 72 tons, the maximum catch was in 1991 with 14 379 tons (Fig. 11).

In 1986 a new fishery for Iceland scallop was initiated in the southern part of the Svalbard zone (Fig. 12). Within a short time several new purpose-built and rebuilt vessels 50–60 m in length entered this “gold rush” fishery, which soon moved to the beds north of Svalbard (Moffen) (Rubach and Sundet, 1987; Sundet and Rubach, 1988). Apart from a small experiment involving landings of live scallops in 1987, all vessels were equipped for onboard production of individually frozen scallop muscle (Jakobsen, 1988). Scallop catches peaked in 1987 when a total of more than 4000 tons of muscle (equal to more than 40 000 tons live weight) was landed in Norwegian ports at a first-hand value of about 150 million NOK (Fig. 12). Most of these new scallop dredging vessels participated in this fishery for a limited period, and the number of vessels peaked in 1987 when 25 Norwegian ships were fishing for Iceland scallop. The number of vessels dropped rapidly, and in 1990 only two were still operating. The last scallop dredger left this fishery in 1995, although it had already been sold to Russian owners in 1992. Only sporadic fishing for the Iceland scallop has taken place in the Svalbard zone after 1995.

The years of intense fishing activity had major consequences. Two or three iron dredges weighing several tons each were operated continuously from each vessel, and underwater video recording have demonstrated huge changes in the bottom sediments where the fishery took place (J. Sundet, unpubl.). When this fishery started, USA and Japan were the main markets for scallop muscle from the Svalbard zone and the market prices were high (NOK 75,- per kg), but decreased rapidly to approximately NOK 35,- per kg in 1988 (Jakobsen, 1988). This made the fishery unprofitable and most of the vessels stopped scallop dredging in the Svalbard zone. However, nearly all the scallop beds in the zone had been seriously impacted by the heavy fishing and are now closed for scallop dredging. Scientific surveys in 1996 and 2006 revealed that the beds at Bjørnøya had not recovered from the heavy fishery, whilst the largest bed, at Moffen Island, had partly recovered (Sundet, 2006).

Herring has been fished in the Svalbard zone in 2005 and 2012. The 2005 harvest was 941 tons and in 2012, 19 840 tons was harvested, with a total live weight and value of 34 913 tons and 189 million NOK (Table 1).

The fishery of wolf fishes increased steadily from 1980 up to 2013. The catches have been variable, with two main peaks in 1998 and 2001, when the catch was about 4200 tons both years.

Redfishes have been harvested in the Svalbard zone during all years of the survey. In general the fishery increased from 1980 to the early 1990s when the rate of fishery leveled out. Catches with peaks in 1990, 1991, and 2006, resulted in 1527, 1345 and 1778 tons respectively. The minimum catch was in 1981, when only 1803 tons of redfish was landed.

Overall the fishery of saithe has been relatively stable throughout the period, with an annual mean landing of 399 tons.

Please cite this article in press as: Misund, O.A., et al., Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.02.001

