First assessment of biomass and abundance of cephalopods *Rossia palpebrosa* and *Gonatus fabricii* in the Barents Sea

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Studies on the quantitative distribution of cephalopods in the Arctic are limited, and almost completely absent for the Barents Sea. It is known that the most abundant cephalopods in the Arctic are Rossia palpebrosa *and* Gonatus fabricii. *Their biomass and abundance have been assessed for the first time in the Barents Sea and adjacent waters. The maximum biomass of* R. palpebrosa *in the Barents Sea was 6.216–6.454 thousand tonnes with an abundance of 521.5 million specimens. Increased densities of biomass were annually registered in the north-eastern parts of the Barents Sea. The maximum biomass of* G. fabricii *in the Barents Sea was 24.797 thousand tonnes with an abundance of 1.705 billion specimens. The areas with increased density of biomass (higher than 100 kg km^{-2}) and abundance (more than 10,000 specimens km^{-2}) were concentrated in deep-water troughs in the marginal parts of the Barents Sea and in adjacent deep-water areas. The biomass and abundance of* R. palpebrosa *and* G. fabricii *in the Barents Sea were much lower than those of major taxa of invertebrates and fish and than those of cephalopods in other parts of the World Ocean. It has been suggested that the importance of cephalopods in the Arctic ecosystems, at least in terms of quantitative distribution, could be somewhat lower than in the Antarctic or the tropics. Despite the impact of ongoing warming of the Arctic on the distribution of cephalopods being described repeatedly already, no impact of the current year's climate on the studied species was found. The only exception was the abundance of* R. palpebrosa, *which correlated with the current year's climate conditions.*

Keywords: Biomass assessment, abundance assessment, Cephalopoda, *Rossia palpebrosa*, *Gonatus fabricii*, Barents Sea

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INTRODUCTION

Cephalopods are one of the most important groups in marine ecosystems (Boyle & Rodhouse, 2005; Jereb *et al.*, 2010). Their biomass and abundance can reach very high values in the north Pacific, south-western Atlantic and some other parts of the World Ocean (Pierce & Guerra, 1994; Boyle & Rodhouse, 2005). The significance of this group among the commercial invertebrates is great: the annual worldwide catch of cephalopods can exceed 4 million tonnes (Jereb *et al.*, 2010; Arkhipkin *et al.*, 2015). It is obvious that studies of biomass and abundance stock assessment should precede commercial fisheries.

Recently the Arctic has attracted the attention of scientists from all over the world especially because of the ongoing climate changes there (Walther *et al.*, 2002; Jakobsen & Ozhigin, 2012). The environmental conditions of the Arctic, such as the low temperatures and salinity (mean surface values are −1°C and 30°/$_{oo}$, respectively), are unfavourable for cephalopods, so only a few species constantly live there (Treshnikov, 1985; Nesis, 2001; Golikov *et al.*, 2013b). According to Nesis (1987, 2001), and our own data, the

most abundant cephalopod species in the Arctic are *Rossia palpebrosa* Owen, 1834 (Sepiolida) and *Gonatus fabricii* (Lichtenstein, 1818) (Teuthida). Bobtail squid, *R. palpebrosa*, is the most abundant species of demersal cephalopods and has a nektobenthic lifestyle (Nesis, 2001; Golikov *et al.*, 2014). There are only scarce data on the quantitative distribution of *R. palpebrosa*: its densities of biomass and/or abundance are known for the Spitsbergen area (Lubin & Sabirov, 2007), along the southern shore of Greenland (Frandsen & Wieland, 2004) and for the western part of the Baffin Sea (Treble, 2007). In the two latter sources density has been calculated for all of the Arctic species of the *Rossia* genus, and denoted as *Rossia* sp. Thus, the importance of this species for the ecosystem is not fully understood, and there are no fisheries of this species. The squid *G. fabricii* is the only pelagic species of Arctic cephalopods (Nesis, 1987, 2001). It is a very important food source for whales, pinnipeds and fish in the Arctic, but no fisheries are currently known (Bjørke & Gjøsaeter, 1998; Bjørke, 2001; Nesis, 2001; Roper *et al.*, 2010). Due to its importance for the food chains, there are more data on the quantitative distribution of *G. fabricii*, but most of these are only for certain parts of the Greenland area, the Greenland and Norwegian Seas (Nesis, 1965; Kristensen, 1977, 1984; Wiborg, 1979, 1980, 1982; Wiborg *et al.*, 1982, 1984; Sennikov *et al.*, 1989; Piatkowski & Wieland, 1993; Frandsen & Wieland, 2004; Treble, 2007).

