Northwest Atlantic Fisheries Organization

Serial No. N6897 **SCR Doc. 18/068**

NAFO/ICES *PANDALUS* ASSESSMENT GROUP MEETING –OCTOBER 2018

Results of the Norwegian Bottom Trawl Survey for Northern Shrimp (*Pandalus borealis*) in Skagerrak and the Norwegian Deep (ICES Divisions 3.a and 4.a east) in 2018

by

G. Søvik and T. H. Thangstad

Institute of Marine Research
Box 1870 Nordnes, N-5817 Bergen, Norway

Abstract

The timing of the Norwegian shrimp survey in Skagerrak and the Norwegian Deep (ICES Divs. 3.a and 4.a east) has changed from 1984 to present. The result is a series of three different biomass index time series, lasting from two to nineteen years. New series were initiated in both 2004 (May) and 2006 (February). Conducting the survey in the 1st quarter gives good estimates of both recruitment and SSB. Thus, the newest time series has been established at the most optimal time of the year.

The biomass index fluctuated around a high level from the mid 1990s to 2002 when the first time series was discontinued. The biomass index decreased from 2008 to 2012, increased from 2013 to 2015, and then decreased again in 2017-2018. The recent stock size is at a lower level compared with the stock size in earlier years.

Recruitment (abundance of the 1-group) in Skagerrak has been lower in recent years compared with 2006-2007, with the exception of 2014 when the recruitment was very good and at a higher level than in 2006-2007. For most of the time series (2006-2016), recruitment has been much lower in the Norwegian Deep compared with Skagerrak, suggesting that Skagerrak is a nursery area for the stock. The low recruitment is probably the main reason behind the low stock size in recent years. Recruitment in 2017 and 2018 was at an intermediate level.

Introduction

A trawl survey for northern shrimp (*Pandalus borealis*) in Skagerrak and the Norwegian Deep (ICES Divs. 3.a and 4.a east, and the northeast corner of Div. 4.b) has since 1984 been conducted annually by the Norwegian Institute of Marine Research (IMR) with the objective of assessing the distribution, biomass, abundance, recruitment, size distribution, and demographic composition of the shrimp stock, the size of the stocks of shrimp predators, as well as measuring hydrographical conditions in the distributional area of this shrimp stock.

The survey data consist of: 1) one time series from 1984-2002 (October/November) using R/V *Michael Sars* and the Campelen-trawl; 2) a point estimate for 2003 (October) as R/V *Michael Sars* was taken out of service and substituted with R/V *Håkon Mosby*, whose winches at that time were not powerful enough for the Campelen-trawl, resulting in the survey being conducted with the Shrimp trawl 1420; 3) a start of a potential new time series as the survey in both 2004 and 2005 was conducted in May/June with R/V *Håkon Mosby*

using the standard Campelen trawl; and 4) one time series from 2006 until present (January/February), using R/V *Håkon Mosby* and R/V *Kristine Bonnevie* (from 2017) and the Campelen trawl. Conducting the survey in the 1st quarter gives good estimates of the 1-group (recruitment) and SSB (berried females) and was recommended by the *Pandalus* working group in 2004 (ICES 2005).

This paper presents the results of the 2018 survey.

Material and Methods

Survey design

The survey area covers depths of approximately 100 to 550 m in ICES Divs. 3.a and 4.a east. A couple of stations are also located in the northeast corner of Div. 4.b. The survey is stratified by four depth zones (100-200 m, 200-300 m, 300-500 m, and >500 m), and area (Table 1, Fig. 1). In 2007, the strata system was revised. The depth contours were updated using GIS and the bathymetric database GEBCO, and the strata areas were recalculated accordingly. Strata 1-4 were extended north to 60º N in order to incorporate the two northernmost stations in the strata system, and the deep-water area in the middle of Skagerrak (>500 m) was included as a 17th stratum as four trawl stations are located in this area. A second revision of the strata system in 2008 moved the northern border of stratum 1 to 59º N as the two trawl stations in this stratum were not considered representative of the whole area north to 60º N (Fig. 1). Furthermore, the strata areas were recalculated using an "equal area" projection, which gives more correct area estimates than the earlier used projection. In 2016, it was decided to remove stratum 1 from the survey area as it is not adequately covered with only two stations, and there is also no shrimp in this stratum. The survey area is now 14 504 nm^2 (Table 1).

The survey has a fixed station design, assuming that the temporal variation in the shrimp stock generates the necessary randomness. In 2006, it was decided that the 100 stations trawled during the 2000 survey should be considered fixed stations for future surveys. In 2008, thirteen stations (positions found in old survey reports from 1984-1996) were added in order to obtain a better coverage of the area. In 2013, all stations were trawled and/or inspected on the OLEX system. Eight trawl stations were removed due to rough bottom conditions and one new station was included. In 2015, seven stations in the Swedish EZZ were included after request from Swedish fishers. In 2016, one station was removed from the list due to new cables on the sea floor preventing trawling, and the two stations in former stratum 1 were moved to strata 2 and 4. In 2017, two stations were included just south of Lindesnes (positions from fisher) to improve the coverage. The new list of stations consists of 111 fixed stations. A complete station list is given in the 2017-survey report (Thangstad et al. 2017). The deepest and shallowest stations have depths of respectively 540 and 111 m. A coverage of one haul per 131 nm^2 is obtained when all 111 stations are trawled. In some years, part of the survey area has not been covered due to time and weather constraints. As Div. 4.a east is more exposed than 3.a, it is generally the former area which in some years has been poorly covered.

A Campelen 1800/35 bottom trawl with rockhopper gear is used. Strapping was introduced on the survey in 2008 to ensure fixed trawl geometry independent of depth. A 10 m rope 200 m in front of the doors gave a door spread of 47-48 m. In 2017, the strapping (10 m) was moved to 100 m in front of the doors. IMR works towards standardising scientific trawling, including strapping, over all its research vessels, thus during the sea trial in 2018 it was concluded that it was possible to use a 15 m strapping rope 100 m in front of the doors. Mesh size in the cod end is 20 mm with an inner lining net. From 2018, an inner lining net of 10 mm will be standard. Tow duration was 1 hour until 1989 when it was reduced to 0.5 hour. Mean tow speed until 2012 was roughly 3 knots (Table 2), but in 2013-2016, the mean tow speed was lower (2.2-2.5 knots) and the variation between stations increased. In 2017 and 2018, with more trawl instruments on board *Kristine Bonnevie*, trawling has been conducted on speed-of-water-through-trawl, not speed-over-ground, which partly explains the high average speed-over-ground values of 3.4 and 3.3 knots in respectively 2017 and 2018 (Table 2). Trawling is carried out around the clock, but no compensation for diurnal vertical migration is made.

Stock size index

Biomass and abundance estimates are calculated using SAS (version 9.4). Swept area is estimated by applying a wingspread of 11.7 m to tow length. Tow length is set to time towed multiplied by a towing speed of 3 knots. The swept area is thus 0.019 nm^2/hour.

The catch in each tow divided by the swept area represents a sample of shrimp density (in kg and numbers) in a stratum. From these samples the mean and standard error of the density in each stratum are calculated and multiplied by the area of the respective stratum to give estimates of strata biomass and abundance. Strata estimates are summed to give the overall value for the survey area.

Due to weather and time constraints, some strata have not been covered in some years. For any missing stratum in year *t*, the stratum biomass is estimated as follows. 1) The proportion of biomass (*p*) (out of the total biomass) in the specific stratum is taken as the mean of all *p*'s from years where data exist for all strata. Mean *p*'s are calculated separately for the first and last time series. 2) The total biomass for year *t*, *B,* is calculated as: $B = (\Sigma$ biomass in all strata with data in year $t) / (1- p)$. The biomass in the missing stratum, $B_{stratum}$, is then given as: $B_{stratum} = B * p$. These calculations assume that the distribution of shrimp remains constant from year to year.

Standard errors are calculated as: SE (whole survey area) = $\sqrt{[\Sigma (SE (stratum)^2)]}$.

A biomass index of potential shrimp predators is calculated as average catch (tons) / nm^2 over all hauls of 23 fish species/fish families.

Biological samples

Samples of approximately 300 shrimp are taken from each trawl haul, sorted by sexual characteristics (stage) and measured with a precision of 0.1 mm (carapace length (CL)). When the total catch contains less than 300 shrimp the sample equals the total catch. An overall carapace length frequency distribution, as well as length distributions per area (Skagerrak and the Norwegian Deep), are estimated using CL truncated to the nearest mm below. The length frequency distributions are partitioned into age groups by modal analysis using the method of Bhattacharya (1967) (FISAT (version 1.2.2), http://www.fao.org/fi/oldsite/STATIST/fisoft/fisat/index.htm).

In January/February, the youngest age group is almost 1 year old (hatching of eggs takes place from February to April). A recruitment index is estimated as the abundance of these (almost) 1-year old shrimp from the modal analysis. There is a positive correlation between the abundance of 1-year old shrimp in January/February in one year and the number of 2- and 3-year old shrimp in the following two years (Fig. 2).

Hydrographical measurements

CTD is normally taken at each trawl station. To avoid damage on the equipment, the CTD is not lowered further than 10 m above the bottom. In 2018, there were problems with the CTD configuration during the survey and there are therefore no CTD-data from the last 32 trawl stations (Fig. 3).

Results and discussion

Area coverage

In 2018, the survey was carried out from January 6 to 30. The trawl gear was tested in the sea (15 tows) before the ordinary survey started (towing with open cod end on sandy bottom, both with and against the current). Hundred and twenty-six trawl stations were covered, and 109 out of these were regular trawl stations (Fig. 4). Two tows were done in new positions advised by an onboard observer from the local fishermen's organisation. The data from these two tows were not included in the indices. There were technical problems with the trawl on one station. Calculations were carried out using data from the other 108 valid stations.

Temperature and salinity

The bottom temperature in the survey area in January/February during 2006-2015 ranged from 6.0 to 8.5 °C (Søvik and Thangstad 2015). The year 2016 was the warmest observed in the time series back to 2006 (Fig. 5), with 4 and 9 trawl stations in respectively Skagerrak and the Norwegian Deep with bottom temperatures >8.5 °C. This is still within the range of winter bottom temperatures from the area (December-March) in 1982-2002 (range 5-9 °C) (Schlüter and Jerosch 2009). In 2017, 15 stations in the Norwegian Deep had a bottom temperature above 8.5 °C, but these were mostly in shallow areas (only one station in Skagerrak).

The annual average survey temperatures have varied between 7 and 8 °C, except in 2011 (an exceptionally cold year) and 2016 (Table 3). In 2016, mean bottom temperature was 8.24 and 7.75 °C in the Norwegian Deep and Skagerrak respectively, the highest mean temperature observed in both areas. The mean temperature in the Norwegian Deep in 2016 was almost a degree higher than the mean temperature in 2015. In 2017, mean temperature decreased compared with 2016 in the Norwegian Deep, but not in Skagerrak (Table 3). The mean temperature in 2018 decreased compared with the previous year, in both areas, but the year 2018 is among the three warmest in Skagerrak and among the five warmest in the Norwegian Deep.