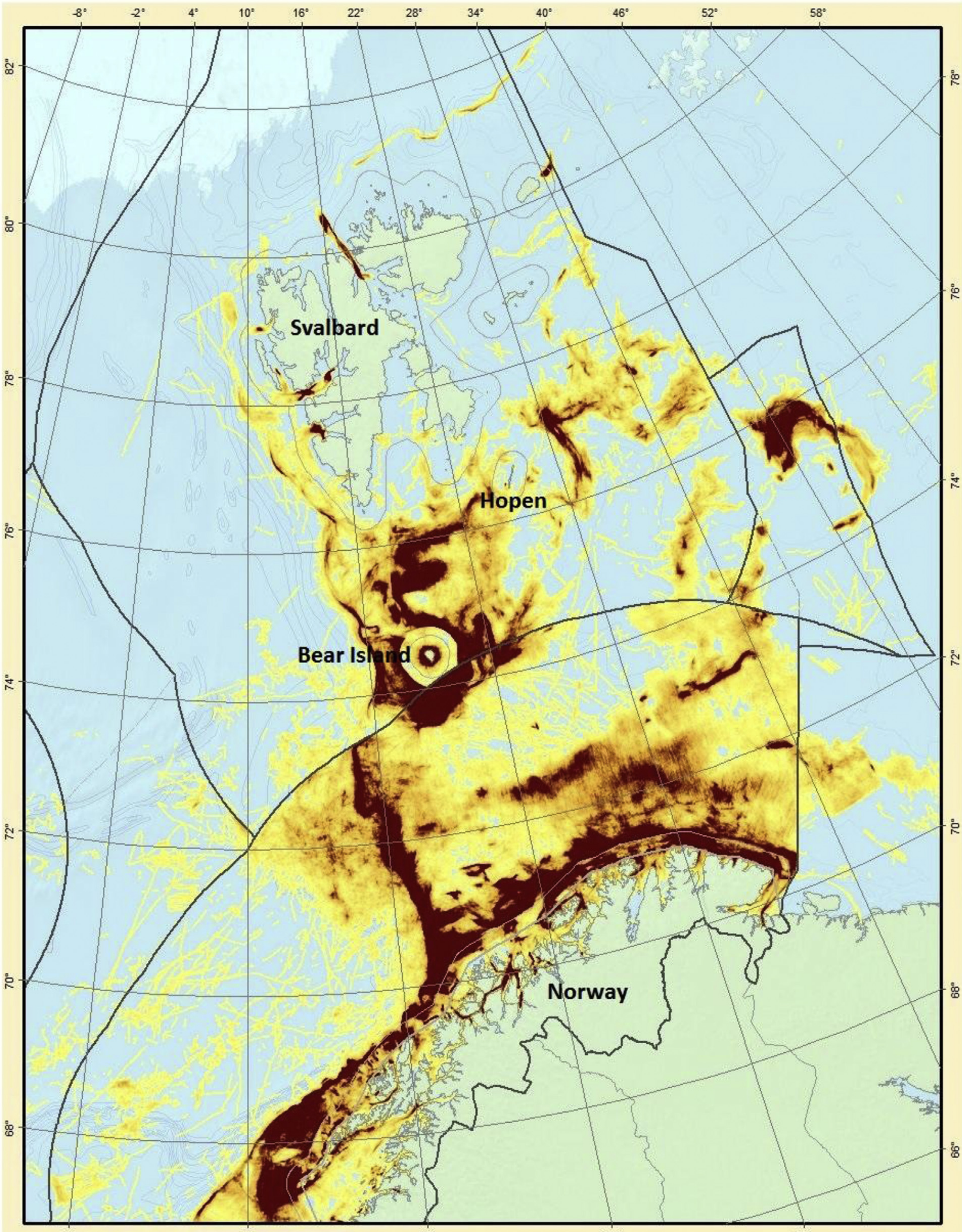

Fig. 5. Areas where Norwegian vessels >15 m fished between 2006 and 2008. The map shows aggregated tracks of fishing vessels running between 1 and 5 knots, which is taken as indication of fishing activity (J. Watne, pers. com.). Scale: yellow color: low fishing intensity, brown color: high fishing intensity.

The highest landing was in 1990 with 2373 tons, and lowest landing was in 1980 with 0.005 tons.

The fishery of tusk has shown a general increase but with great inter-annual variations. There are three major peaks: 1990 and 1991, 1995 and 2007. The highest landing was in 2007 with 245 tons and the lowest was in 1982 with a mere 0.018 tons.

Please cite this article in press as: Misund, O.A., et al., Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.02.001

Table 1
Total value and live weight of the main fish and shellfish species caught by Norwegian fishing vessels in the Svalbard Zone 1980–2013.

Common name	Latin name	Weight (1000 tons)	Value (1000 NOK)
Northeast Arctic cod	*Gadus morhua*	757 731	9 514 180
Northern shrimp	*Pandalus borealis*	635 736	8 895 348
Capelin	*Mallotus villosus*	2 964 598	4 383 255
Northeast Arctic haddock	*Melanogrammus aeglefinus*	239 604	2 421 294
Greenland halibut	*Reinhardtius hippoglossoides*	50 050	957 624
Iceland scallop	*Chlamys islandica*	99 559	735 843
Wolffishes	*Anarhchicas* spp.	30 836	204 479
Herring	*Clupea harengus*	34 913	188 735
Redfish	*Sebastes* spp.	13 356	105 153
Saithe	*Pollachius virens*	12 368	94 043
Tusk	*Brosme brosme*	29 268	28 425
Ling	*Molva molva*	1119	14 785
Atlantic halibut	*Hippoglossus hippoglossus*	170	5989
Sum		4 842 966	27 549 154