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These researches contain only the densities of biomass and/or abundance. The density is expressed in specimens or g (kg) per time period, and the data are usually obtained using different catching gear in each case. It all makes it hard to obtain a comprehensive picture. The total stock of *G. fabricii* biomass in the Norwegian and Greenland Seas with the Harstad pelagic trawl was assessed by Bjørke (1995, 2001), Bjørke & Gjøsaeter (1998) and Dalpadado *et al.* (1998). The biomass of *G. fabricii* from these papers was extrapolated to the Barents Sea by Dommasnes *et al.* (2001) and Blanchard *et al.* (2002). The Barents Sea differs from the Norwegian and Greenland Seas greatly due to its oceanographic conditions and bottom relief: it is much shallower, with the main part being occupied by a shelf, and it is located further into the Arctic, at a much greater distance from the reach of the warm Atlantic water masses (Boitsov *et al.*, 2012; Jakobsen & Ozhigin, 2012). This all makes the mentioned extrapolations of *G. fabricii* biomass stock values from the Norwegian and Greenland Seas (Dommasnes *et al.*, 2001; Blanchard *et al.*, 2002) incorrect.

As the studies on the quantitative distribution of cephalopods in the Arctic are rather limited, and almost completely absent for the Barents Sea, the main goal of our paper was to assess the biomass and abundance of the two most plentiful species of cephalopods in the Barents Sea. Also, an additional goal was to check whether recent climate changes in the Arctic influence the mentioned cephalopod species' biomass and abundance there.

MATERIALS AND METHODS

Sampling and material analysis

Samples of *R. palpebrosa* collected during the period 2007–2012 and of *G. fabricii* collected between 2009 and 2012 in the Barents Sea and adjacent parts of the Kara, Norwegian and Greenland Seas and of the Central Polar Basin were analysed. The borders of the studied area are $\sim 68°42'N–82°31'N$ and $4°45'E–76°29'E$ (Figure 1). The samples were obtained annually in August to September during cruises of RV 'Vilnus', 'Smolensk' and 'F. Nansen' of the Polar Research Institute of Marine Fisheries and Oceanography and RV 'G.O. Sars', 'Johan Hjort', 'Jan Mayen' (later 'Helmer Hanssen') and 'Christina E' of the Institute of Marine Research.

In total, 871 specimens of *R. palpebrosa* and 699 specimens of *G. fabricii* were studied. We only had biomass and quantity, no other data, for 183 specimens of *R. palpebrosa* and 231 specimens of *G. fabricii*; for all others additional biological analysis was performed: mantle length (ML) was measured, and sex and maturity stage were assigned. Maturity stages of *G. fabricii* were assigned using the scales for squids (Lipinski & Underhill, 1995; Nigmatullin *et al.*, 2003). The scale of maturity stages used for *R. palpebrosa* was developed (Golikov *et al.*, 2013a) based on the mentioned cephalopod scales.

Rossia palpebrosa were sampled with bottom trawl gear. *Gonatus fabricii* were sampled with the same gear and pelagic trawl gear. The bottom trawl gear was a Campelen 1800 shrimp bottom trawl with rockhopper gear. The mesh size was 80 mm (stretched) in the front and 16–22 mm at the cod end. The horizontal opening was 20 m, and the vertical opening was 5 m (McCallum & Walsh, 1997; Johannesen *et al.*, 2012). The pelagic trawl gear used was a Harstad trawl with a 20×20 m mouth opening; the mesh sizes of the panels ranged from 100 mm in the first panel to 30 mm in the last. The cod end consists of three nets of different mesh sizes, with the smallest being 7 mm (Eriksen *et al.*, 2011; Johannesen *et al.*, 2012).