Average salinity has varied between 34.9 and 35.3 ‰ in the same time period (Table 3). This is in agreement with winter salinity data from the area, which in the period 1982-2002 was between 35 and 36 ‰ (Schlüter and Jerosch 2009).

Strapping

The introduction of strapping in 2008 caused the average door spread to decrease from more than 50 m in 2006-2007 to 45-48 m in 2008-2012 (Table 4). The former relationship of increased door spread with increased depth disappeared with the introduction of strapping. In 2013-2016, however, mean door spread has varied between 48 and 51 m. In 2015 and 2016, there was also a positive relationship between door spread and depth (Table 4, Fig. 6). It is unclear why the use of strapping did not prevent this. Door spread was high in 2017 with a mean of 52.5 m, but with low variation around the mean and no relationship with depth. Following standards for research trawling at IMR, door spread should be between 48 and 52 m (https://kvalitet.hi.no/docs/pub/dok06004.pdf). In 2018, however, mean door spread was 55.0 m. Door spread during the sea trial had been within acceptable limits, but on the softer bottom on shrimp grounds, door spread increased. It was concluded that the strapping rope needs to be shortened from 15 to 10 m on next year's survey.

The inter-annual difference in door spread is not corrected for in the calculations.

Stock size indices

The biomass index increased from the late 1980s to the early 1990s, remained at a stable level until the mid 1990s when it increased further to this time series' maximum in 1997 (Table 5, Fig. 7). A decrease in 1998-2000 was followed by an increase in 2001 and 2002. The very low 2003 biomass estimate (Table 5) could have resulted from the use of the Shrimp trawl 1420, which had mesh size in the cod end of 36 mm, and no lining. However, the trawl opening is taller compared with the Campelen trawl. The 2005 mean value is lower than that of 2004, but not statistically different. The 2007 value was 77% higher than the 2006 value, but was influenced by the very high mean biomass in stratum 16 (Table 5) which was due to a very large catch in one single trawl haul. From 2008, the biomass declined steadily to the recent time series' minimum in 2012. From 2013 to 2015, the biomass increased (Fig. 7). The 2015-biomass estimate includes an estimated value for stratum 2 which was not covered that year, based on the mean of all *p*'s from years back to 2006 (see above). It is likely that the estimated value of 1481 t (Table 5) in stratum 2 in 2015 is too high, as the stock has contracted into the southern part of the Norwegian Deep in recent years (see below). The biomass of stratum 17 in 2015 (2990 t) is probably also too high (Table 5). Mean density was highly influenced by one good trawl haul (out of three).

The 2016 biomass estimate of 3730 t was the lowest in the time series back to 2006. Only a handful of the trawl stations had shrimp catches of >10 kg/nm trawled. Investigations into the survey showed that there had been problems with unequal lengths of the wires towing the trawl, and the survey was therefore invalidated.

The 2017 biomass estimate was 8800 t, which is at the same level as the 2014 estimate. The 2018 biomass estimate decreased to 8250 t. The good 2013 year-class (see below) is now gone from the stock, and the biomass seems to be decreasing.

Total abundance of shrimp (Fig. 8) shows the same overall trend as the biomass index, but the abundance index increased in 2014 (when the large 2013 year class was 1 year old) rather than in 2015, as the biomass index did.

Trends in the survey time series have followed trends in LPUE-indices closely for many years. The Danish and Norwegian LPUE-series also have their minimum in 2012. All three LPUE-series (Danish, Swedish and Norwegian) have declined since 2015 (ICES 2017, Annex 5).

Distribution

During the 1980s and 1990s, the shrimp biomass in the Norwegian Deep was larger than the biomass in Skagerrak (Fig. 10). This has changed from the first to the last time series (2006-2018), and the biomass in Skagerrak is presently estimated to be larger than in the Norwegian Deep. It is particularly the proportion of the survey biomass in stratum 2 in the northern part of the Norwegian Deep that has decreased. In 1987 and 1998-1999, more than 30% of the total survey biomass was found in this stratum, compared with 2-6% in 2006-2018 (Fig. 10). Seasonal shifts in shrimp distribution in connection with larval hatching, documented in recent years by positions of trawl hauls of commercial fishing vessels in logbooks (Søvik and Thangstad 2016) seem to take place from deeper to shallower parts of the trench, not over larger areas. Thus, the decrease in biomass in the northern part of the Norwegian Deep probably is not due to the shift in the timing of the survey, from October/November to January/February. Rather, it seems that the declining shrimp stock has contracted into the southern part of the Norwegian Deep and Skagerrak.

The depth distribution of shrimp differs between the Norwegian Deep and Skagerrak (Fig. 11. In the former area, the largest proportion of the biomass is found in strata covering depths between 200 and 300 m and very little shrimp biomass is found in the shallowest strata 1 and 5 (100-200 m). In Skagerrak, on the other hand, the biomass is more or less equally distributed between the depth strata of 100-200 m, 200-300 m, and 300-500 m. The pattern is the same for both the October/November time series and the recent time series.

Size and age

The model analysis of the 2018-data gave three age groups in Skagerrak and four in the Norwegian Deep (Table 6, Fig. 12). The bulk of the shrimp biomass in 2018 consisted of shrimp larger than 15 mm CL dominated by 2-year old shrimp (Fig. 12). Length frequency distributions for the years 2006-2018 show that in most years in the whole Skagerrak/Norwegian Deep area there are two clearly distinguishable age groups in the first quarter of the year (the 1-group and 2-group) as well as a 3+-group (Fig. 13a). In the length frequency distributions from earlier years in October/November (1984-2002) often four age groups are distinguishable (0-, 1-, and 2-groups as well as a 3+-group) (Fig. 13b). Numbers per age group back to 1984 are given in Table 7a and b.

In Skagerrak, recruitment (1-group) declined from 2007 to 2010, increased in 2011 and 2012, but declined again in 2013 (Fig. 14). In 2014, the recruitment increased to the highest level observed in this recent time series. In 2015, recruitment was again low, but increased in 2017 to the mean of the series. The 2018 recruitment was at the same level as the 2017 recruitment. In the Norwegian Deep in 2006-2009 and in 2011-2014, recruitment was very low compared with Skagerrak. Recruitment in the Norwegian Deep seems to be constantly very low. The much larger abundance of 1-year old shrimp in Skagerrak indicates that these waters constitute a nursery area for the stock. The generally low recruitment since 2008 has probably been the main reason causing the low stock size in recent years. It is not known why recruitment has been so low.

Predator abundance

Mean catch per trawl haul (tons/nm^2) in 2018 is given for potential shrimp predators (Table 8). Saithe was the most abundant species, with an average catch of 12.9 ktons/nm^2. Blue whiting was the second most abundant species. Rabbit fish and whiting were the third and fourth most abundant species. The total index of predator biomass was estimated to 46.2 ktons/nm^2 in 2018, which is a decrease from 2017 (influenced by a high blue whiting estimate), but at the same level as the 2014-2015 estimates. Results from the first survey series (1984-2002) range from 28.6 to 63.1 tons/nm^2 (ICES 2004), while in 2004-2005 the index was respectively 58.1 and 115.4 tons/nm^2 (ICES 2006).

The index of total predator biomass was earlier heavily influenced by the indices for saithe and roundnose grenadier, and in 2013 and 2017, also by the blue whiting index. Some shallow trawl stations yield large catches of saithe, while roundnose grenadier is caught mainly in the deep parts of Skagerrak. Thus, the estimate of these two indices depends partly on the number of shallow and deep stations covered each year. A predator index excluding saithe, roundnose grenadier as well as blue whiting shows less inter-annual variation (Fig. 15) and fluctuated without a trend between 2007 and 2015. An increase was seen from 2015 to 2017-2018. This is in line with increasing trends in stock size observed in recent stock assessments of demersal fish species in the North Sea and Skagerrak (ICES 2016ab).

References

Bhattacharya, C. G. 1967. A simple method of resolution of a distribution into Gaussian components. Biometrics 23: 115-135.

ICES 2004. Report of the *Pandalus* assessment working group, 26 – 29 August 2003. ICES CM 2004/ACFM: 05. 42 pp.0

ICES 2005. Report of the *Pandalus* assessment working group, 27 October – 5 November 2004. ICES C.M. 2005/ACFM:05, 74 p.

ICES 2006. *Pandalus* assessment working group report (WGPAND), 26 October – 3 November 2005. ICES CM 2006/ACFM:10. 60 pp.

ICES. 2016a. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) 26 April – 5 May 2016, Hamburg, Germany. ICES CM 2016/ACOM: 14. 1023 pp.

ICES. 2016b. Report of the Working Group for the Bay of Biscay and the Iberian waters Ecoregion (WGBIE) 13 – 19 May 2016, ICES HQ, Copenhagen, Denmark. ICES CM 2016/ACOM: 12. 485 pp.

NAFO/ICES. 2017. NAFO/ICES *Pandalus* Assessment Group Meeting, 27 September to 3 October 2017. Swedish University of Agricultural Sciences, Lysekil, Sweden. NAFO SCS Doc. 17/17 Serial No. N6762. ICES CM 2017/ACOM:09. 103 pp.

Schlüter, M., and Jerosch, K. 2009. Digital atlas of the North Sea. Alfred Wegener Institute for Polar and Marine Research et al. 91 pp. hdl: 10013/epic.34893.d001.

Søvik, G. and Thangstad, T. 2015. Results of the Norwegian Bottom Trawl Survey for Northern Shrimp (*Pandalus borealis*) in Skagerrak and the Norwegian Deep (ICES Divisions IIIa and IVa east) in 2015. NAFO SCR Doc. 15/058. 26 pp.

Søvik, G. and Thangstad, T. 2016. The Norwegian Fishery for Northern Shrimp (*Pandalus borealis*) in Skagerrak and the Norwegian Deep (ICES Divisions IIIa and IVa east), 1970-2016. NAFO SCR Doc. 16/057.

Thangstad, T.H., Søvik, G., Gabrielsen, H., Henriksen, I., Karlsen, K. E., Kvalsund, M. og Vedholm, J. 2017. Reketokt i Norskerenna og Skagerrak januar 2017. (In Norwegian). Toktrapport/Havforskningsinstituttet/ISSN 1503 6294/Nr. 1 – 2018. 65 pp.

Table 1. The estimated biomass available to the trawl (Ktons) and abundance (millions) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 2018. Depth intervals are given in meter, and stratum area in nm^2. SE is the standard error.