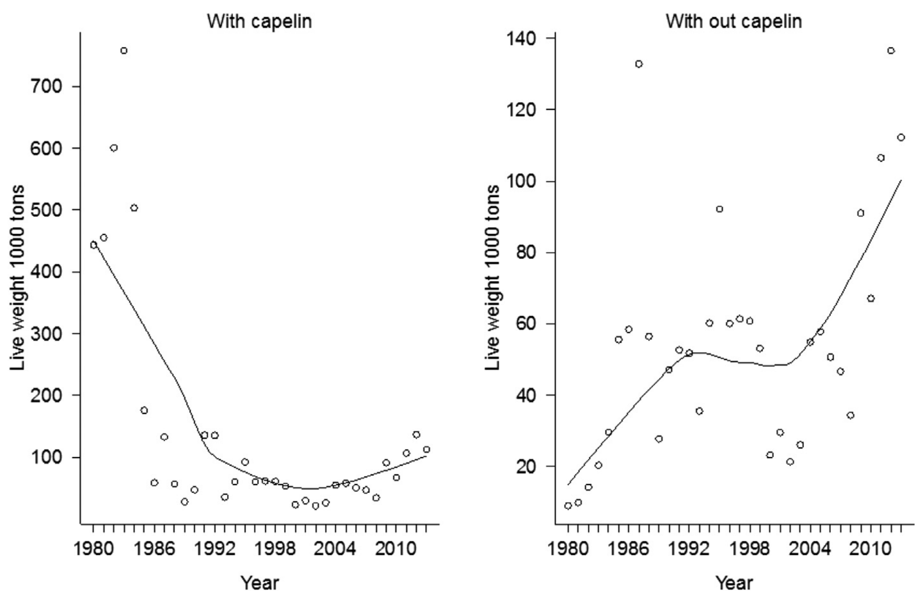

Fig. 6. Live weight of fish landed from the Svalbard zone by Norwegian vessels 1980–2013. With capelin included (left) and without capelin (right).

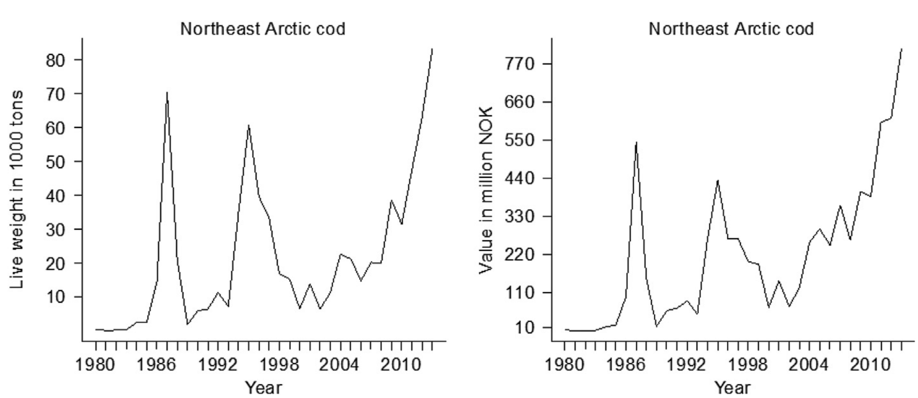

Fig. 7. Live weight (left) and value (right) of Northeast Arctic cod landed by Norwegian vessels 1980–2013 from the Svalbard zone.

Ling fishery has seen a slight increase throughout the period, in particular since 2000. The highest landing was in 2007 with 202 tons, and the lowest was in 2000 with 0.349 tons.

Landings of Atlantic halibut have increased from 2004 from the Svalbard zone. However, the total harvest is only 170 tons, giving a total value of about 4.7 million NOK. Atlantic halibut is the most highly priced fish species caught in the Svalbard zone. The 12.7 tons of Atlantic halibut caught in 2013 brought in 36 NOK per kg.

4. Discussion

The total landings (4.84 million tons) from the Svalbard zone for

Please cite this article in press as: Misund, O.A., et al., Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.02.001

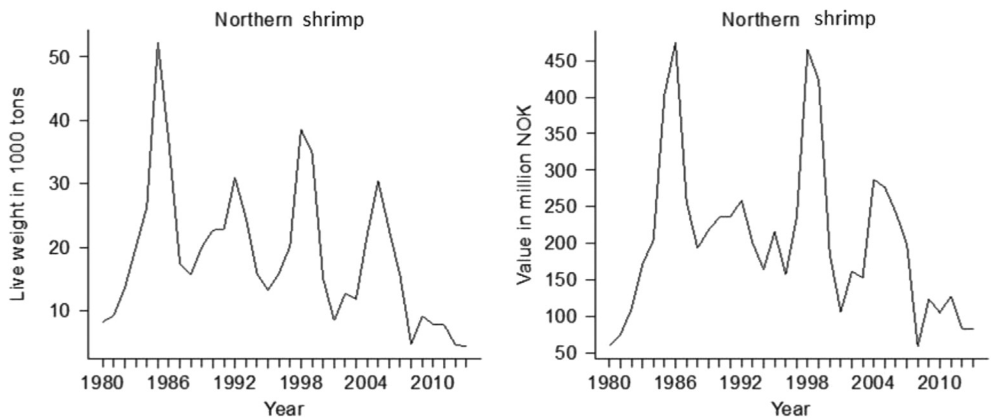

Fig. 8. Live weight (left) and value (right) of Northern shrimp landed by Norwegian vessels 1980–2013 from the Svalbard zone.

