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Research survey results pertaining to northern shrimp (*Pandalus borealis*) in the Barents Sea and Svalbard area 2004-2015

by

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Abstract

The estimated mean biomass index has varied considerably since the early 1980s. The 2010-12 values were at a relatively high level. The 2014 and 2015 estimates are down from this level by about 33%. Since 2004 the areas of high shrimp density are gradually found further east in the Barents Sea. The changes in distribution may be associated with influx of warmer water from the south-west into the Barents Sea.

Introduction

Research bottom trawl surveys have been conducted to assess the stock status of northern shrimp, *Pandalus borealis*, in the Barents Sea. The main objectives were to obtain index values for stock biomass, abundance, recruitment and demographic composition. Recently (since 2004) the monitoring of a multitude of other ecosystem variables has been included in what now is named the joint Norwegian-Russian "Ecosystem survey" (www.imr.no).

For the assessment of Barents Sea shrimp three survey time series are available: (1) The Norwegian shrimp survey 1982-2004 (ICES, 2002, 2003, 2005), (2) The Russian shrimp survey 1984-2002 and 2005 (ICES 2006), and (3) The joint Norwegian-Russian ecosystem survey since 2004. The ecosystem survey (3) combines surveys 1 and 2, as well as several earlier 0-group and groundfish surveys.

This paper updates the information regarding shrimp from survey (3) and includes data from both Norway and Russia. The survey biomass indices derived here are used as input in the assessment model for this stock.

Methods

Survey and coverage

The joint Norwegian-Russian ecosystem survey has since 2004 been conducted annually from August to October by 4-5 research vessels simultaneously covering the entire Barents Sea. On average 360 bottom trawl hauls are taken each year from the edge of the continental shelf in the west, to Novaja Semlja in the east, from the coast of Norway and Russia in the south to the ice-edge in the north (Olsen, 2006) (Fig. 1).

In most of the covered area both in the Norwegian and Russian EEZs the survey follows a regular grid with ecosystem sampling stations approx. 30-35 nm apart (Fig. 1). In the important juvenile shrimp areas in the central Barents Sea (Hopen Deep), additional demersal trawl stations are placed at ½ the standard grid size

to get a more detailed coverage of the shrimp distribution in this area. In the other high density shrimp area in the north-west around Spitsbergen a depth-stratified survey is conducted. Here stations are placed approx. every 30-35 nm as in the other areas, but in addition a number of extra bottom trawl stations are placed at irregular intervals within this part of the survey area. The additional "shrimp stations" were reduced in numbers in 2008, and have since been omitted altogether.

Sampling trawl gear
Sampling of demersal species like shrimp within the ecosystem survey is conducted with a standard Norwegian research trawl, which is a modified Campelen 1800 shrimp trawl with rockhopper ground gear (Fig. 2). Mesh size in the cod-end is 22 mm with a 6 mm lining. A juvenile (Hoita) bag with 0.8 mm lining was has occasionally been attached under the trawl in front of the cod-end in order to collect juvenile shrimp < 10 mm in the catch.

Trawl geometry and behaviour of the trawl were monitored using *Scanmar* trawl sensors. The Norwegian vessels used standard *Steinshamn* W9 bottom V trawl doors with an area of 6.7 m^2 and a weight of 2 250 kg. "Strapping" – a rope 150-180 m in front of the doors locks the distance the trawl doors to approximately 50 m – is used. The towing time is 15 min. GPS positions were used to calculate towed distance. A speed sensor (symmetry) was used on all bottom hauls, giving information about the direction and amount of currents entering the trawl and making it possible to tow at the right speed and geometry in proportion to underwater crosscurrents by adjusting wires or warps to compensate a skewed trawl. Other trawl settings are described in detail in a separate manual for rigging of trawl and trawl equipment (Engås, 1995).

Sampling routines
For each haul on board Norwegian vessels, samples of 250-300 adult shrimp specimens are taken from the main bag, sorted by sexual characteristics, and measured by calliper to the nearest mm below (carapace length, cpl, as defined in Allen (1959); McCrary (1971)). A sample of up to 100 juvenile individuals is taken from the Hoita bag and measured the same way as the adults. Shrimp sampling on board Russian vessels is done in a similar manner.

Russian and Norwegian scientists use different database systems (BioFox and Regfisk, respectively) to register biological data from marine animal surveys. At the end of the survey the Russian ecosystem data are converted and included in the Norwegian database system; however, it has to date not been possible to convert the Russian shrimp length data, so that normally only total weight per haul is given. The length- and sex frequency distribution in the samples was weighted by total catch and stratum area to obtain estimates of the overall distribution.

Area stratification
Data from the sampling were stratified by depth and area as in Fig. 3. Five main areas are identified which each are further sub-divided into 6 depth strata (0-600 m). The depth strata boundaries follow depth contours obtained from the GEBCO world bathymetry database (http://www.gebco.net). The individual strata were constructed using ArcGIS software; then each stratum's area was calculated in km^2 using an equal area projection (Europe Albers Conic) (Table 1, Fig. 4).

Swept area analysis
The catch in each tow divided by the swept area represents a sample of shrimp density in a stratum. From these samples the mean and standard error of the density in each stratum was calculated and multiplied by the area of the stratum to give an estimate of stratum biomass and abundance. Standard error was calculated as $B * 0.985$ Cochran (1977) for strata with only one tow. The means and their standard errors for the strata were summed to give the overall values for the survey area. The calculations were done using the SAS statistical software (Anon., 1988).

Inconsistencies in survey coverage
Due to heavy ice conditions, the north.eastern part of the survey area was poorly covered in 2014 and therefor there was no hauls taken in stratum 3 (Fig 2). For the 2004-2013 survey period this area accounts for on average 13% of the biomass (range: 8-27%). The 2014 biomass for area 3 was estimated by calculating the

average ratio of biomass density in area 3 to biomass density in the remaining survey area for the 2009-2013 period and applying this average to the density of the 2014 surveyed area. Estimates of variance for area 3 was taken as the variance of the area 3 2009-2013 estimates (Table 4).

Results

Biomass

The estimate of mean biomass has varied considerably since the early 1980s (Fig.5). From 2004 to 2006 biomass increased by about 66% and then decreased again back to the 2004-level in 2008. The 2010-12 values are back up close to that of 2006 while the 2014 and 2015 values are down again from this level by about 33% (Table 3, Fig. 5).