Stratum	Depth (m)	Area (nm^2)	Hauls	Biomass	SE	Abund.	SE
2	200-300	2 500	9	0.13	0.06	28	12
3	100-200	277					
4	200-300	1 560	6	0.38	0.18	105	47
5	100-200	1 401	6	0.03	0.01	7	3
6	200-300	1 159	9	0.71	0.18	165	44
7	300-500	555	3	0.37	0.17	80	37
8	100-200	136					
9	200-300	590	7	0.23	0.09	52	20
10	300-500	541	4	0.21	0.14	54	38
11	100-200	367	8	0.87	0.28	232	68
12	200-300	254	6	0.71	0.26	205	86
13	300-500	739	7	0.83	0.25	234	66
14	100-200	1 411	15	0.76	0.29	149	57
15	200-300	739	16	1.36	0.31	319	80
16	300-500	1 138	11	1.66	0.54	484	175
17	> 500	1 137	3	0.01	0.00	6	2
Total		14 504	110	8.25	0.90	2119	253

Table 2. Annual mean towing speed with standard deviation (SD) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep), 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl.

	mean	SD
2006	2.52	0.24
2007	3.01	0.19
2008	3.05	0.38
2009	2.87	0.30
2010	2.85	0.20
2011	2.90	0.22
2012	2.93	0.23
2013	2.47	0.50
2014	2.18	0.52
2015	2.34	0.48
2016	2.49	0.49
2017	3.36	0.32
2018	3.34	0.24

Table 3. Average temperature (°C) and salinity (‰) (with standard deviation) for all trawl hauls (with available CTD data) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 2006-2018. The 2012 data result from only 22 CTD casts (8 in the Norwegian Deep and 14 in Skagerrak) due to difficulties with the CTD-winch.

Norwegian Deep

	Temperature (°C)		Salinity (‰)	
	mean	SD	mean	SD
2006	7.40	0.58	35.25	0.02
2007	7.90	0.50	35.20	0.07
2008	7.58	0.35	35.18	0.06
2009	7.43	0.32	35.26	0.04
2010	7.30	0.55	35.16	0.05
2011	6.61	0.47	35.15	0.04
2012	7.84	0.75	35.18	0.03
2013	7.48	0.35	35.21	0.06
2014	7.05	0.54	35.17	0.04
2015	7.27	0.49	35.10	0.09
2016	8.24	0.37	35.22	0.06
2017	7.97	0.62	35.16	0.04
2018	7.76	0.38	35.11	0.06

Skagerrak

	Temperature (°C)		Salinity (‰)	
	mean	SD	mean	SD
2006	7.01	0.65	35.13	0.10
2007	7.30	0.80	35.17	0.07
2008	7.03	0.36	34.88	0.31
2009	7.13	0.57	35.11	0.22
2010	7.47	0.46	35.16	0.28
2011	5.44	0.68	34.86	0.21
2012	7.28	0.64	35.01	0.22
2013	7.48	0.47	35.19	0.08
2014	7.29	0.71	35.07	0.14
2015	7.24	0.41	34.97	0.19
2016	7.75	0.57	35.11	0.17
2017	7.74	0.38	35.16	0.10
2018	7.69	0.59	35.00	0.18

Table 4. Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 2006-2018: average door spread with standard deviation (SD), regression coefficient from the linear regression, and R^2. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl.

	mean	sd	regression coefficient	R^2
2006	52.9	4.4	0.025	0.14
2007	51.6	1.8	0.014	0.31
2008	47.0	1.7	-0.004	0.05
2009	45.3	3.2	-0.012	0.10
2010	46.9	2.2	0.001	0.00
2011	47.7	2.2	-0.005	0.04
2012	47.5	3.0	-0.001	0.00
2013	51.1	1.5	-0.001	0.00
2014	48.7	1.3	-0.002	0.01
2015	51.1	3.5	0.015	0.18
2016	49.7	2.4	0.015	0.29
2017	52.5	1.1	0.001	0.00
2018	55.0	1.9	0.002	0.01

Table 5. Estimated biomass (t) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) by year and stratum, 1984-2018. Strata 1-10 are in the Norwegian Deep, while strata 11-17 are in Skagerrak (see Fig. 1). Values from the different survey time series are not comparable (see text). SE is the standard error. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl.

Survey		Stratum																	Total area	
Year	Series	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Index	SE
1984	1	0	3480	-	1430	4210	2090	570	-	510	250	290	[1]530	1010	1050	1060	1060	[1]57	17597	3217
1985	1	0	5630	-	1280	2100	2440	1270	180	990	1340	410	600	1370	2690	3110	1750	0	25180	3137
1986	1	0	3120	-	280	90	1870	530	-	[1]503	370	0	400	1180	1590	1140	440	0	11513	1799
1987	1	0	6050	-	1690	1680	2590	670	0	1160	550	290	430	550	1670	750	750	0	18830	3193
1988	1	0	1420	-	620	440	890	400	0	280	410	410	260	410	500	500	300	0	6830	956
1989	1	-	1280	-	2010	0	1520	540	-	510	500	410	360	780	920	1220	570	0	10640	1324
1990	1	0	1620	-	1840	0	1980	300	0	1060	380	510	650	700	1290	1240	1120	0	12700	1750
1991	1	0	3160	-	3390	60	1890	450	-	1200	350	660	530	980	2180	1650	1820	90	18400	2409
1992	1	0	2910	-	620	940	4790	1440	290	490	1190	1920	550	1220	2010	1980	970	0	21340	2928
1993	1	0	1320	-	3010	180	1570	550	-	1050	270	2080	560	1310	1710	2650	1300	240	17770	2054
1994	1	0	2710	-	2060	380	2610	840	-	770	360	1450	740	1300	2130	1550	1590	10	18500	1586
1995	1	0	3530	-	1070	180	2840	740	360	1010	230	1460	400	800	2240	1780	930	0	17590	1732
1996	1	0	4950	-	1280	140	3060	1640	-	730	330	3630	1300	1350	2470	1880	1180	200	24150	2498
1997	1	0	8820	-	2080	520	2900	1720	280	1020	630	2420	840	1470	3220	2090	3230	800	32020	2771
1998	1	0	6860	-	2010	530	1830	610	-	910	730	680	500	720	1660	2090	1060	0	20190	2057
1999	1	0	5830	-	2430	230	1580	410	-	760	230	1130	580	620	2160	1540	290	0	17790	1915
2000	1	0	4250	-	3000	510	1720	420	290	270	290	800	330	180	2220	2160	980	0	17400	1957
2001	1	1230	5460	-	4810	1790	2330	700	-	350	470	350	170	520	3440	1770	1180	0	24560	2837
2002	1	0	[1]5187	-	[1]2857	160	1590	1160	-	1560	660	1110	580	490	3600	3670	2190	0	24815	1937
2003	2	-	-	-	1410	750	2770	840	300	1240	430	480	770	960	2210	1950	850	-	14960	
2004	3	-	4000	-	3230	0	2940	990	-	940	650	570	1300	1250	8840	3780	3570	350	32400	3570
2005	3	0	5480	-	3150	0	2570	1730	-	1540	870	900	640	1140	3200	2180	3760	0	27150	3028
2006	4	-	2920	-	2010	[2]118	2110	[2]1188	-	380	130	870	900	1910	2730	2050	2130	[2]92	19538	2303
2007	4	-	3500	-	1620	120	2980	740	-	1250	1050	2040	1320	6860	1380	2140	12470	0	37470	8055
2008	4	20	2910	-	1210	290	2550	1230	-	650	160	780	1480	3980	1200	570	2420	40	19500	2539

2009	4	0	1840	-	680	190	3400	220	-	410	70	520	1660	1270	800	2060	1680	70	14860	2208
2010	4	0	1620	-	580	30	1230	1290	-	590	500	200	400	640	660	890	1450	30	10100	1733
2011	4	0	520	-	760	20	1930	600	40	470	690	310	320	500	690	880	720	160	8620	1069
2012	4	-	2)651	-	300	10	1070	140	-	260	40	310	390	1280	390	490	820	10	6161	897
2013	4	40	330	-	780	0	880	490	-	370	450	460	340	910	440	650	860	0	7000	838
2014	4	0	180	-	800	0	240	2)539	-	150	2)346	430	530	1350	540	990	2720	40	8855	1582
2015	4	-	2)1481	-	2460	90	590	420	-	1200	260	620	530	2180	210	260	720	2990	14010	3280
2016	4	-	170	-	390	840	180	70	-	240	50	340	90	200	490	450	210	10	3730	881
2017	4	-	230	-	640	90	1390	150	-	680	50	400	480	1260	390	1860	1170	0	8800	1460
2018	4	-	130	-	380	30	710	370	-	230	210	870	710	830	760	1360	1660	10	8250	897

1) estimated as the stratum's mean portion of total biomass (averaged over 1985, 1987-2001) applied to the total biomass of the year.
2) estimated as the stratum's mean portion of total biomass (averaged over 2007-2011, and 2013) applied to the total biomass of the year. Not updated with 2017-2018 data.

Table 6. Mean carapace length (CL) with standard deviation (SD), abundance (millions) and proportion of age groups from the 2018 survey length frequency distribution in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep).

Skagerrak				
age	CL (mm)	SD	abundance	proportion
1	11.89	1.29	587	0.35
2	17.40	1.34	853	0.51
3+	21.47	1.77	236	0.14

Norwegian Deep				
age	CL (mm)	SD	abundance	proportion
1	10.48	1.74	34	0.07
2	15.83	1.71	342	0.67
3	20.30	1.19	62	0.12
4+	23.23	1.57	71	0.14

Total				
age	CL (mm)	SD	abundance	proportion
1	12.27	1.65	757	0.35
2	17.30	1.41	1099	0.50
3+	21.68	1.80	338	0.15

Table 7a. Estimated numbers per age group in the shrimp stock (*Pandalus borealis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep), 1984-2002 (October/November).

	0-group	1-group	2-group	3-group
1984	273	2324	576	599
1985	197	2869	1536	402
1986	100	849	767	9
1987	75	1955	1435	571
1988	196	401	530	12
1989	816	1613	616	
1990	320	1882	602	139
1991	150	2210	1049	250
1992	2038	2133	1127	122
1993	356	2681	945	7
1994	212	1518	1347	209
1995	164	1322	673	985
1996	642	2270	973	918
1997	187	3228	2337	366
1998	249	1912	1205	
1999	254	1769	370	992
2000	561	2152	1007	181
2001	483	2463	1879	
2002	338	2349	839	172

Table 7b. Estimated numbers per age group in the shrimp stock (*Pandalus borealis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep), 2006-2018 (January/February). The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl.

	1-group	2-group	3-group	4-group
2006	1806	2297	592	
2007	1795	7293	1361	
2008	705	1750	1160	629
2009	425	1485	1087	
2010	155	1345	256	
2011	330	779	559	
2012	830	696	103	
2013	663	1029	309	
2014	2261	774	360	
2015	346	2125	491	268
2016	233	384	275	
2017	880	1117	361	
2018	757	1099	338	

Table 8. Index of predator biomass (mean catch in tons per nm^2) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl.