Data analysis

The relations of sampled biomass/abundance and total biomass/abundance at the point of sampling are shown by the following equations (Walsh, 1996):

$$b = fqB_c,$$
$$n = fqN_c,$$

where f – fishing effort, q – catchability coefficient, b – sampled biomass, B_c – total biomass at the point of sampling, n – sampled abundance and N_c – total abundance at the point of sampling. The fishing effort value (f) is not usually used in scientific surveys because the trawls used are standardized by using the same tow duration and the catches obtained are recalculated for the same towing time (Walsh, 1996). The standard towing time for the bottom trawl gear was 15 min at 3 knots, equivalent to a towing area of about 25,000 m². If the towing duration was different, the biomass and abundance of catch were recalculated for the mentioned standard square. The pelagic trawl was towed for a standard time of 60 min (20 min each at the surface, 20 m and 40 m, and additional tows deeper if there were hydro-acoustic registrations of 0-group fish farther down). This method is detailed in Eriksen *et al.* (2011). For convenient comparison with the bottom trawl gear we recalculated the catch for 15 min also, equivalent to a towing area of about 18,000 m². There are no catchability coefficients (q) for Arctic cephalopods in the literature. Nonetheless, we presume it is necessary to use a catchability coefficient, as its efficacy was proved by modern papers on cephalopod stock assessment (Pierce & Guerra, 1994; Walsh, 1996; Shuntov & Bocharov, 2003) as well as classical works on fisheries biology (Baranov, 1918; Gulland, 1964). There are no catchability coefficients for bobtail squids at all in the literature. With our bottom gear, Campelen 1800, the only catchability coefficients known for the invertebrates are the ones from Lubin (2006, 2010): $q = 0.002$ for all macrobenthic (the ones bigger than a few millimetres in size) invertebrates and $q = 0.28$ for nektobenthic shrimp, *Pandalus borealis* Krøyer, 1838. The latter one was used in calculations for *R. palpebrosa*. Catchability coefficients for boreopacific Gonatidae from Shuntov & Bocharov (2003) were used in calculations for *G. fabricii*: $q = 0.01$ if ML < 40 mm, $q = 0.05$ if ML 41–80 mm, $q = 0.1$ if ML > 80 mm. With the mentioned coefficients, the total biomass at the point of sampling with bottom and pelagic trawl gears was respectively:

$$B_c = \frac{b \times 10^6}{q \times S_C \times 10^{-3}},$$

$$B_c = \frac{b \times 10^6}{q \times S_H \times 10^{-3}},$$

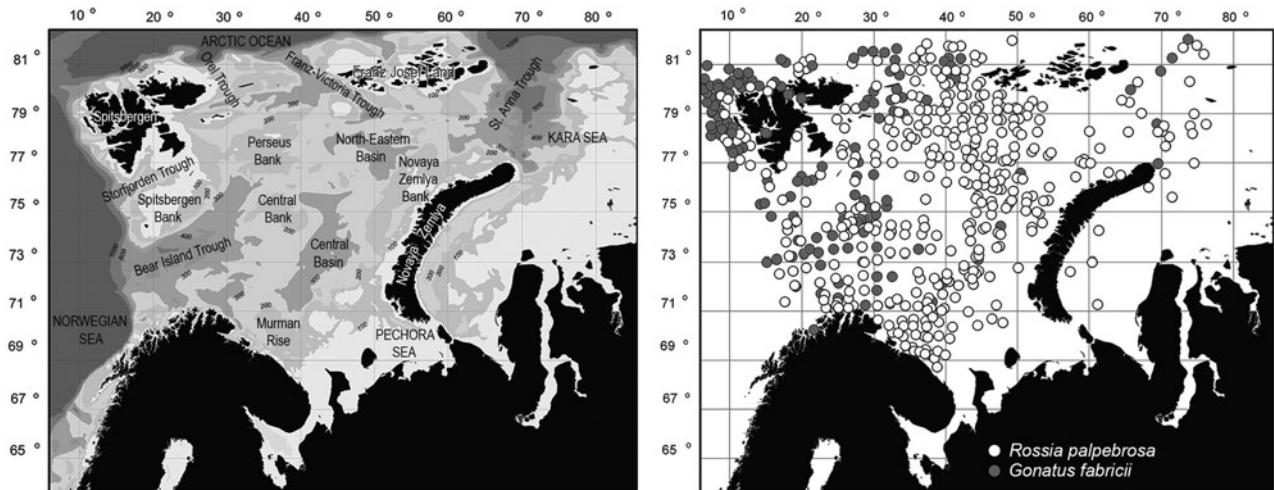where b – sampled biomass (g per 15 min towing), B_c – total