Demography

Overall size distributions (Fig. 11) indicate a relatively large amount of smaller shrimp in 2004 which likely based the increase in stock biomass until 2006 (Fig. 4). The recruitment index – estimated abundance of shrimp at 13-16mm CL supposed to enter the fishery in the following one-two years decreased since 2004 (Fig. 12). Nevertheless, total biomass increased in 2009 and 2010 questioning the predictive capability of the recruitment index. The demographic information was not updated since 2009 (additional recruitment information for this period is available from the Russian survey analyses)

Distribution

The spatial distribution of shrimp biomass has changed (Fig. 6,7,10). Since 2004 the areas of high shrimp density are gradually found further east in the Barents Sea (Fig. 10). A noticeable shift is seen from 2007-09 when the percentage of biomass in stratum 2 declines while that of area 4 increases (Fig 7 upper). At the same time no significant changes in depth distribution were seen (Fig 7 lower). The average densities have increased times four in stratum 4 between 2007 and 2010 while those of stratum 2 have declined substantially (Fig 9 upper).

Environment

Temperatures in the Barents Sea have been high since 2004, largely due to increased inflow of warm water masses from the Norwegian Sea. An increase from 2011 to 2012 was observed in near-bottom temperatures primarily in the north and northwestern parts of the Barents Sea, but also in the southwest where temperatures at the bottom were the highest on record since 1951 (pers. comm. R. Ingvaldsen/A. Trofimov).

Shrimps were only caught in areas where bottom temperatures were above 0°C. Highest shrimp densities were observed between zero and 4°C, while the limit of their upper temperature preference appears to lie at about 6-8°C. The warming of the western Barents Sea coincides with the shift in shrimp distribution eastwards (Fig. 13), thus temperature is probably a factor in explaining the observed change in spatial distribution.

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Table 1. Number of hauls, estimated total biomass, density and coefficient of variation (CV) by stratum and year (for further details on stratification see Fig. 3).

Stratum			2004				2005				2006				2007				2008				2009				2010				2011				2012			
Name	Depth	Area	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV
(code)	(m)	(kkm^2)	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%
1.1	0-100	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	79	2	85	2	83	2	15	3	0	0	0	6	119	2	99	8	11	0	107
1.2	100-200	40	17	5943	150	49	16	6182	156	58	9	7005	177	74	10	3390	86	49	16	4102	104	45	4	9370	236	84	12	479	12	53	18	10860	274	86	21	18108	457	76
1.3	200-300	20	26	15311	776	26	24	18859	956	29	25	15539	788	21	20	11765	596	25	22	13862	703	39	4	6231	316	55	5	14927	757	68	12	13734	696	28	12	13852	702	43
1.4	300-400	10	30	12721	1316	24	23	10148	1050	22	25	5200	538	14	22	11870	1228	28	16	4571	473	35	5	10597	1096	63	3	17462	1806	116	11	12905	1335	29	13	8996	931	26
1.5	400-500	7	17	4327	608	28	18	4164	585	22	14	4254	598	23	11	5370	755	23	7	5248	738	38	3	7846	1103	58	2	3235	455	113	8	4766	670	20	12	4710	662	24
1.6	500-600	6	8	1696	293	25	10	3018	522	40	6	2035	352	42	6	1670	289	39	7	1234	213	50	1	657	114	85	0	0	0	0	1	1108	191	85	6	439	76	35
2.1	0-100	41	1	0	0	0	1	0	0	0	2	0	0	0	2	0	0	0	1	0	0	0	1	74	2	85	4	0	0	0	4	0	0	0	7	30	1	83
2.2	100-200	153	25	3260	21	50	16	7383	48	36	23	1512	10	51	24	2399	16	39	16	2038	13	59	21	1610	11	31	0	2801	18	0	34	6115	40	50	34	4003	26	38
2.3	200-300	230	34	150557	654	21	69	153493	667	14	69	242092	1051	16	67	168005	730	18	62	116391	505	21	43	74409	323	20	50	150357	653	18	46	113698	494	14	59	114279	496	17
2.4	300-400	119	35	81699	685	18	56	95050	797	12	63	143045	1199	13	67	130541	1094	9	29	65561	550	16	25	39008	327	16	26	55106	462	17	25	60257	505	20	23	82715	693	15
2.5	400-500	43	7	29982	698	22	28	18289	426	11	27	24034	559	11	27	30831	717	13	15	11106	258	15	11	20794	484	20	11	15684	365	15	14	12054	280	18	15	17096	398	16
2.6	500-600	2	0	0	0	0	1	783	490	85	1	29	18	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	363	227	85	1	0	0	0
3.1	0-100	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	265	10	85	2	0	0	0	3	34	1	77
3.2	100-200	61	23	4054	66	86	9	222	4	59	12	584	10	37	13	489	8	72	5	870	14	72	4	295	5	38	8	62	1	67	13	21767	356	74	14	1549	25	47
3.3	200-300	83	50	12389	150	31	23	136155	1646	98	20	33372	404	48	33	25034	303	26	14	15580	188	44	9	39901	482	47	18	25710	311	73	21	17690	214	32	27	18030	218	26
3.4	300-400	35	50	44459	1270	35	25	29951	855	59	34	22089	631	32	35	26424	755	24	14	12890	368	37	10	19272	550	27	10	18419	526	40	14	40996	1171	43	16	24588	702	34
3.5	400-500	12	8	5501	458	45	3	62	5	31	2	2749	229	46	4	8491	707	107	3	1381	115	57	3	2546	212	31	1	9058	754	85	1	164	14	85	4	5634	469	95
3.6	500-600	2	4	372	179	74	3	306	147	120	1	686	330	85	6	276	133	52	2	6	3	141	2	338	163	50	0	0	0	0	3	434	208	99	3	1345	646	69
4.1	0-100	13	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	1	787	62	85	1	12	1	85	0	0	0	0	1	23	2	85	0	0	0	0
4.2	100-200	75	2	564	8	126	10	462	6	75	6	218	3	70	11	0	0	0	11	1473	20	83	11	3331	44	65	11	1021	14	45	14	2171	29	41	18	28403	379	65
4.3	200-300	119	15	22445	188	40	25	33658	282	35	11	72137	604	26	26	28109	236	39	21	55148	462	22	28	179029	1500	20	25	181147	1518	20	25	155111	1300	23	28	168543	1412	19
4.4	300-400	34	8	13596	398	43	7	12213	357	38	5	12211	357	79	9	9586	280	43	8	21229	621	30	7	12464	365	33	7	40390	1181	34	12	33948	993	33	8	26762	783	71
5.1	0-100	188	14	0	0	0	28	44	0	82	54	2	0	101	35	0	0	0	27	0	0	0	3	100	1	42	26	424	2	78	25	9	0	44	26	16	0	102
5.2	100-200	71	15	962	14	94	19	2567	36	52	23	0	0	0	20	1327	19	40	19	820	12	76	11	1055	15	51	20	3487	49	58	21	447	6	76	18	900	13	61
5.3	200-300	40	11	38646	963	13	11	33817	843	26	22	37384	932	20	18	25316	631	20	22	19033	474	18	11	22939	572	35	11	46218	1152	28	9	23519	586	28	13	39731	990	22
5.4	300-400	25	8	8596	343	29	7	12009	480	30	7	18413	736	37	12	16229	649	18	10	15382	615	32	6	21988	879	24	6	10524	421	51	7	15086	603	24	7	22659	905	20
Total	0-600	1504	408	457078	304	0 9	433	578834	385	0 23	461	644592	0 429	8	480	507122	337	7	349	368792	245	0 9	226	473949	315	10	260	596776	397	9	348	547344	364	9	396	602433	401	8

Continues next page.....