Species		biomass index													
English	Latin	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	mean
Blue whiting	*Micromesistius poutassou*	0.13	0.13	0.12	1.21	0.27	0.62	3.30	29.03	1.88	5.25	6.26	31.18	6.38	
Saithe	*Pollachius virens*	7.33	39.75	208.32	53.89	18.53	7.52	5.66	112.80	14.13	8.56	6.93	9.71	12.87	
Cod	*Gadus morhua*	0.51	1.28	0.78	2.01	1.79	1.66	1.26	1.69	2.92	2.37	2.74	2.00	2.05	
Roundnose grenadier	*Coryphaenoides rupestris*	3.22	6.85	19.02	19.03	10.05	4.99	4.43	1.97	2.90	1.46	0.3	1.41	2.17	
Rabbit fish	*Chimaera monstrosa*	2.24	2.15	3.41	3.26	3.51	2.73	2.22	3.05	3.90	2.19	1.7	5.99	5.03	
Haddock	*Melanogrammus aeglefinus*	0.97	4.21	1.85	3.18	3.46	5.82	5.75	5.18	2.15	2.60	1.66	1.86	1.51	
Redfish	Scorpaenidae	0.18	0.40	0.26	0.43	0.80	1.02	0.37	0.47	0.48	0.20	0.25	0.53	0.97	
Velvet belly	*Etmopterus spinax*	1.31	2.58	1.95	2.42	2.52	1.47	1.59	2.67	1.91	2.51	1.2	4.19	3.85	
Skates, rays	Rajidae	0.41	0.95	0.64	0.17	0.60	0.88	0.98	1.00	2.25	1.69	0.35	1.64	1.20	
Long rough dab	*Hippoglossoides platessoides*	0.22	0.64	0.42	0.28	0.47	0.51	0.56	0.56	1.17	1.45	0.52	0.94	0.81	
Hake	*Merluccius merluccius*	0.98	0.78	0.64	2.56	1.60	0.56	0.52	1.06	0.69	0.59	1.07	1.24	1.66	
Angler	*Lophius piscatorius*	0.15	0.91	0.87	1.25	1.70	0.92	0.17	0.65	0.75	0.58	0.9	1.13	0.57	
Witch	*Glyptocephalus cynoglossus*	0.24	0.74	0.54	0.16	0.13	0.24	0.29	0.27	0.35	1.38	0.28	0.47	0.17	
Dogfish	*Squalus acanthias*	0.31	0.19	0.28	0.14	0.11	0.21	0.60	1.02	1.00	0.36	0.24	0.42	0.45	
Black-mouthed dogfish	*Galeus melastomus*	0.00	0.05	0.05	0.15	0.09	0.09	0.09	0.12	0.11	0.35	0.34	0.26	0.24	
Whiting	*Merlangius merlangus*	0.35	1.01	1.35	3.02	2.42	3.07	1.64	2.02	3.38	1.59	1.87	2.60	4.56	
Blue Ling	*Molva dypterygia*	0	0	0	0	0	0	0	0.01	0.01	0.03	0	0.01	0.03	
Ling	*Molva molva*	0.04	0.11	0.34	0.79	0.64	0.24	0.17	0.22	0.32	0.63	0.18	0.90	0.99	
Four-bearded rockling	*Rhinonemus cimbrius*	0.06	0.14	0.04	0.03	0.05	0.03	0.09	0.04	0.06	0.12	0.05	0.04	0.05	
Cusk	*Brosme brosme*	0.20	0	0.02	0.05	0.13	0.29	0.04	0.10	0.05	0.19	0.01	0	0.14	
Halibut	*Hippoglossus hippoglossus*	0.08	0.07	3.88	0.09	0.20	0.05	0.19	0	0	0.10	0	0.16	0.09	
Pollack	*Pollachius pollachius*	0.06	0.25	0.03	0.13	0.12	0.15	0.07	0.24	0.65	0.23	0.08	0.10	0.15	
Greater forkbeard	*Phycis blennoides*	0	0	0	0.01	0.04	0.02	0.05	0.06	0.12	0.05	0.07	0.18	0.22	
Total		18.99	63.19	244.81	94.26	49.23	33.09	30.04	164.23	41.18	34.48	27.00	66.96	46.16	70.28
Total (except saithe and roundnose grenadier)		8.44	16.59	17.47	21.34	20.65	20.58	19.95	49.46	24.15	24.46	19.77	55.84	31.12	25.37

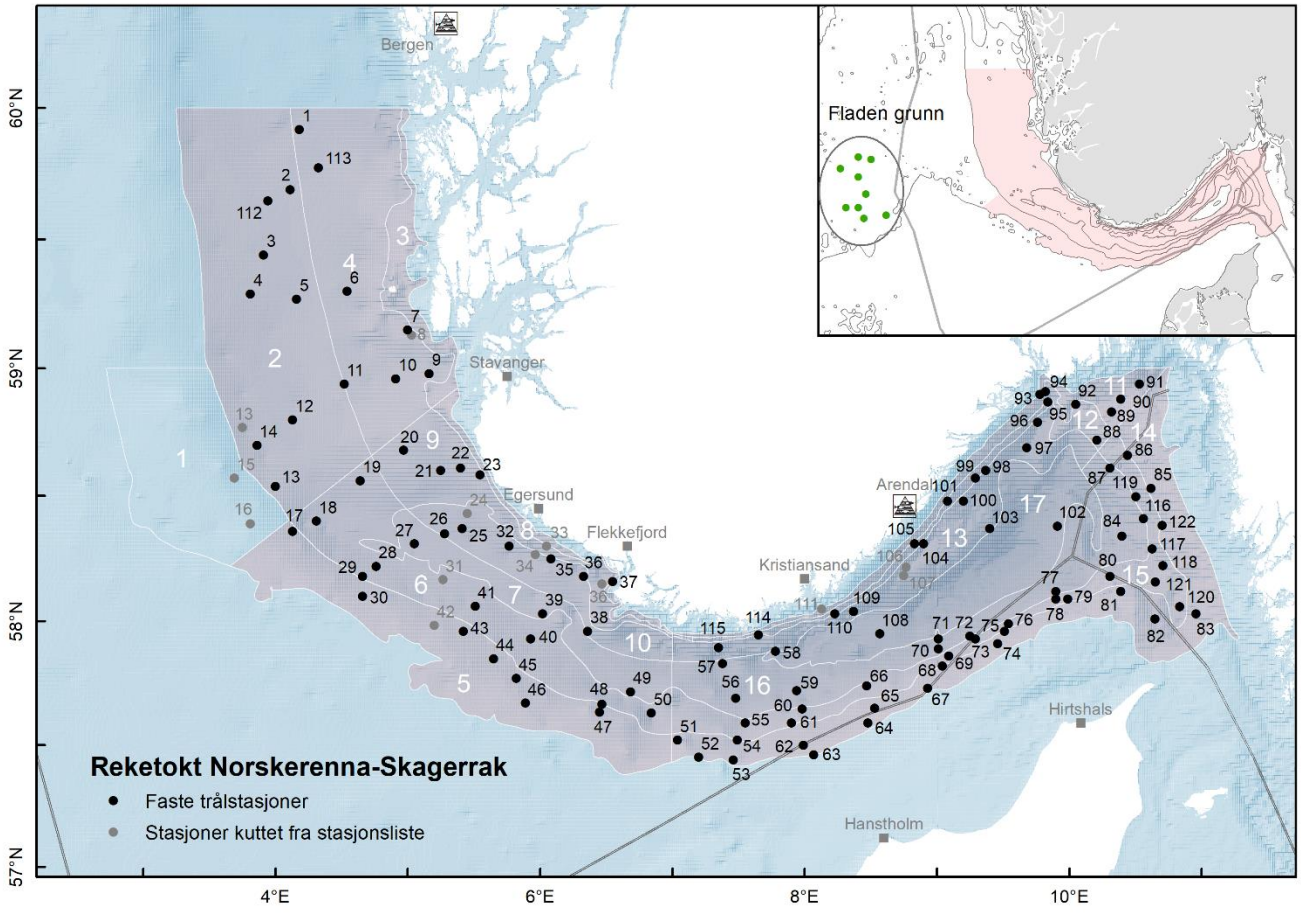

Fig. 1. Norwegian shrimp survey in Skagerrak and the Norwegian Deep (ICES Divs. 3.a and 4.a east): the strata system with the 111 fixed trawl stations. Trawl stations marked in grey have been deleted from the station list (see text). Trawl stations on Fladen Ground (from previous surveys in 1987-1994), although planned visited in 2018, were not trawled due to weather conditions. Strata areas are given in Table 1.

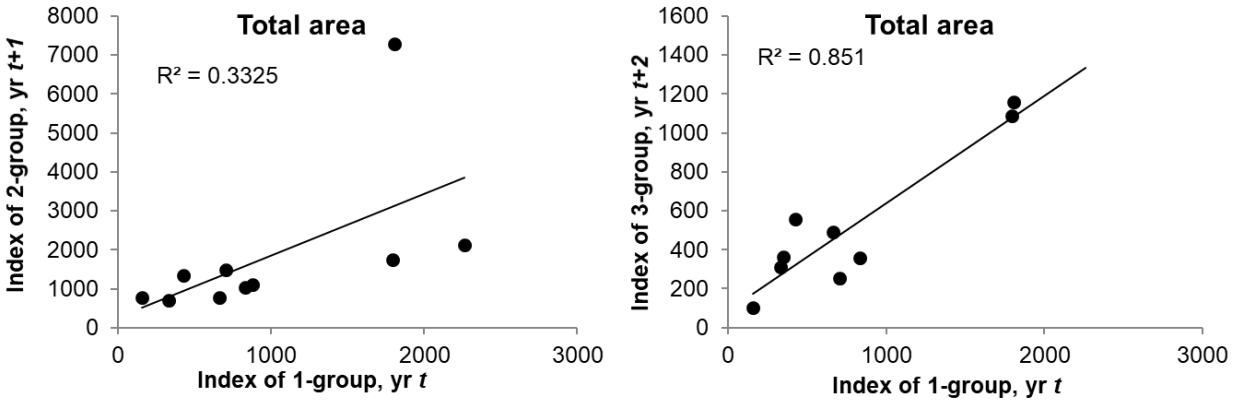

Fig. 2. Correlation between the index of 1-year old shrimp (*Pandalus borealis*) (indices are given in abundance in millions) in year *t* and the index of 2-year old shrimp in year *t*+1 (left); and correlation between the index of 1-year old shrimp in year *t* and the index of 3-year old shrimp in year *t*+2 (right), in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep). Data from January/February 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure.