Fig. 9. Northern shrimp trawler M/V "Remøy" (about 60 m, built 2005) trawling north of Svalbard.

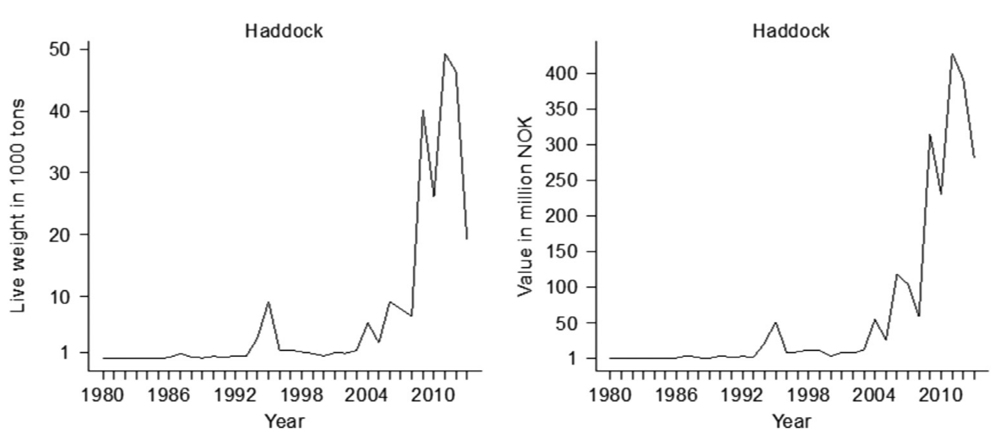

Fig. 10. Live weight (left) and value (right) of Northeast Arctic haddock landed by Norwegian vessels 1980–2013 from the Svalbard zone.

the period 1980–2013 correspond to about twice the current annual catch (about 2.5 million tons) of the Norwegian fishing fleet, and the total value (27.55 billion NOK) is roughly 1 1/2 times the total annual value of the landings from the Norwegian fishing fleet in recent years (e.g. 18.6 billion NOK in 2013) (Misund, 2014). On average, the Norwegian fisheries in the Svalbard zone have a first-hand value of about 800 million NOK per year, which amounts to about 4% of the annual value of the total landings from the Norwegian fishing fleet.

For demersal species like Northeast Arctic cod, Northeast Arctic haddock, wolf fishes, tusk, ling and Atlantic halibut, there is an increasing trend in the landings from the Svalbard zone. For

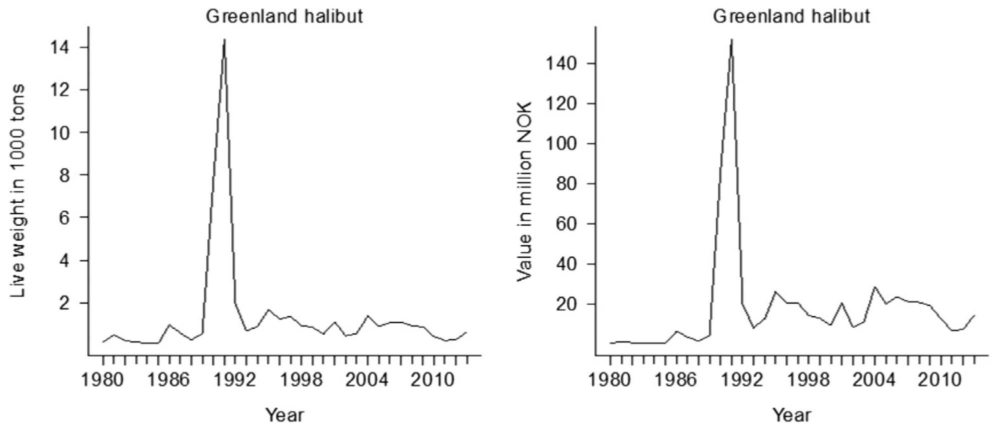

Fig. 11. Live weight (left) and value (right) of Greenland halibut landed by Norwegian vessels 1980–2013 from the Svalbard zone.