Table 1. Continued from previous page

Stratum			2013				2014				2015			
Name	Depth	Area	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV	Hauls	Biom.	Dens.	CV
(code)	(m)	(kkm^2)	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%	(#)	tons	kg/km^2	%
1.1	0-100	50	8	77	2	107	2	0	0	0	3	0	0	0
1.2	100-200	40	26	7708	194	55	12	7664	193	79	9	1683	42	91
1.3	200-300	20	13	11453	581	29	7	7381	374	41	7	11099	563	48
1.4	300-400	10	12	6469	669	24	6	15050	1557	93	4	5030	520	28
1.5	400-500	7	12	4162	585	26	7	3408	479	29	3	3073	432	36
1.6	500-600	6	3	1485	257	57	4	1901	329	28	4	2356	407	61
2.1	0-100	41	7	0	0	0	3	0	0	0	3	108	3	118
2.2	100-200	153	30	2552	17	54	29	2794	18	46	31	2389	16	50
2.3	200-300	230	60	123561	537	16	58	86397	375	15	54	99992	434	14
2.4	300-400	119	27	81481	683	13	21	53177	446	16	21	60353	506	19
2.5	400-500	43	12	20454	476	13	11	11815	275	24	11	17896	416	19
2.6	500-600	2	0	0	0	0	0	0	0	0	0	0	0	0
3.1	0-100	26	3	2	0	122	0	6042	231	0	1	6405	245	0
3.2	100-200	61	16	3126	51	41	0	14118	231	0	8	252	4	67
3.3	200-300	83	28	35982	435	33	0	19121	231	0	22	22241	269	43
3.4	300-400	35	14	21474	613	25	0	8097	231	0	13	16485	471	56
3.5	400-500	12	5	6946	578	84	0	2776	231	0	1	2943	245	14
3.6	500-600	2	0	0	0	0	0	481	231	0	0	510	245	0
4.1	0-100	13	0	0	0	0	1	2921	231	0	0	3096	245	0
4.2	100-200	75	6	24059	321	82	16	9283	124	101	15	9840	131	18
4.3	200-300	119	19	75453	632	17	31	78327	656	13	26	83027	696	21
4.4	300-400	34	7	17514	512	35	7	19152	560	40	8	20301	594	11
5.1	0-100	188	31	80	0	54	27	143	1	89	24	152	1	6
5.2	100-200	71	19	1575	22	56	19	638	9	48	20	676	10	48
5.3	200-300	40	10	46068	1148	23	10	16848	420	28	10	17859	445	26
5.4	300-400	25	5	19970	798	46	8	12467	498	24	3	13215	528	24
Total	0-600	1504	373	511649	340	7	279	380001	253	7	301	400980	0 267	7

Table 2. Indices (ktons) of annual mean total biomass from survey 1: The Norwegian shrimp survey 1982-2004; survey 2: The Russian shrimp survey 1984-2002 and 2005; and survey 3: The joint Norwegian-Russian ecosystem survey since 2004.

Year	Survey 1	Survey 2	Survey 3
1982	327	-	-
1983	429	-	-
1984	471	661	-
1985	246	468	-
1986	166	399	-
1987	146	346	-
1988	181	233	-
1989	216	603	-
1990	262	1028	-
1991	321	1192	-
1992	239	876	-
1993	233	892	-
1994	161	404	-
1995	193	248	-
1996	276	441	-
1997	300	765	-
1998	341	576	-
1999	316	966	-
2000	247	800	-
2001	184	468	-
2002	196	980	-
2003	212	-	-
2004	151	-	365
2005	-	656	527
2006	-	-	605
2007	-	-	474
2008	-	-	354
2009	-	-	424
2010	-	-	597
2011	-	-	547
2012	-	-	602
2013	-	-	512
2014	-	-	380
2015			401

Table 3. Estimated biomass, abundance and mean weight of the total and fishable (>16 mm cpl) stock and of recruits (13-16 mm cpl). Demografic data since 2009 not analysed.

	Biomass (ktons)				Abundance (#10^9)			Mean weight (g)		
Year	Total	Fishable	Recruites	CV (%)	Total	Fishable	Recruites	Total	Fishable	Recruites
2004	365	261	97	9	98	47	44	3.73	5.54	2.21
2005	527	446	78	22	121	85	33	4.35	5.26	2.38
2006	605	517	85	8	135	97	35	4.48	5.34	2.45
2007	474	426	46	7	90	71	17	5.27	6.02	2.67
2008	354	317	34	9	69	52	14	5.14	6.05	2.46
2009	424	343	-	10	-	-	-	-	-	-
2010	597	482	-	9	-	-	-	-	-	-
2011	547	442	-	9	-	-	-	-	-	-
2012	602	487	-	8	-	-	-	-	-	-
2013	512	413	-	7	-	-	-	-	-	-
2014	380	307	-	7						
2015	401	324	-	7						

Table 4. Estimating biomass in the unsurveyed area 3 in 2014: estimates of shrimp biomass density in the total area (Dens. Total), in stratum 3 (Dens. Str. 3) and their rations. Lower table gives Average, standard deviation and coefficient of variation of the values marked in green in the upper table.