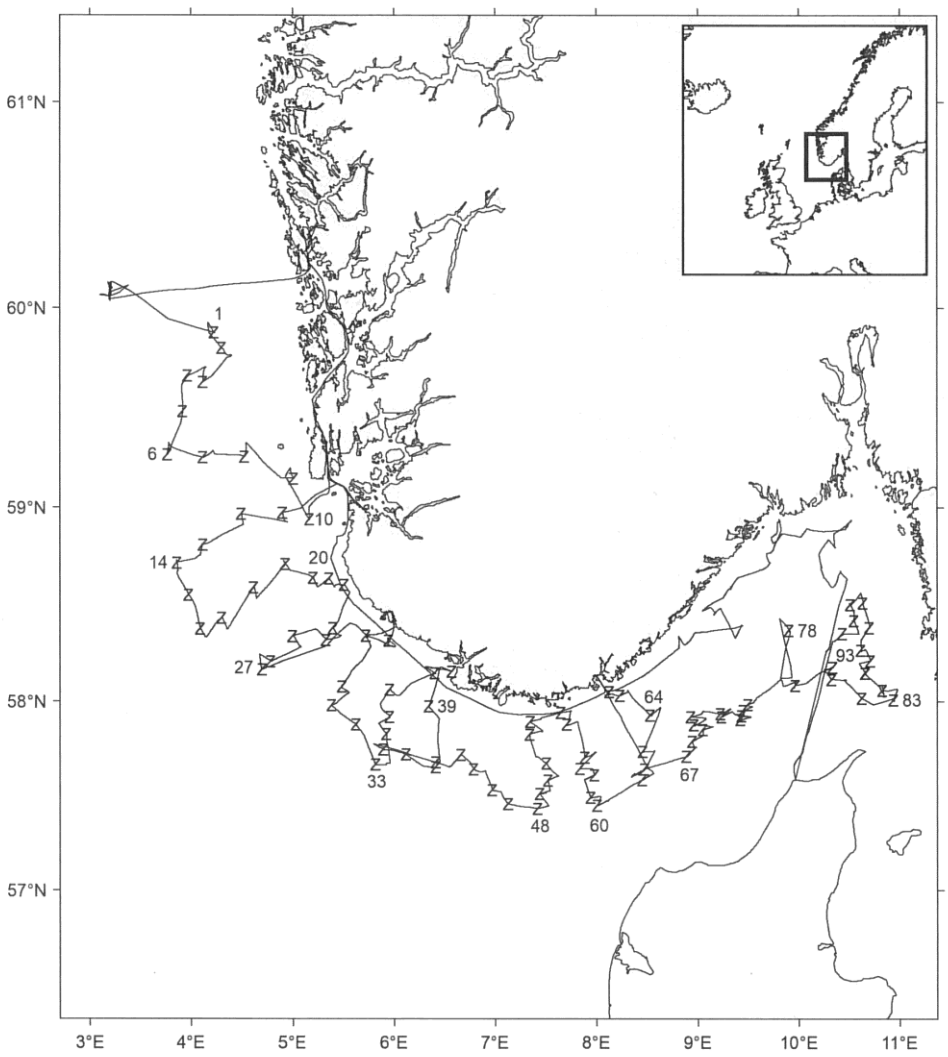

Fig. 3. CTD-stations (z) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in January 2018.

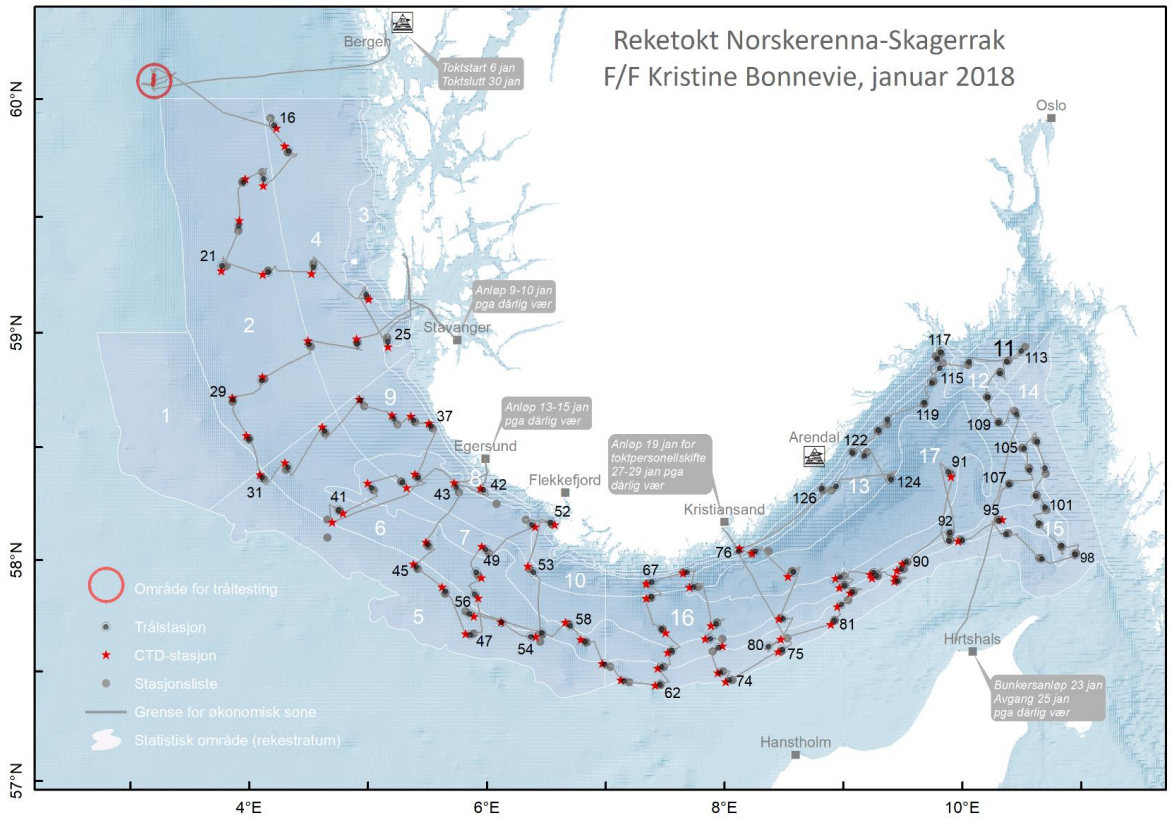

Fig. 4. The Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in January 2018 with R/V *Kristine Bonnevie*: sailing route with station list (grey dots), trawled stations (black dots) and CTD-stations (red stars). The red circle shows area for testing of trawl gear.

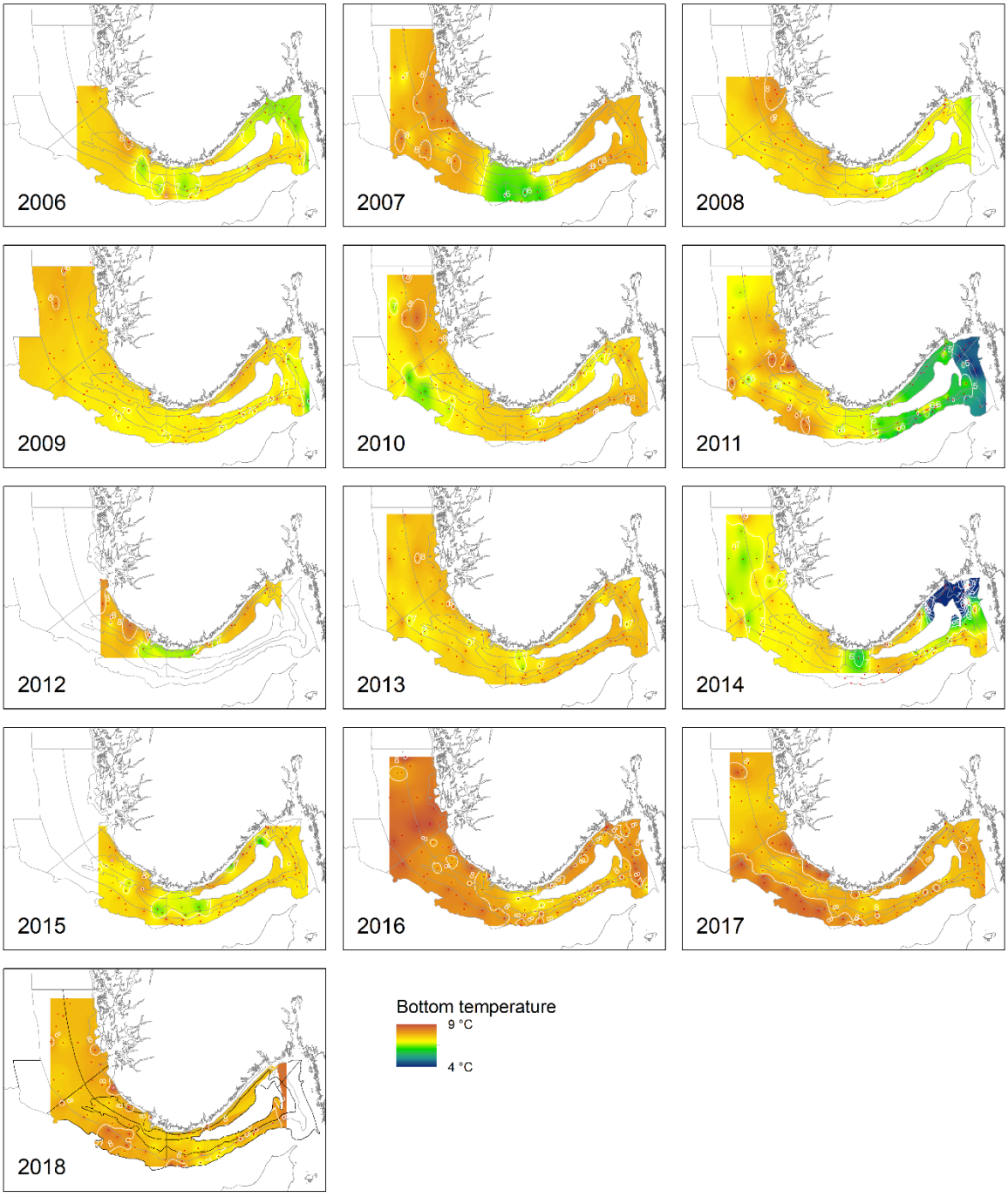

Fig. 5. Bottom temperatures (ºC) from CTD from the Norwegian shrimp survey in 2006-2018 in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep).