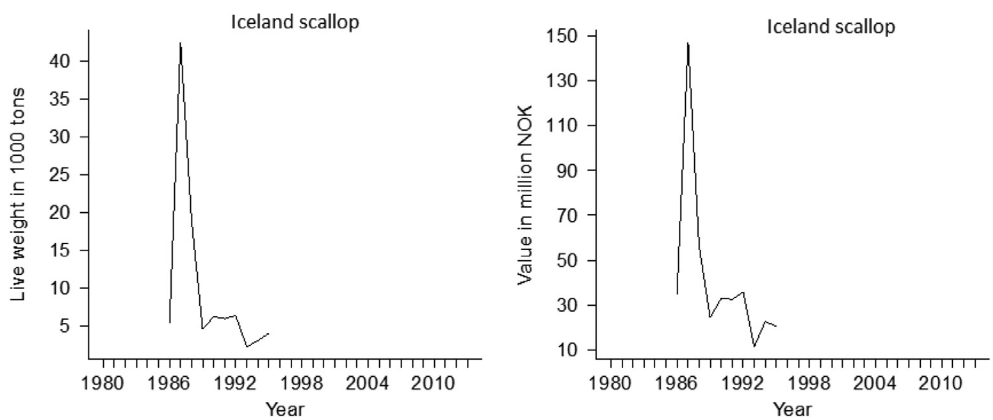

Fig. 12. Live weight (left) and value (right) of Iceland scallop landed by Norwegian vessels 1980–2013 from the Svalbard zone.

Northeast Arctic cod and Northeast Arctic haddock this increase can probably be attributed to a combination of large quotas and a northward shift of these species as waters have warmed, and larger feeding areas have become available during the light season. The record size of the cod stock, which led to increased fishing quotas, has been found to be partly due to the increased area available for feeding, as described above, but mainly to successful management in recent years, when fishing pressure has been reduced considerably and allowed for increase of stock size (Kjesbu et al., 2014). For wolf fishes, tusk, ling and Atlantic halibut, larger catches in the Svalbard zone can probably be attributed to warming waters and larger feeding areas.

All demersal fish species caught in the Svalbard zone can also be caught on the fishing grounds off the coast of Northern Norway and in the Barents Sea. Vessels aiming to fish in the Svalbard zone must spend at least two days in transit, traveling 400 nautical miles extra to and from the fishing grounds. Fishers optimize their economy by choosing the most profitable fishing ground, where high catch rate will counterbalance transit costs. This indicates that the increased landings from the Svalbard zone in recent years result from fish stocks moving north and becoming more readily available in the Svalbard zone than in areas farther south, at least for certain periods of the year. The sea ice has also retreated northwards, which has opened up new areas for the fishery in e.g. the Northern Barents Sea and north of Svalbard.

Northeast Arctic cod seem to have followed warm Atlantic Water masses flowing along the slope west of the Svalbard archipelago and become available for fisheries in the Svalbard zone periodically in the mid 1980s, the mid 1990s, and from about 2000. Inflow of warm Atlantic Water masses is evident in our temperature records from the section along 78° North during these periods. Similar recordings of warm Atlantic Water in the core of the West Spitsbergen current at 79° North have been made by Ivanov et al. (2012). Other gadoid species like Northeast Arctic haddock followed into the Svalbard zone from about 2000.

Northern shrimp catches have varied but gradually declined over the period 1980–2013. The declining catch is not related to a warming of the area, as estimated Northern shrimp biomass in the area has been variable in the period, but has shown a tendency toward an increase in recent years (Hvingel and Berenboim, 2011). Instead, the reduced landings of Northern shrimp can be attributed to fewer vessels participating in the fishery (Standal, 2003). Northern shrimp trawling technology has developed substantially through the period, from many 30 m long converted vessels towing one trawl, to today's purpose-built, ice-strengthened and powerful vessels towing triple trawls. But prices have been a challenge, and many vessels fishing for shrimp have been decommissioned because the economic results have been unsatisfactory.

The large “summer” fishery for capelin in the Svalbard zone ended due to Norwegian fishery regulations that limited capelin harvest to a winter fishery exclusively along the coast of Finnmark and Troms Counties. The harvest control rule for capelin agreed in the Joint Norwegian–Russian Fishery Commission is that there should be 95% certainty that at least 200 000 tons will reach the coast to spawn (Gjøsæter et al., 2011), and a “summer” capelin fishery is therefore not permitted.

Please cite this article in press as: Misund, O.A., et al., Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.02.001

The Icelandic scallop "gold rush" fishery in the Moffen area ended abruptly due to economic loss for the actors involved (Sundet and Zolotarev, 2011). The new purpose-built ships were sold and most of them converted for other activities. One of the vessels (M/V "Concordia"), still operates as a scallop dredger on the Newfoundland fishing grounds.