	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Dens. Total	0.204	0.261	0.372	0.283	0.220	0.253	0.370	0.317	0.375	0.302
Dens.str. 3	0.295	0.658	0.271	0.267	0.140	0.239	0.244	0.370	0.234	0.308
Ratio	1.441	2.525	0.728	0.943	0.634	0.944	0.661	1.166	0.623	1.020

Average	0.883
SD	0.059
CV	7 %

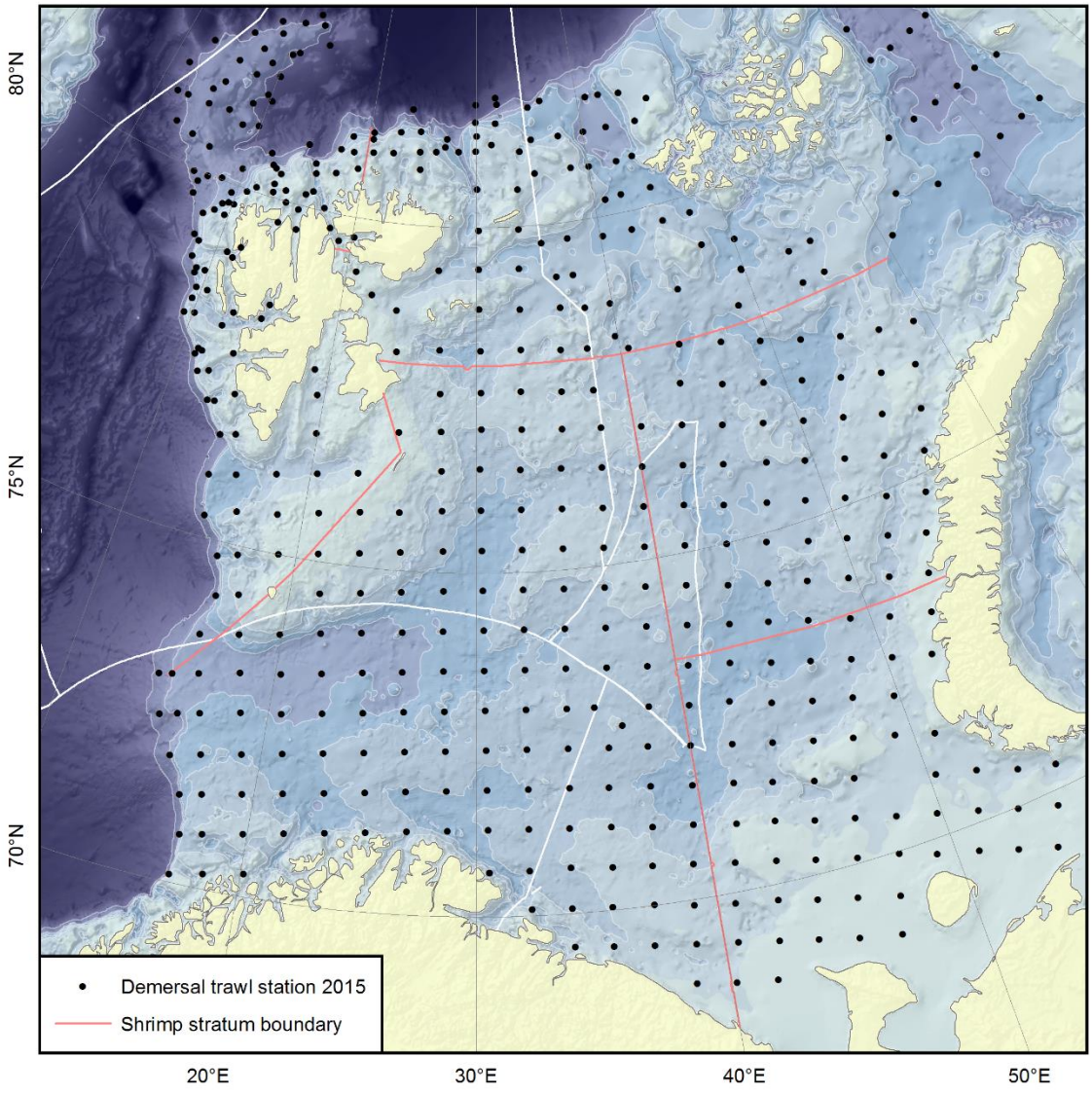

Fig. 1. Sampling locations of the 2015 Norwegian-Russian ecosystem survey in the Barents Sea.

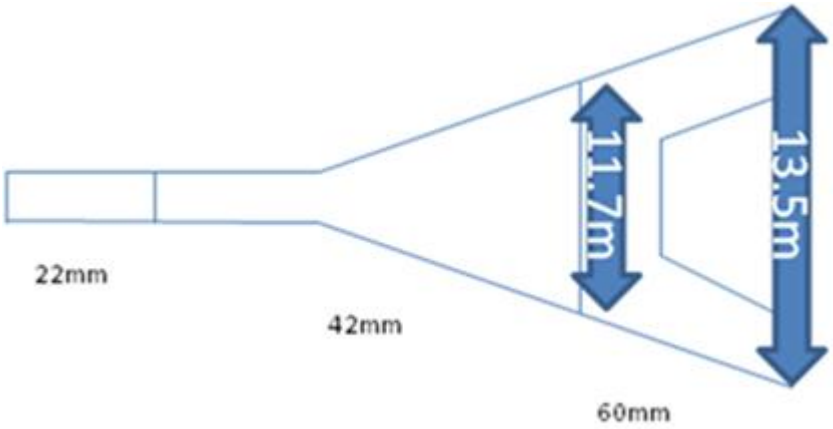

Fig. 2. Schematic drawing of a Campelen 1800 survey bottom trawl with 22 mm mesh size in the cod-end, 42 mm in the mid-section, and 60 mm in the trawl opening. The width of the trawl opening (11.7 m) and wing spread (13.5 m) is also indicated.