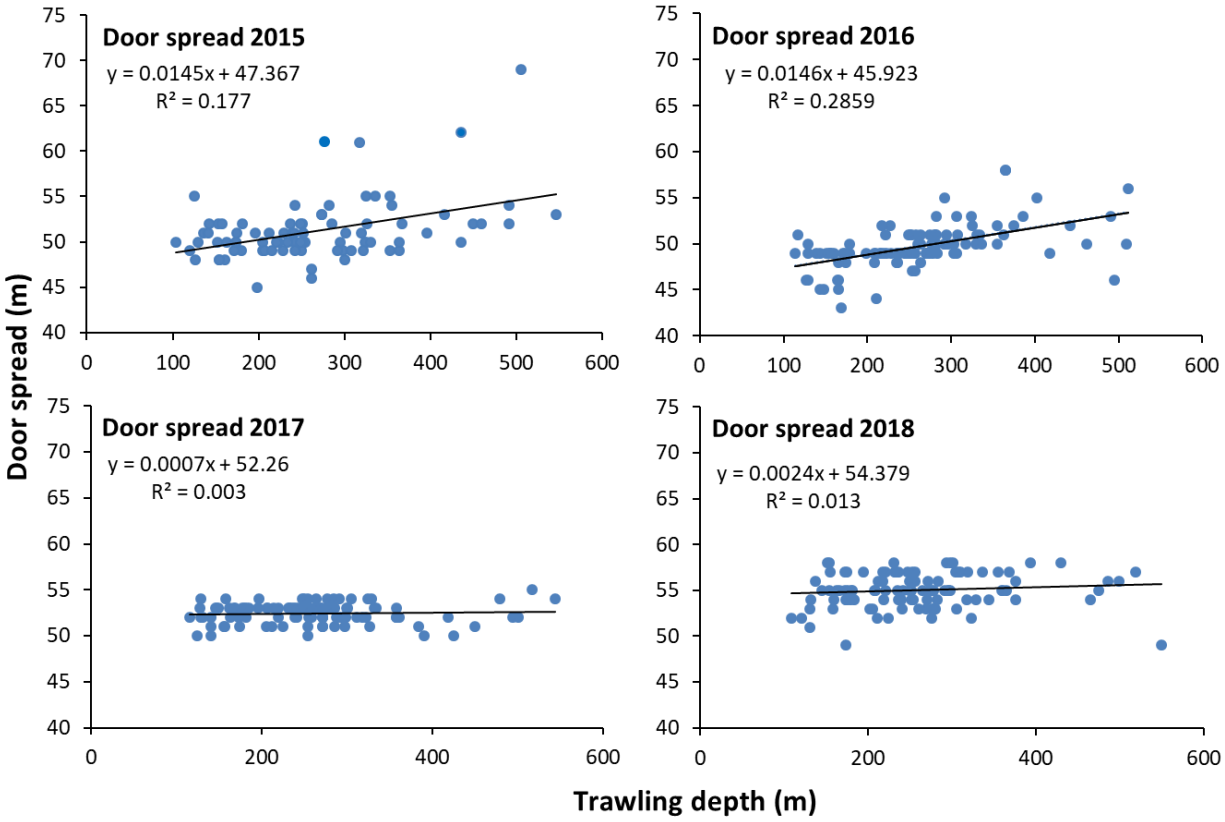

Fig. 6. Door spread (m) by trawling depth (m) for all valid trawl stations on the 2015-2018 Norwegian shrimp surveys in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep).

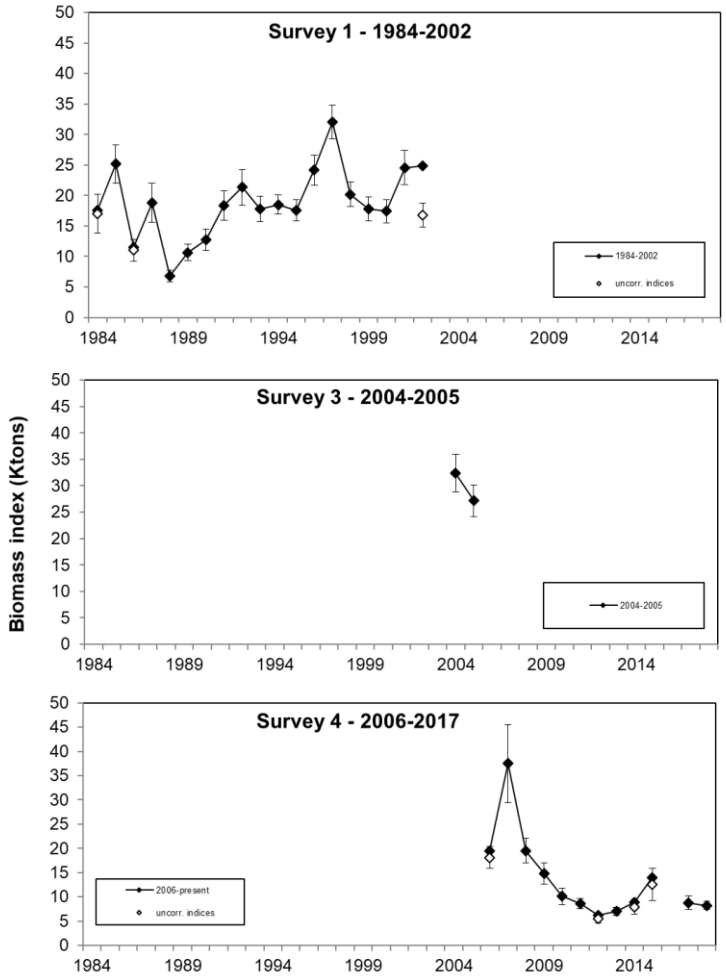

Fig. 7. Biomass index (with standard error) of shrimp (*Pandalus borealis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep), 1984-2018. The 2003-value is not shown. The 2016-survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure. Uncorrected values (◊) due to missing strata (see Table 5) are plotted.

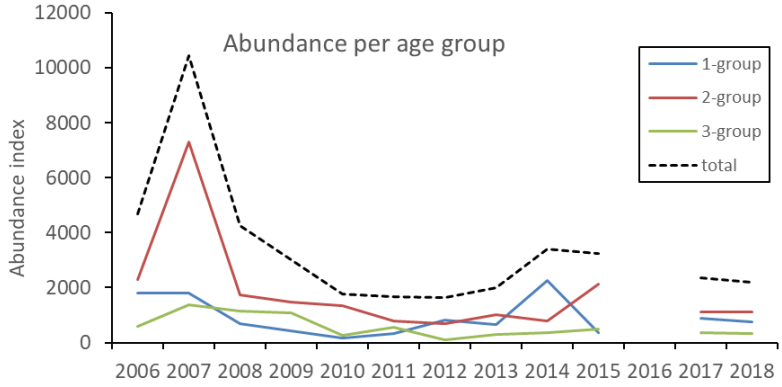

Fig. 8. Abundance index per year class of shrimp (*Pandalus borealis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep), 1984-2018. The 2016-survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure. Indices are not corrected for missing strata (see Table 5).

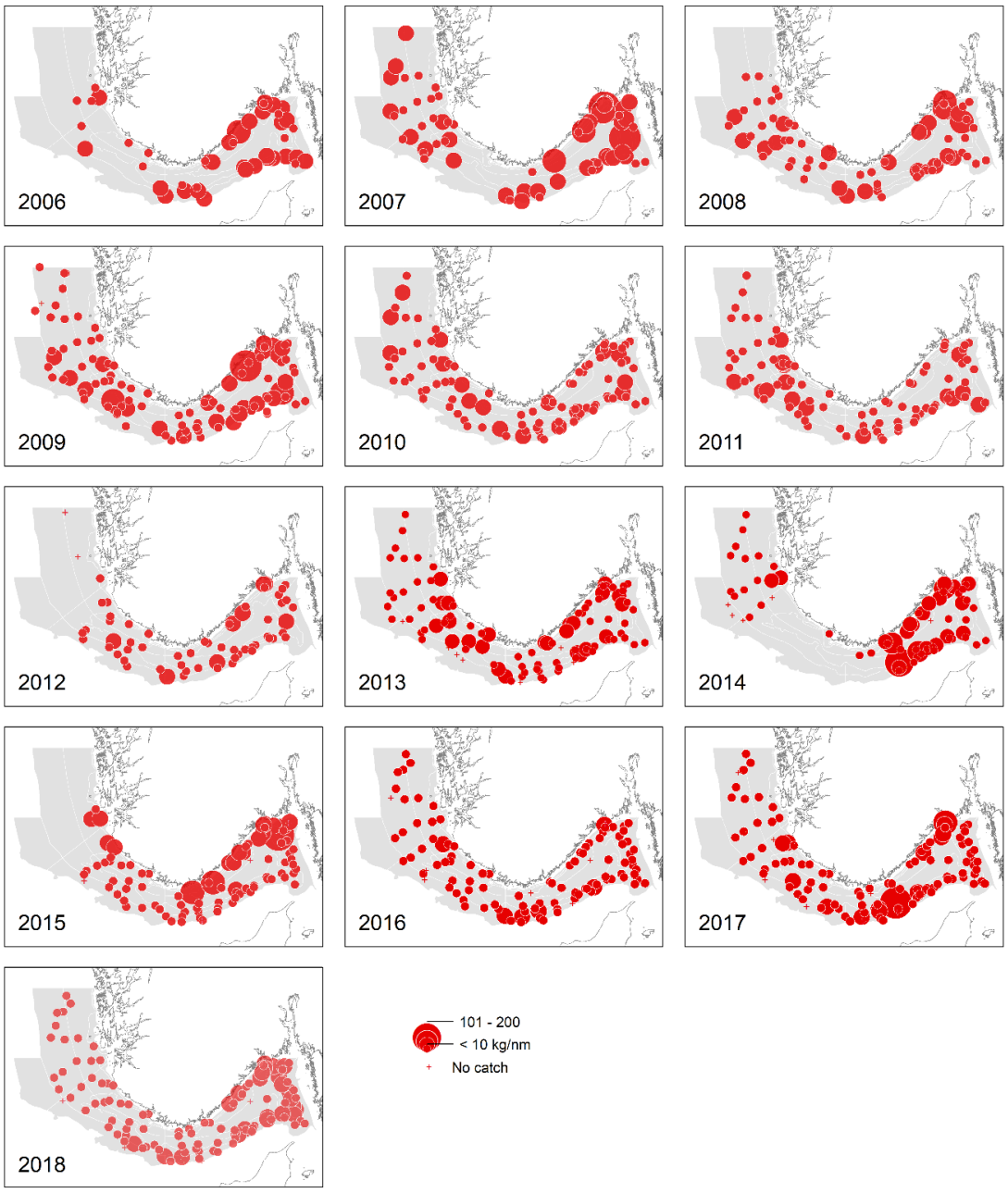

Fig. 9. Shrimp (*Pandalus borealis*) catches per trawl station (kg/nm) from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in January/February 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl, but the data have not been taken out of the figure.