Our analysis of the fisheries statistics from the Svalbard zone shows that no fishery has developed for the rather abundant polar cod (Ajiad et al., 2011). The reported 236 tons landed by Norwegian vessels in the 34-year period were most probably been taken as by-catch in the bottom trawl for shrimp. The polar cod was targeted for a pelagic trawl fishery in the early 1970s, but low prices offered for catch intended for processing to fish meal and fish oil terminated the interest in a polar cod fishery. Russian vessels have traditionally landed polar cod for human consumption, and the catch has varied from about 0 to 332 000 tons annually (Ajiad et al., 2011). The polar cod is present in the Svalbard zone, but is more abundant in the Northeastern Barents Sea. The potential for a commercial fishery exists, but polar cod is an important feed fish for cod and ice-edge related sea birds and marine mammals (Hop and Gjøsæter, 2013). Future quotas should therefore be set in an ecosystem context, as has been done for capelin in the Barents Sea (Gjøsæter et al., 2011).

The Svalbard zone has traditionally been – and still is – an area where sea mammals are hunted. Analysis of hunting statistics for marine mammals is beyond the scope of our article, but it should nonetheless be stated that in recent years, most of the Norwegian scientific quota for minke whale (*Balaenoptera acutorostrata*) has been taken in the Svalbard zone. A small number of ringed seals (*Pusa hispida*) are still shot in the fjords of Svalbard. In the long run, balanced harvest from all levels of the marine food webs is necessary if we are to increase the seafood harvest to feed a growing human population (Garcia et al., 2012).

There have been speculations concerning the possibility that commercially valuable boreal fish species will move farther into the Arctic Ocean as waters warm and the ice sheet retreats (e.g. Hollowed et al., 2013). Demersal fish species such as Northeast Arctic cod are not expected to migrate beyond their natural depth range, and should therefore stop at the slope of the continental slope north of Svalbard, where the deep polar basin begins. But species with a more pelagic orientation such as redfish and Greenland halibut might possibly migrate farther into the deep polar basin if water temperatures rise in the future (Hollowed et al., 2013). Nevertheless, the light regime will prevail, and it is likely that boreal fishes will migrate south at the onset of polar night in late October – early November.

As outlined, the fisheries in the Svalbard zone are distant water fisheries, which implies that each vessel is equipped and supplied to fish in the Svalbard zone for shorter or longer time, depending on its size, carrying capacity, and whether the catch is going to be delivered fresh or frozen. According to Norwegian regulations, catch cannot be landed in Svalbard, even though harbors exist in Longyearbyen, Barentsburg, Svea and Ny-Ålesund. Longyearbyen also has an international airport with regular flights year around. However, landing of catch to transit vessels takes place regularly in sheltered fjords in Svalbard.

In the future, landing of catch could be possible in Svalbard. If fish resources remain available due to a more northern distribution as a response to warmer waters as predicted by climate change models, landing at Svalbard could become an alternative. Such a scenario has been discussed in the Russian settlement in Barentsburg; the Strategic Business Plan developed by the Longyearbyen Town Council and the Svalbard Business Association in 2014 also argues in favor of permitting fish to be landed in Svalbard (Anon, 2014). For over a century, the economy of Longyearbyen was based on the mines of Store Norske Spitsbergen Kullkompani (www.snsk.no), but the future of coal mining looks dim due to low prices and the need to reduce CO_2 emissions from fossil fuels. Alternative activities are being considered, among them landing of fish and shellfish from the fjords and waters of the Svalbard archipelago.

4.1. Future prospects

Global warming altering the Arctic marine ecosystems will affect the availability of commercial fishing resources in the Svalbard zone. These changes may be divided in two major groups: changes in species distribution caused by increase in sea temperature, and changes in species diversity due to human activities such as increased ship traffic in the Arctic (Ware et al., 2014).

Fossheim et al. (2015) documented a rapid northward shift in the distribution of boreal fish communities in the Barents Sea due to 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. Thus further increase in biomass of boreal fishes should be expected in Svalbard waters, and it is therefore quite likely that there will be increased fishing activity in these waters in the years to come.