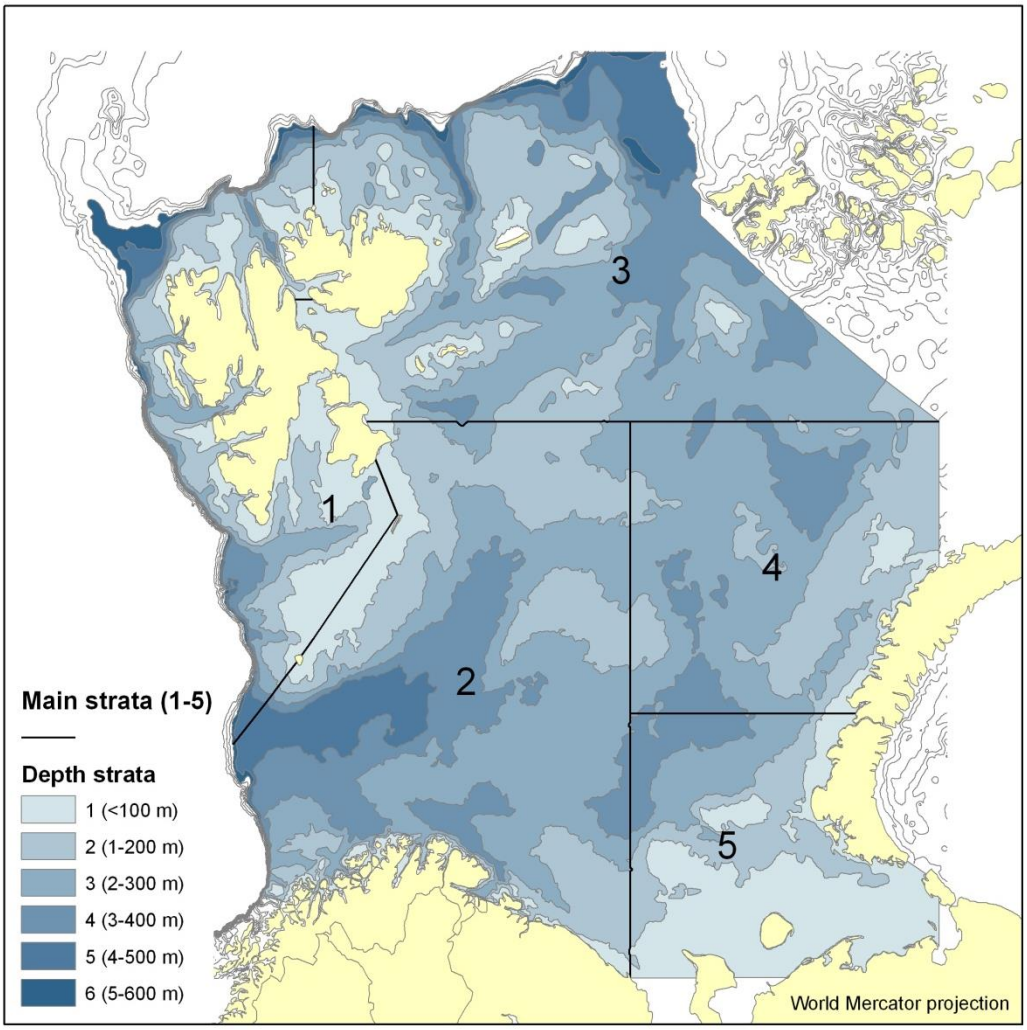

Fig. 3. The survey stratification scheme. Each stratum is given a code for [main area]+[depth stratum within]; e.g. [1.3] indicates main stratum = 1 and depth stratum = 3, i.e. covering depths from 201 to 300 m (see also Table 1).

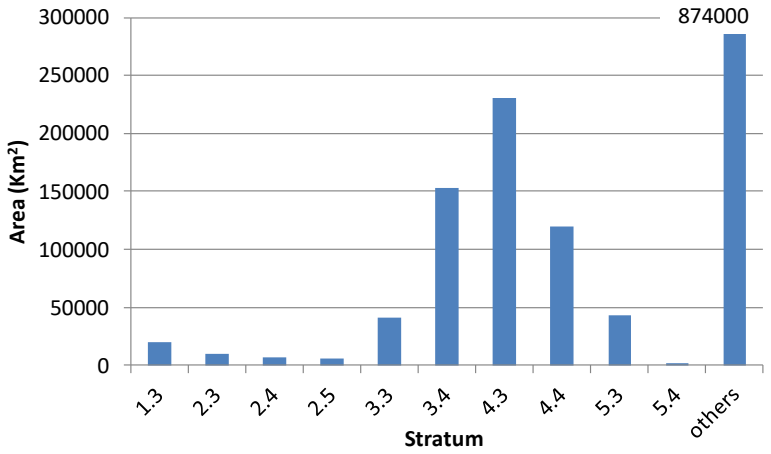

Fig. 4. Areas of the 10 most important strata (code: see Table 1 and Fig. 3 for definition).

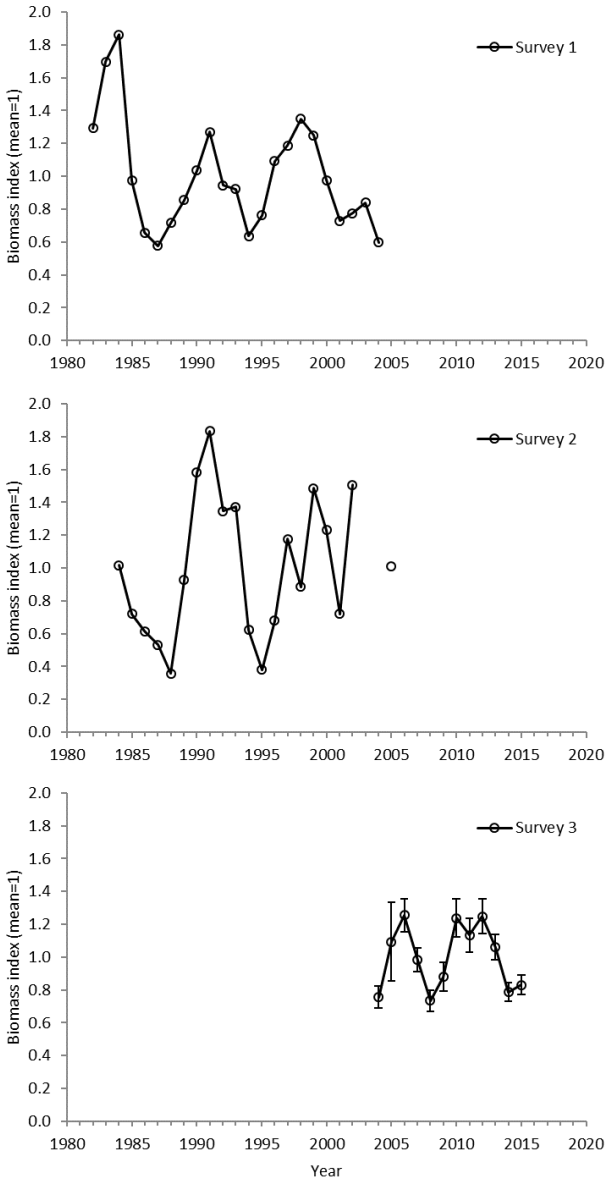

Fig. 5. Indices of annual mean biomass from survey 1: The Norwegian shrimp survey 1982-2004; survey 2: The Russian shrimp survey 1984-2002 and 2005; and survey 3: The joint Norwegian-Russian ecosystem survey.