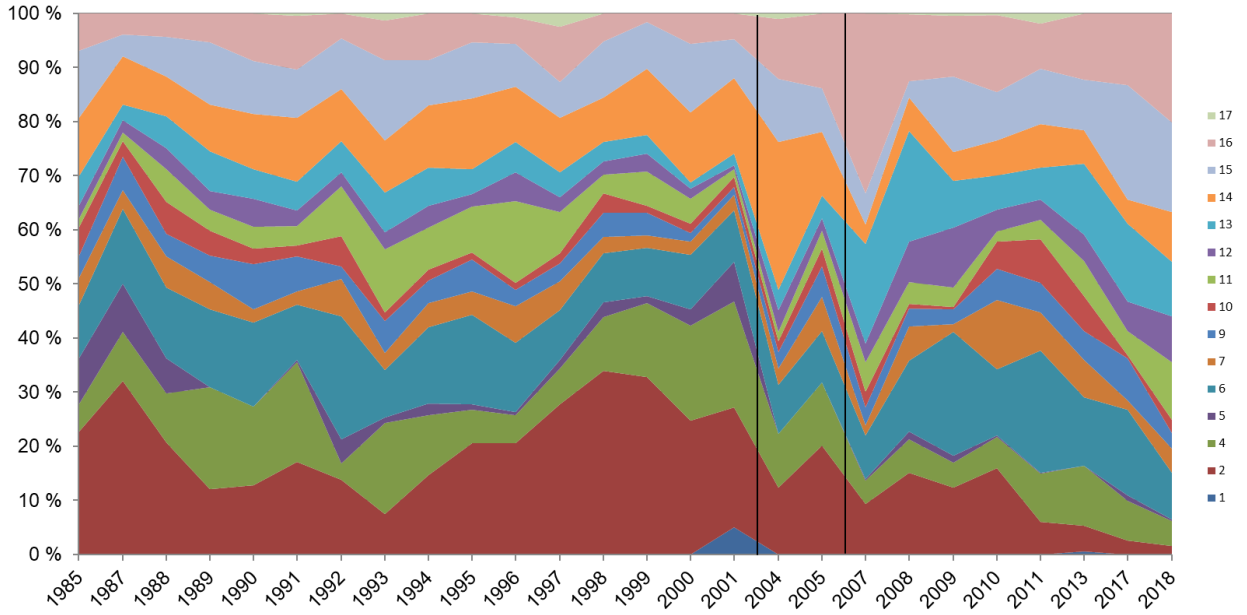

Fig. 10. The proportion of shrimp biomass (*Pandalus borealis*) per stratum from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in years when all survey strata have been covered, in the time period 1984-2018. Strata 1-10 are in the Norwegian Deep, and strata 11-17 are in Skagerrak (see Fig. 1). The vertical lines mark the different survey time series (1984-2002, 2004-2005, 2006-2018). The 2003-value is not shown. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure.

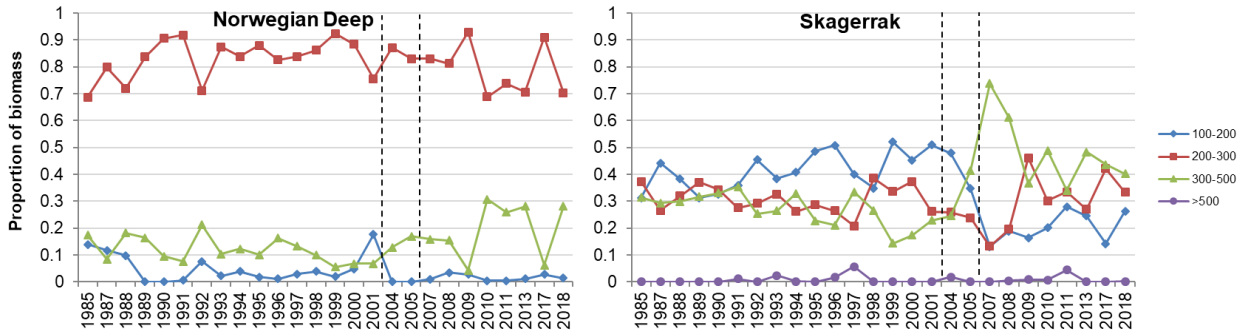

Fig. 11. The proportion of shrimp biomass (*Pandalus borealis*) per depth interval from the Norwegian shrimp survey in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in years when all survey strata have been covered, in the time period 1984-2018. The vertical lines mark the different survey time series (1984-2002, 2004-2005, 2006-2018). The 2003-value is not shown. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure.

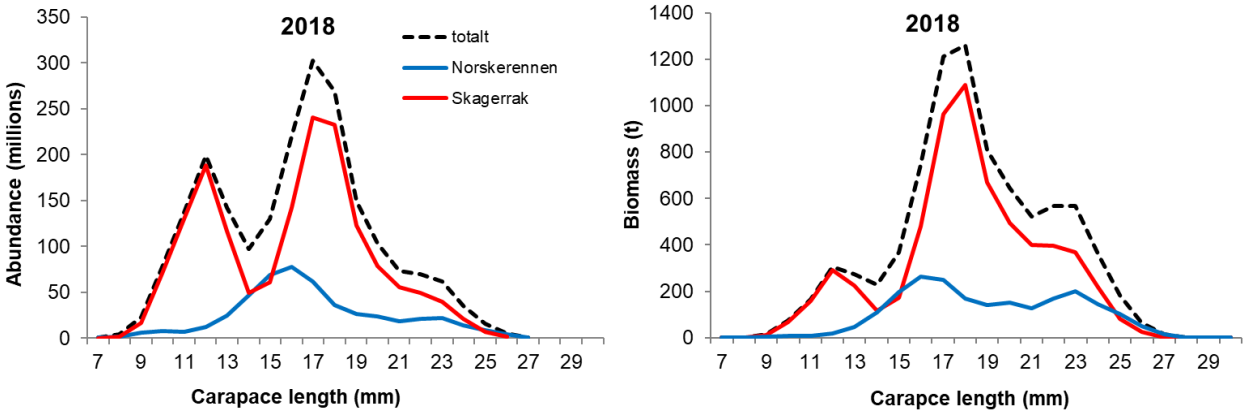

Fig. 12. Length frequency distributions (left) and biomass per length (right) of the shrimp stock (*Pandalus borelis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) by area and total, in 2018. Mean weight per length are Danish average values for 1998-2011.

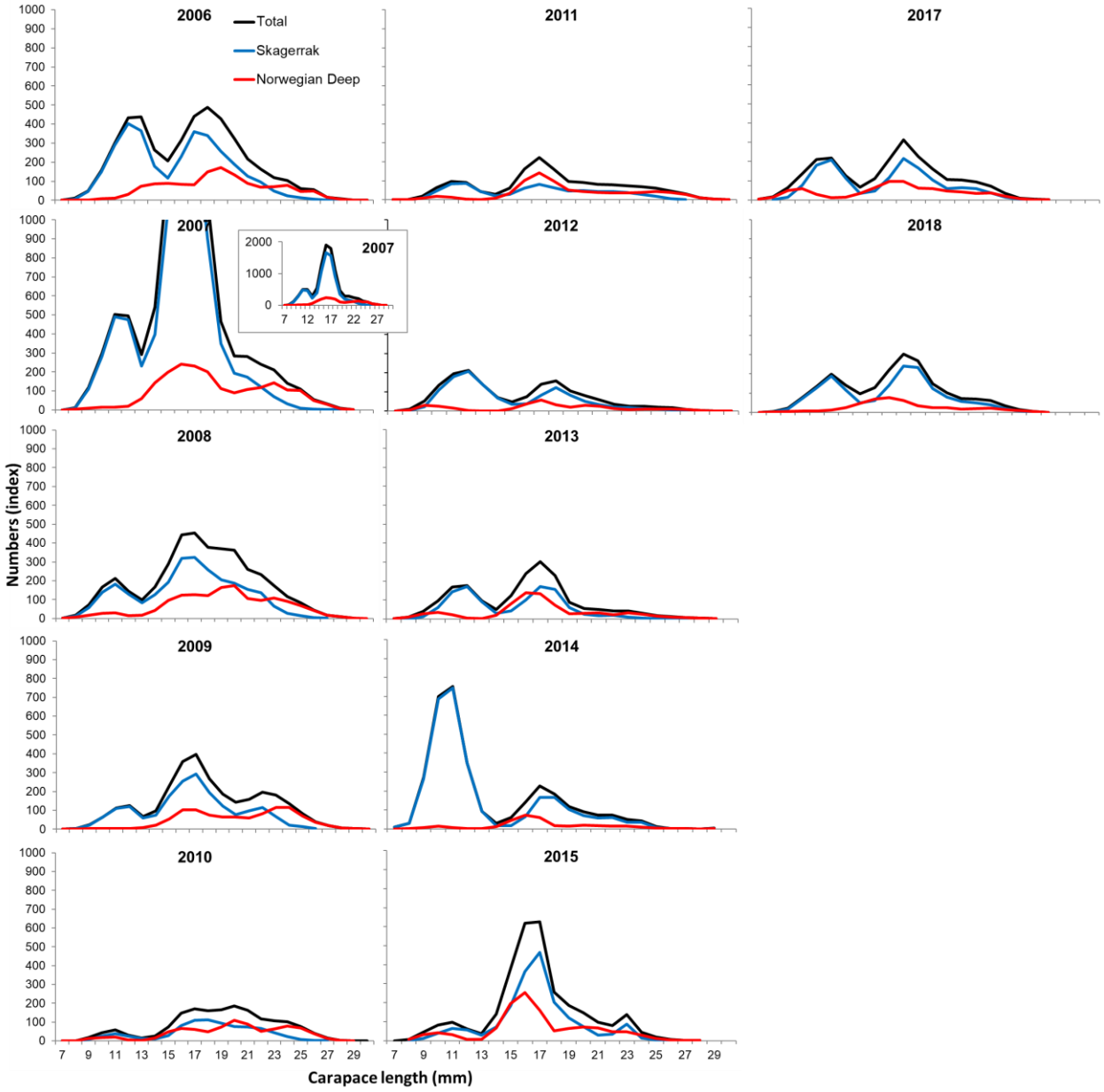

Fig. 13a. Length frequency distributions for the shrimp stock (*Pandalus borelis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) by area and total, in 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure.