Fig. 1. Study area in the Barents Sea and adjacent waters with main bottom relief elements, depths and positions of trawl catches.

biomass at the point of sampling (kg km^{-2}), q – catchability coefficient, S_C – standard area of bottom towing (25,000 m²), S_H – standard area of pelagic towing (18,000 m²), 10^6 – coefficient to convert m² to km² and 10^{-3} – coefficient to convert g to kg. In this case, total abundance at the point of sampling with bottom and pelagic trawl gears was respectively:

$$N_c = \frac{n \times 10^6}{q \times S_C},$$

$$N_c = \frac{n \times 10^6}{q \times S_H},$$

where n – sampled abundance (specimens per 15 min towing), N_c – total abundance at the point of sampling (specimens km^{-2}), q – catchability coefficient, S_C – standard area of bottom towing (25,000 m²), S_H – standard area of pelagic towing (18,000 m²) and 10^6 – coefficient to convert m² to km².

Isoline maps of biomass and abundance distribution were plotted based on the obtained data using the method of kriging (Cressie, 1990; Levin, 1994). Total stocks of biomass and abundance for the studied area were calculated as:

$$B = \Sigma s_i B_i,$$

$$N = \Sigma s_i N_i,$$

where s_i – cohort area (km²), B_i – mean biomass inside the cohort (kg km^{-2}), B – total stock of biomass (kg), N_i – mean abundance inside the cohort (specimens km^{-2}) and N – total stock of abundance (specimens). The obtained values of biomass and abundance were extrapolated to the whole area of the species' range in the studied sea.

It was decided to check whether the climate conditions of the Barents Sea influence the quantitative character of the cephalopod distribution there. This is especially timely at present bearing in mind the ongoing climate changes, which have led to the warming of the Arctic (Walther et al., 2002; Jakobsen & Ozhigin, 2012). As has already been demonstrated, the warming has caused the appearance of new boreal-subtropical cephalopod species in the Arctic (Sabirov et al., 2009, 2012; Golikov et al., 2013b, 2014). The mean inter-

annual values of the Barents Sea water temperatures in the different layers were taken from Jakobsen & Ozhigin (2012). The climate index of the Barents Sea was used as a measure of its climate conditions. It is a complex indicator that is calculated based on many environmental factors (Boitsov et al., 2012). The exact values of the climate index of the Barents Sea for the studied years were provided to us by one of the authors of this term (Trofimov, personal communication). We had only a limited series of annual data, six years for R. palpebrosa and four for G. fabricii, and they do not fit normal distribution. So, the best correlation coefficient to use in that situation was Kendall's tau correlation. Also ANOVA with a posteriori Tukey's honestly significant difference test was used to estimate the significance level of mean value differences (Hammer & Harper, 2006; Zar, 2010).

Surfer 8.0, MapViewer 7.1 (Golden Software) and AreaS 2.1 (Permyakov, http://www.ssaa.ru) were used for map creation and post-processing; Statistica 10 (Statsoft), PAST 2.17c (Hammer & Harper, http://folk.oio.no/ohammer/past) and MS Excel 2003, 2010 were used for statistical analyses and other calculations.