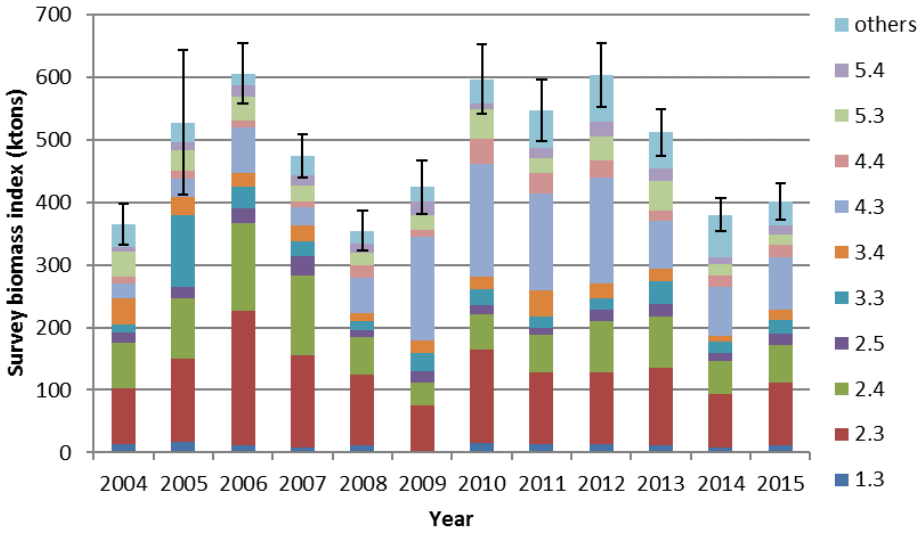

Fig. 6. Estimated mean index of biomass by year and sub-strata (code: see Table 1 and Fig. 3 for definition). Error bars indicate +/- one Standard Error of the overall estimate.

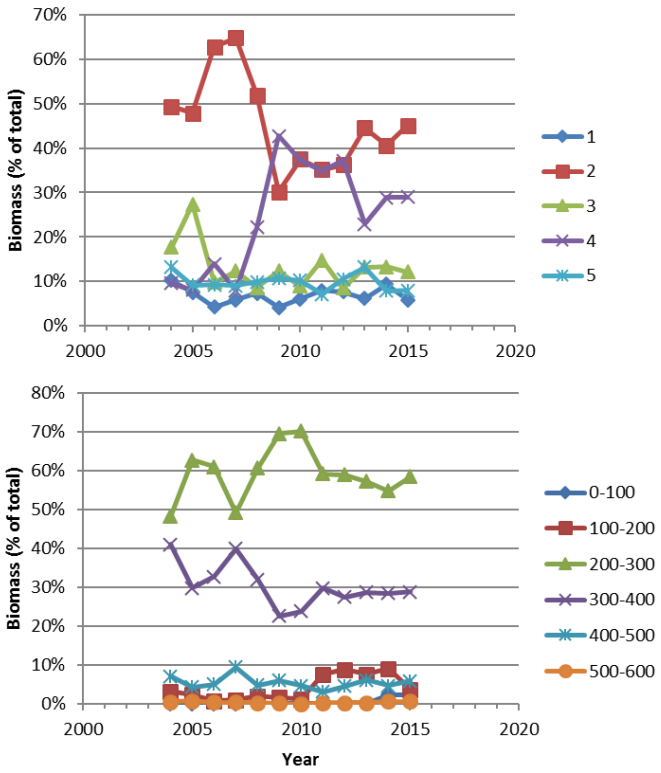

Fig. 7. Percentage of total biomass. *Upper*: by main strata (see fig 3). *Bottom*: by depth strata.

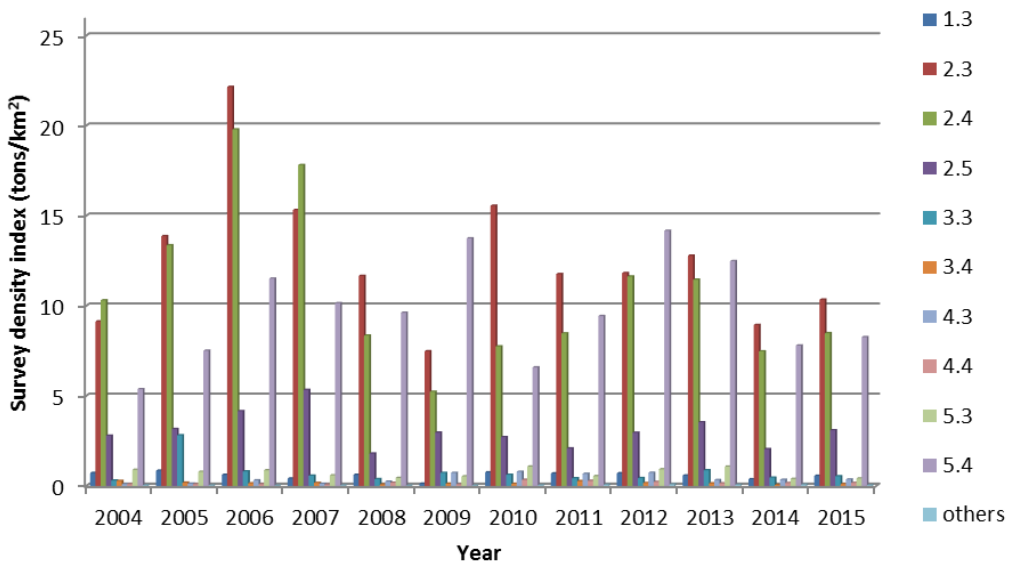

Fig. 8. Estimated mean biomass density by year and strata (code: see Table 1 and Fig. 3 for definition)

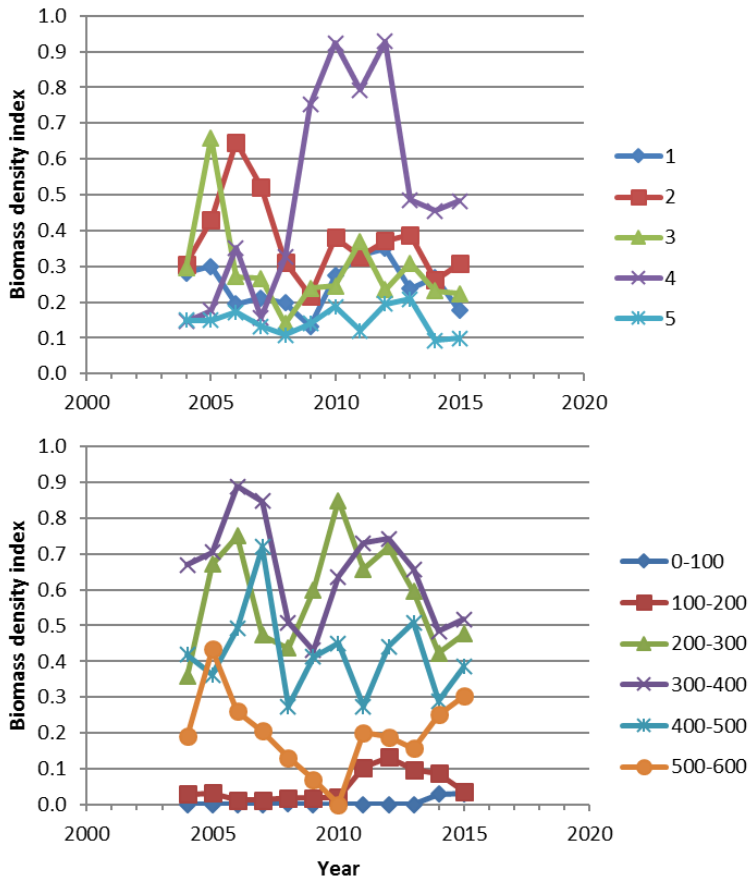

Fig. 9. Estimated mean biomass density index. *Upper*: by main strata (see fig 3). *Bottom*: by depth strata.