In addition, the non-native, commercially attractive snow crab (*Chionoecetes opilio*) has entered the Arctic part of the Barents Sea, where it is rapidly increasing in abundance and conquering new areas (Alvsvåg et al., 2009; Pavlov and Sundet, 2011). With landings of more than 4000 tons in 2014, this crab already represents a significant fishing resource, and model simulations indicate a potential for annual catches to reach between 25 and 75 thousand tons within a few years (Hvingel and Sundet, 2014). The most likely future distribution of this Arctic cold water species suggests that most of these catches will be in the east part of the Svalbard zone which still probably will be rather cold even in times of global warming (Hvingel and Sundet, 2014).

Whether the red king crab (*Paralitodes camtschaticus*), abundant and commercially fished in the eastern fjords of Finnmark in Northern Norway and off the Kola Peninsula could enter the Svalbard waters remains more uncertain. This species seem more related to the shallow coastal areas of the Southeastern Barents Sea, and for the last 25 years there have been no major changes in its distribution further north in the Barents Sea (Pinchukov and Sundet, 2011).

Acknowledgments

We are indebted to Janet Holmén for advice, corrections and suggestions on how to improve the English language of our manuscript. The Norwegian Polar Institute kindly provided Fig. 1. Two anonymous reviewers are tanked for being supportive, and for giving good suggestions and recommendations on how to improve our manuscript.

Funding for R. Skogseth and the construction of the UNIS Hydrographic Database (UNIS HD) merits REOCIRC (Remote Sensing of Ocean Circulation and Environmental Mass Changes, a Research Council of Norway project nr. 222696/F50) and GrønnBille (The Oceanography of Grønnfjorden and Billefjorden, a Research Council of Norway project nr. 227067).

References

Anon, 2014. Strategisk Næringsplan for Svalbard. (Strategic Business Plan for Svalbard). Longyearbyen Town Council and Svalbard Business Association, p. 54. http://www.lokalstyre.no/strategisk-naeringsplan.331278.no.html (In Norwegian).

Ajiad, A., Oganin, I.A., Gjøsæter, H., 2011. Polar cod. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic

Press, Trondheim, pp. 315–328.

Alvsvåg, J., Agnalt, A.-L., Jørstad, K.E., 2009. Evidence for a permanent establishment of the snow crab (*Chionoecetes opilio*) in the Barents Sea. Biol. Invasions 11, 587–595. http://dx.doi.org/10.1007/s10530-008-9273-7.

Berge, J., Johnsen, Geir, Nilsen, F., Gulliksen, B., Slagstad, D., 2005. Ocean temperature oscillations causes the reappearance of blue mussels in Svalbard after 1000 years of absence. In: Marine Ecology Progress Series, vol. 303, pp. 167–175. ISSN 0171-8630.s.

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

Fossheim, M., Primicerio, R., Johannessen, E., Ingvaldsen, R.B., Aschan, M.M., Dolgov, A.D., 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nat. Clim. Change 6. http://dx.doi.org/10.1038/NCLIMATE2647. Advance online publications.

Garcia, S., Kolding, J., Rice, J., Rochet, M.J., Zhou, S., Arimoto, T., Beyer, J.E., Borges, L., Bundy, A., Dunn, D., 2012. Reconsidering the consequences of selective fishing. Science 335, 1045–1047. http://dx.doi.org/10.1126/science. 1214594.

Gjøsæter, H., Ushakov, N.G., Prozorkevich, D.V., 2011. Capelin. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, pp. 201–214.

Gullestad, P., Aglen, A., Bjordal, Å., Blom, G., Johansen, S., Krog, J., Misund, O.A., Røttingen, I., 2014. Changing attitudes 1970 – 2012: evolution of the Norwegian management framework to prevent overfishing and to secure long term sustainability. ICES J. Mar. Sci. 71 (2), 173–182. http://dx.doi.org/10.1093/icesjms/fst094.

Hammer, M., Hoel, A.H.H., 2012. The development of scientific cooperation under the Norway – Russia fisheries regime in the barents sea. Arct. Rev. Law Polit. 3, 244–274.

Hollowed, A.B., Barange, M., Beamish, R.J., Brander, K., Cochrane, K., Drinkwater, K., Foreman, M.G.G., Hare, J.A., Holt, J., Ito, S., Kim, S., King, J.R., Loeng, H., MacKenzie, B.R., Mueter, F.J., Okey, T.A., Pech, M.A., Radchenko, V.I., Rice, J.C., Schirripa, M.J., Yatsu, A., Yamanaka, Y., 2013. Projected impacts of climate change on marine fish and fisheries. ICES J. Mar. Sci. 70 (5), 1023–1037.

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. Res. 9, 878–894.

Hvingel, C., Berenboim, B.I., 2011. Northern shrimp. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, pp. 172–185.