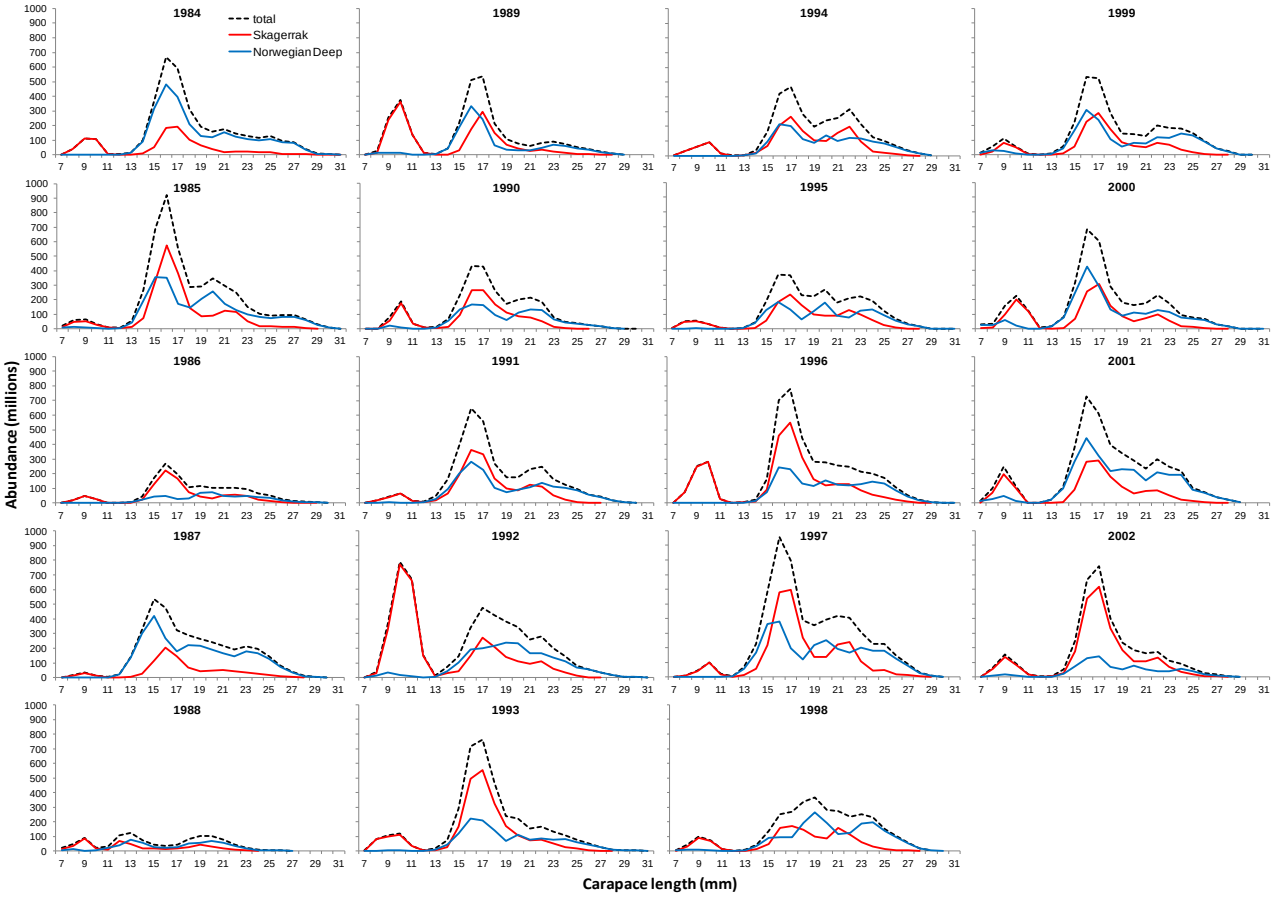

Fig. 13b. Length frequency distributions for the shrimp stock (*Pandalus borelis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 1984-2002.

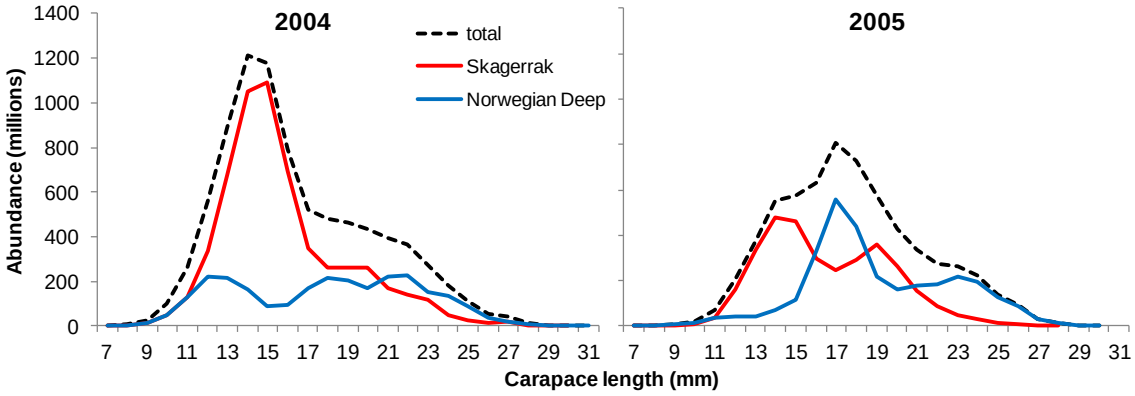

Fig. 13c. Length frequency distributions for the shrimp stock (*Pandalus borelis*) in ICES Divs. 3.a and 4.a east (Skagerrak and the Norwegian Deep) in 2004-2005.

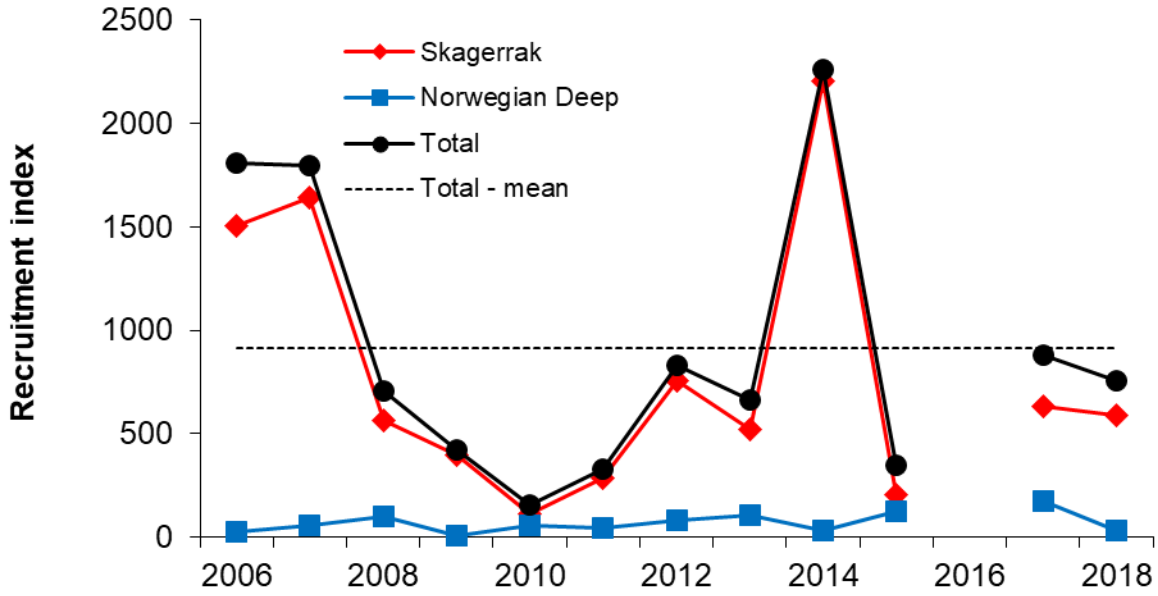

Fig. 14. Recruitment index (abundance in millions) of 1-year old shrimp (*Pandalus borealis*) in ICES Div. 3.a (Skagerrak), Div. 4.a east (the Norwegian Deep), and in the overall area for 2006-2018. The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure. The higher number of 1-year old shrimp in the whole area in 2006 compared with Skagerrak, despite hardly any 1-year old shrimp in the Norwegian Deep, can be explained by the 1-groups in the two areas having different mean lengths. In the total area, shrimp < 15.5 mm are defined as 1-year old by the modal analysis, while the analysis puts shrimp > 12 mm in the 2-group in the Norwegian Deep (see Fig. 13a).

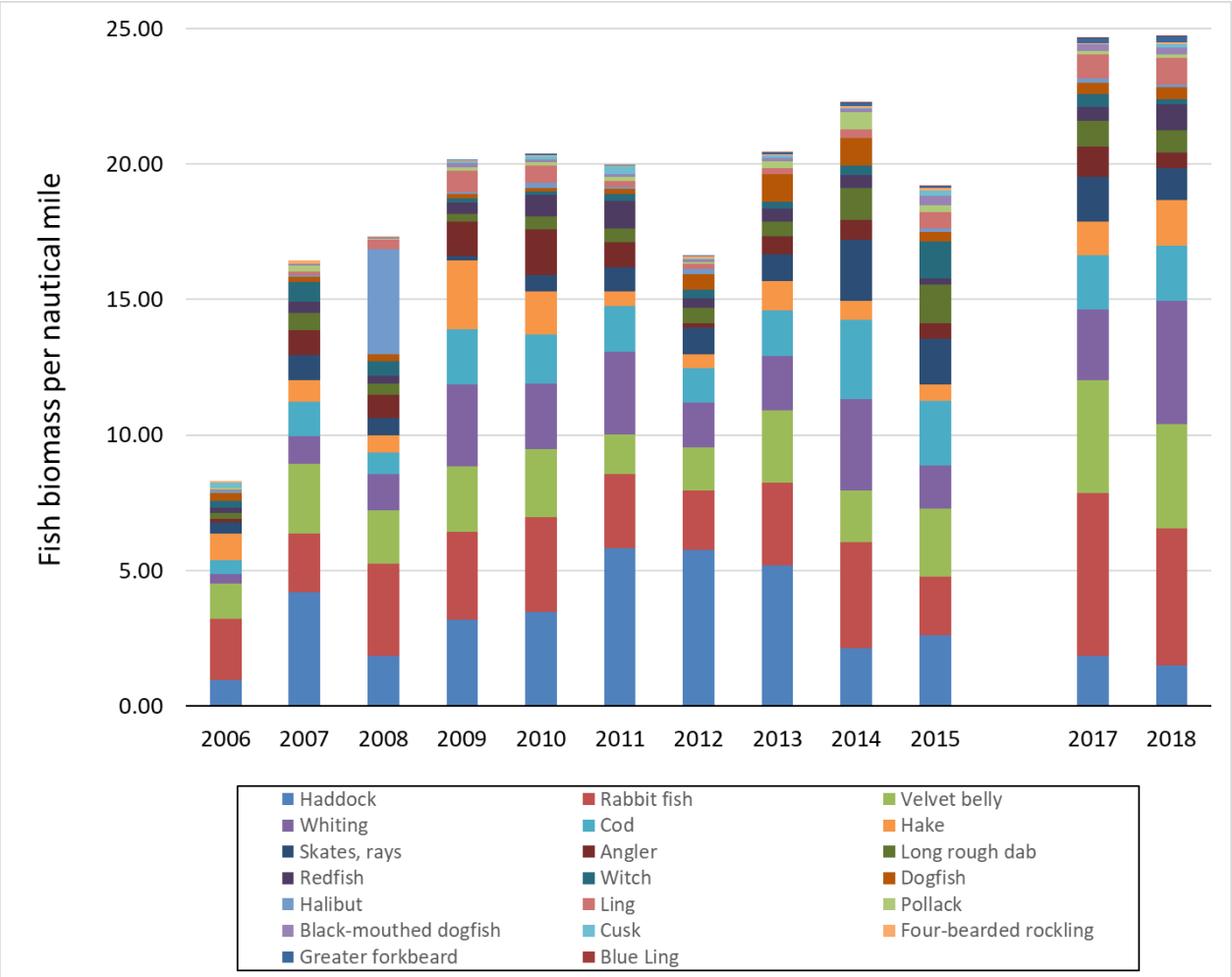

Fig. 15. Indices of demersal fish species (potential shrimp predators) (tons per nm^2) in 2006-2018 in ICES Divs. 3.a and 4. east (Skagerrak and the Norwegian Deep), not including indices of saithe, roundnose grenadier and blue whiting (see text). The 2016 survey was invalidated because of problems with unequal wire lengths of the trawl and these data are therefore not included in the figure.