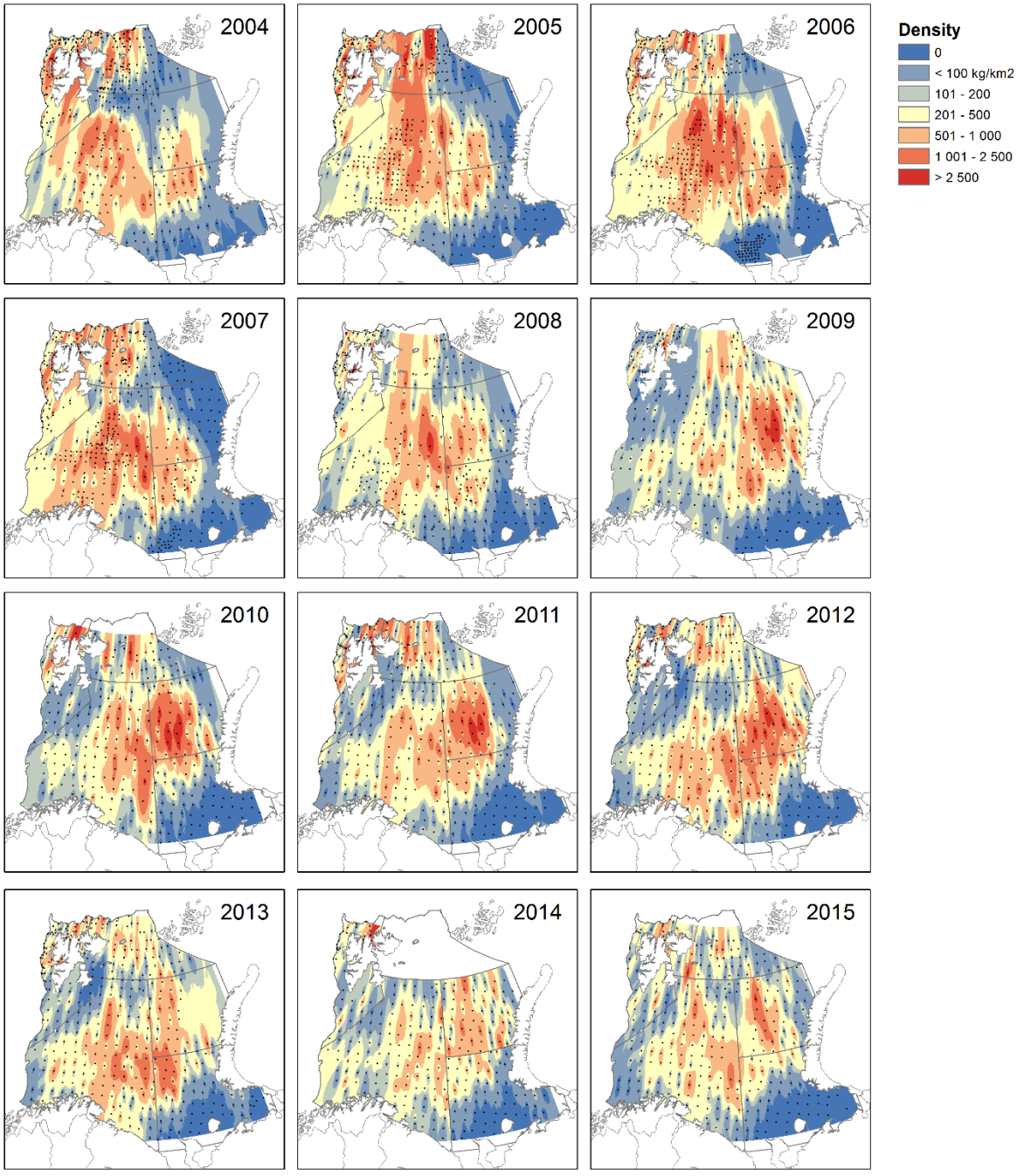

Fig. 10. Shrimp density by year from *inverse distance weighted* interpolation (e.g. Fisher *et al.*, 1987) between trawl stations (black dots) (Europe Albers Equal Area Conic projection).