Hvingel, C., Sundet, J.H., 2014. Snow crab – a new large resource in the Barents Sea. Chron. *Dagens Næringsliv*, week 11 (In Norwegian).

Ivanov, V.V., Alexeev, V.A., Repina, I., Koldunov, N.V., Smirnov, A., 2012. Tracing Atlantic water signature in the arctic sea ice cover east of Svalbard. Adv. Meteorology 11. http://dx.doi.org/10.1155/20127201818. Article ID 201818.

Iversen, T., 1934. Some Observations on Cod in Northern Waters. Preliminary report. In: Fiskeridirektoratets Skrifter, Serie Havundersøkelser, vol. 4 8, pp. 1–4 (Bergen, Norway).

Jakobsen, Ø., 1988. Eventyret haneskjell. Ottar N. R. 170 (2), 88. Tromsø museum, pp. 22–29. (In Norwegian).

Jakobsen, T.J., Ozhigin, V.K., 2011. The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, p. 825.

Kjesbu, O.S., Bogstad, B., Devine, J.A., Gjøsæter, H., Ingvaldsen, R., Nash, R.D.M., Skjaeraasen, J.E., 2014. Synergies between climate and management for Atlantic cod fisheries at high latitudes. Proc. Natl. Acad. Sci. 111, 3478–3483.

Misund, O.A., 2014. Norwegian Fisheries: technologically advanced, biologically sustainable, and economically profitable. Mar. Technol. J. 48 (2), 17–23.

NSIDC, 2013. National Snow and Ice Data Centre. http://nsidc.org/arcticseaicenews/2013/09/draft-arctic-sea-ice-reaches-lowest-extent-for-2013/.

Onarheim, I.H., Smedsrud, L., Ingvaldsen, R.B., Nilsen, F., 2014. Loss of sea ice during winter north of Svalbard. Tellus A 66, 23933. http://dx.doi.org/10.3402/tellusa.v66.23933.

Pavlov, V.A., Sundet, J., 2011. Snow crab. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, pp. 168–171.

Pavlov, A.K., Tverberg, V., Ivanov, B.V., Nilsen, F., Falk-Petersen, S., Granskog, M., 2013. Warming of Atlantic water in two west Spitsbergen fjords over the last century (1912–2009). Polar Res. 32, 11206. http://dx.doi.org/10.3402/polar.v32i0.11206.

Pinchokov, M.A., Sundet, J., 2011. The red king crab. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, pp. 160–167.

Rubach, S., Sundet, J.H., 1987. Ressurskartlegging Av Haneskjell (*Chlamys Islandica* (O.F. Müller)), Ved Jan Mayen Og I Svalbardsonen I 1986, 1. Institutt for Fiskerifag, Universitetet i Tromsø, Serie B: Ressursbiologi nr, p. 70 (In Norwegian).

R Core Team, 2012. R: a Language and Environment for Statistical Computing. R foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0. http://www.R-project.org/.

Sars, G.O., 1878. The Norwegian North Atlantic Expedition 1876-78. BIBSYS ILS, Object I.D. 02135270. Christiania (now Oslo), 1878.

Standal, D., 2003. Fishing the last frontiers – controversies in the regulations of the shrimp trawling in the high Arctic. Mar. Policy 27 (5), 375–388. http://dx.doi.org/10.1016/S0308-597x(03).

Sundet, J.H., 2006. Overvåking Av Haneskjellfelter Ved Bjørnøya Og Moffen I 2006. oktrapport/Havforskningsinstituttet, p. 9. ISSN 1503-6294/Nr. 8 (In Norwegian).

Sundet, J.H., Rubach, S., februar 1988. Ressurskartlegging av haneskjellforekomster ved Jan Mayen og i Svalbardsonen. Norges Fisk. 30 (In Norwegian).

Sundet, J., Zolotarev, P.N., 2011. Iceland scallop. In: Jakobsen, T.J., Ozhigin, V.K. (Eds.), The Barents Sea. Ecosystem, Resources, Management. Tapir Academic Press, Trondheim, pp. 186–192.

Ware, Christopher, Berge, Jørgen, Sundet, Jan Henry, Kirkpatrick, J.B., Coutts, A.D.M., Jelmert, Anders, Olsen, S.M., Floerl, Oliver, Wisz, Mary S., Alsos, Inger Greve, 2014. Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. Diversity & distributions. A J. Biol. invasions Biodivers. 20 (1) http://dx.doi.org/10.1111/ddi.12117. ISSN 1366–9516.s 10-19.s.

Please cite this article in press as: Misund, O.A., et al., Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings, Polar Science (2016), http://dx.doi.org/10.1016/j.polar.2016.02.001