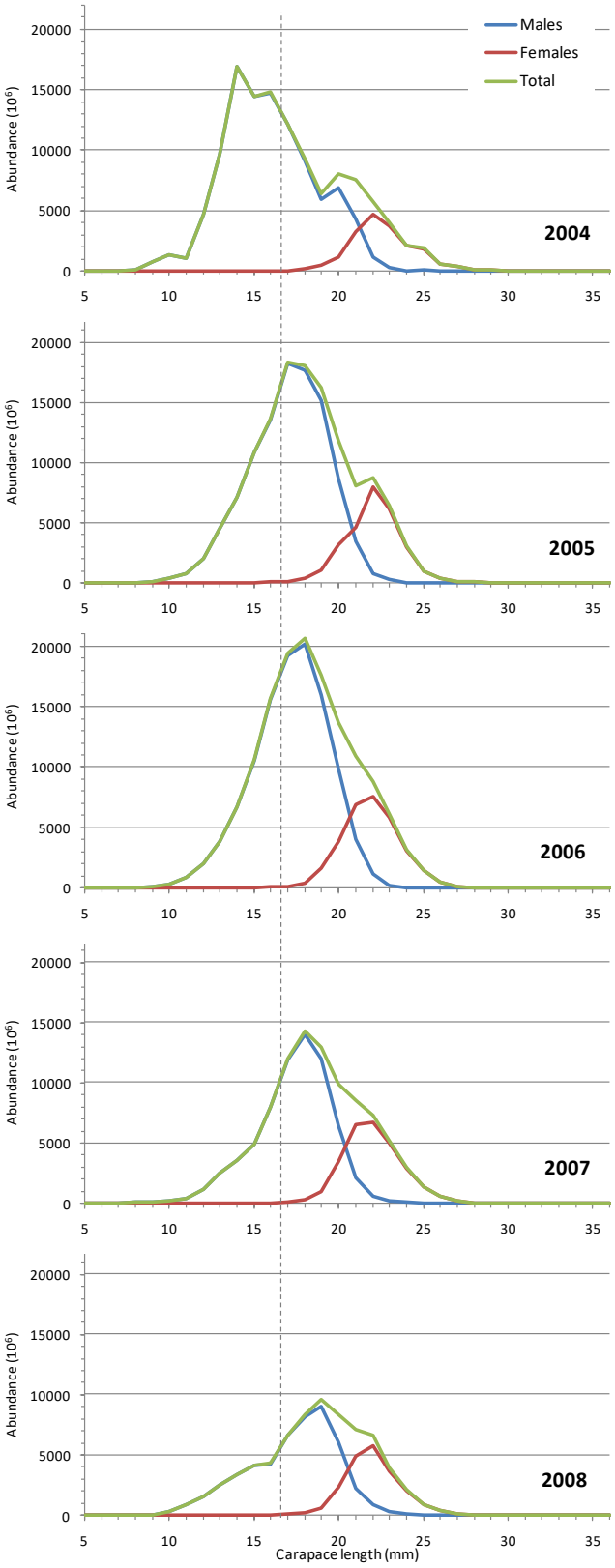

Fig. 11. Shrimp in the Barents Sea: overall size distribution of males, females and total 2004-2008. (No analyses since 2009)

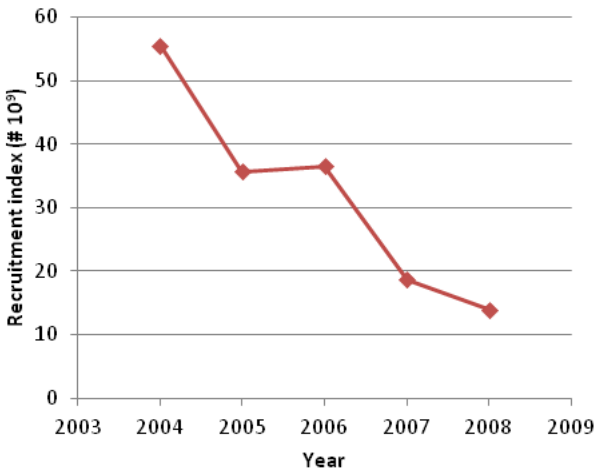

Fig. 12. Index of recruitment: estimated mean abundance of shrimp at size 13-16 mm cpl 2004-2008. (No analyses since 2009).

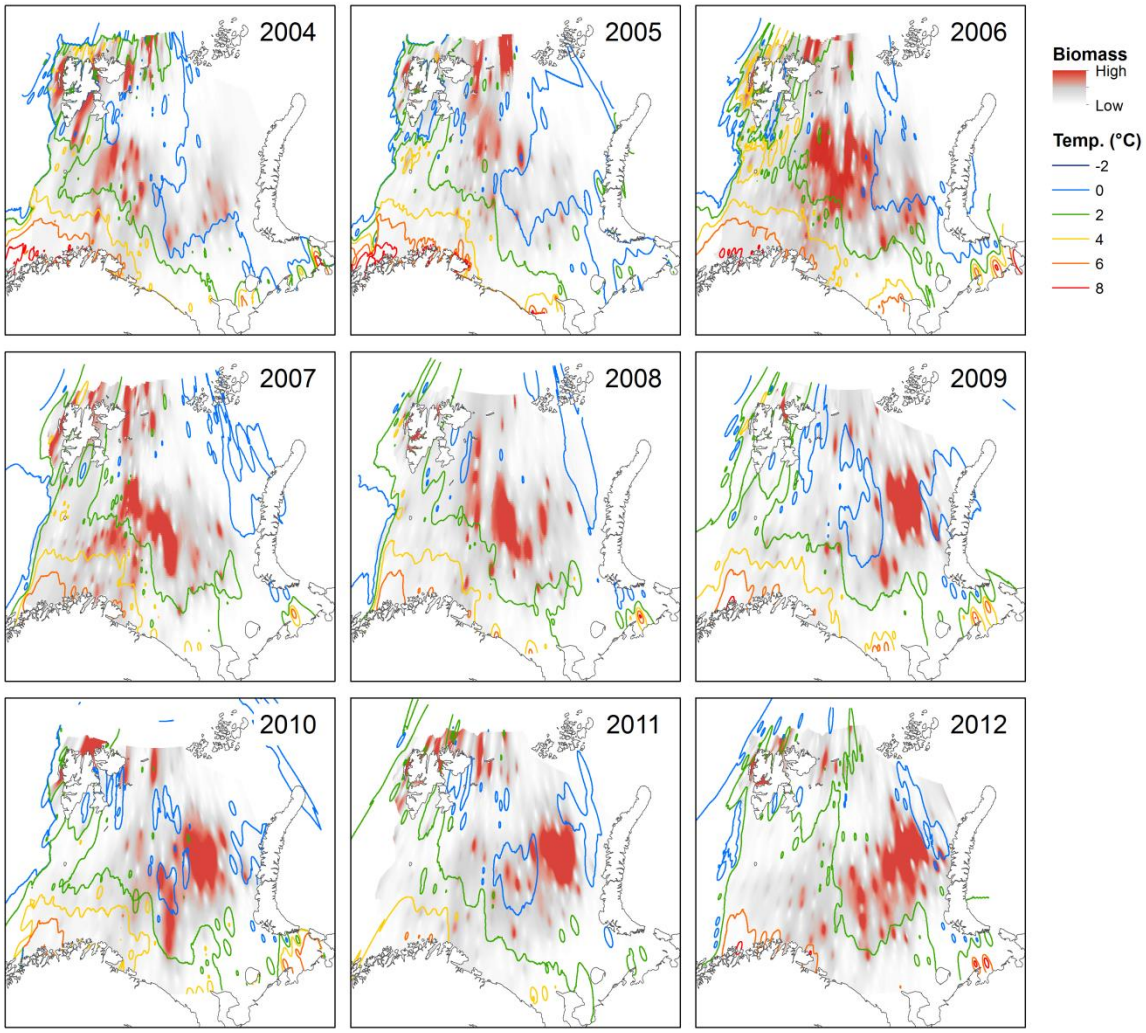

Fig. 13. Bottom temperature contour overlaid shrimp density distributions (see Fig. 7) from ecosystem surveys since 2004 (no data from Russian EEZ in 2013, data 2014-15 not available).