RESULTS

Rossia palpebrosa

Interannual changes in the biomass and abundance of R. palpebrosa were characterized by quite low values. The maximum difference in the interannual biomass during the study period was about 1.5 times, and in abundance about two times. The maximum biomass in the Barents Sea was detected in 2007, 2010 and 2012, when it exceeded 6 thousand tonnes. The minimum biomass, about 4 thousand tonnes, was detected in 2009 (Figures 2 & 3, Table 1). The maximum abundance in the Barents Sea was detected in 2012, when it exceeded 520 million specimens, and this was much lower in all the other studied years. The minimum abundance was detected in 2009, the same as the minimum biomass, and reached about 250 million specimens. So the biomass and abundance of R. palpebrosa changed inter-annually with no significant
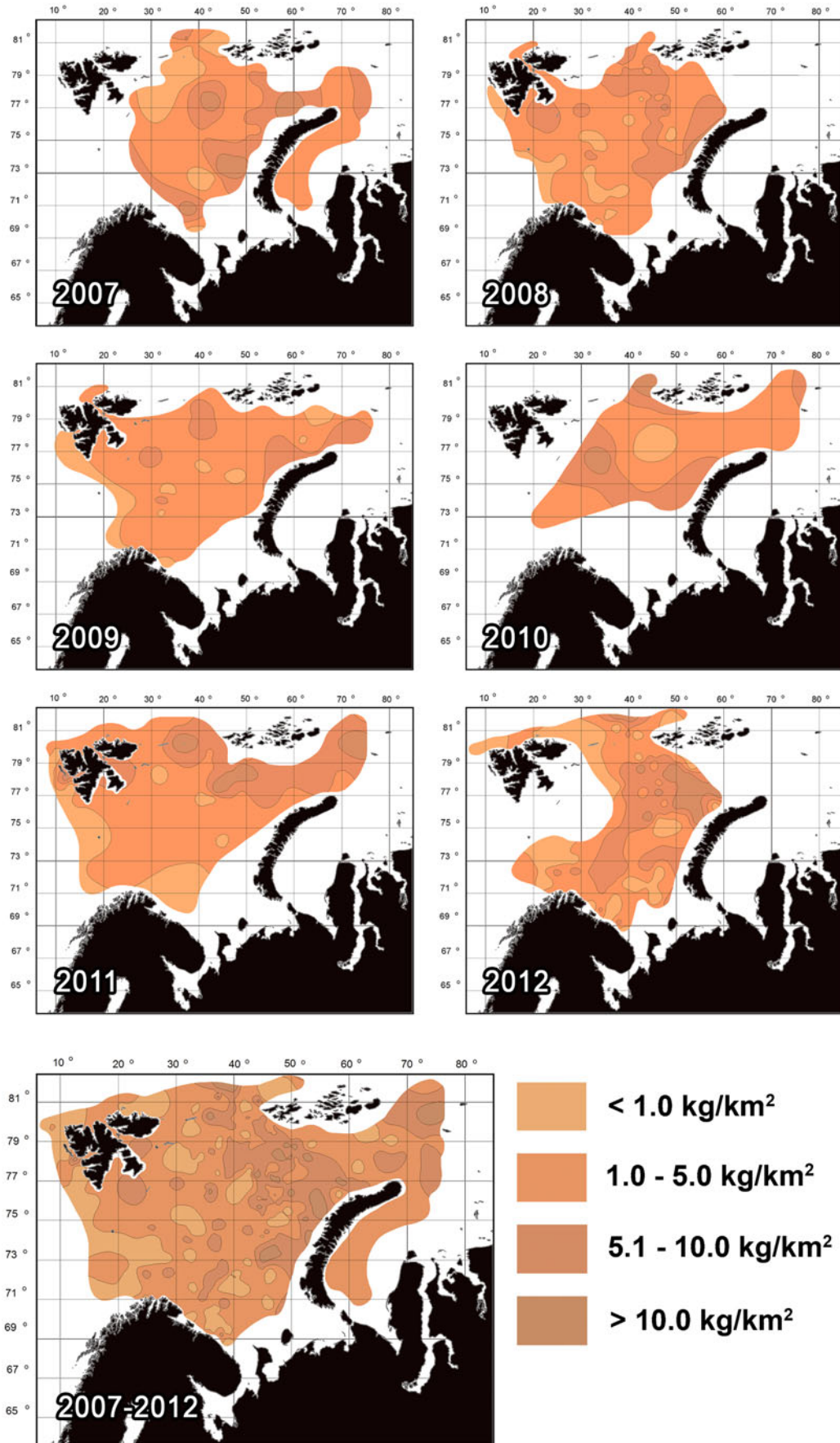
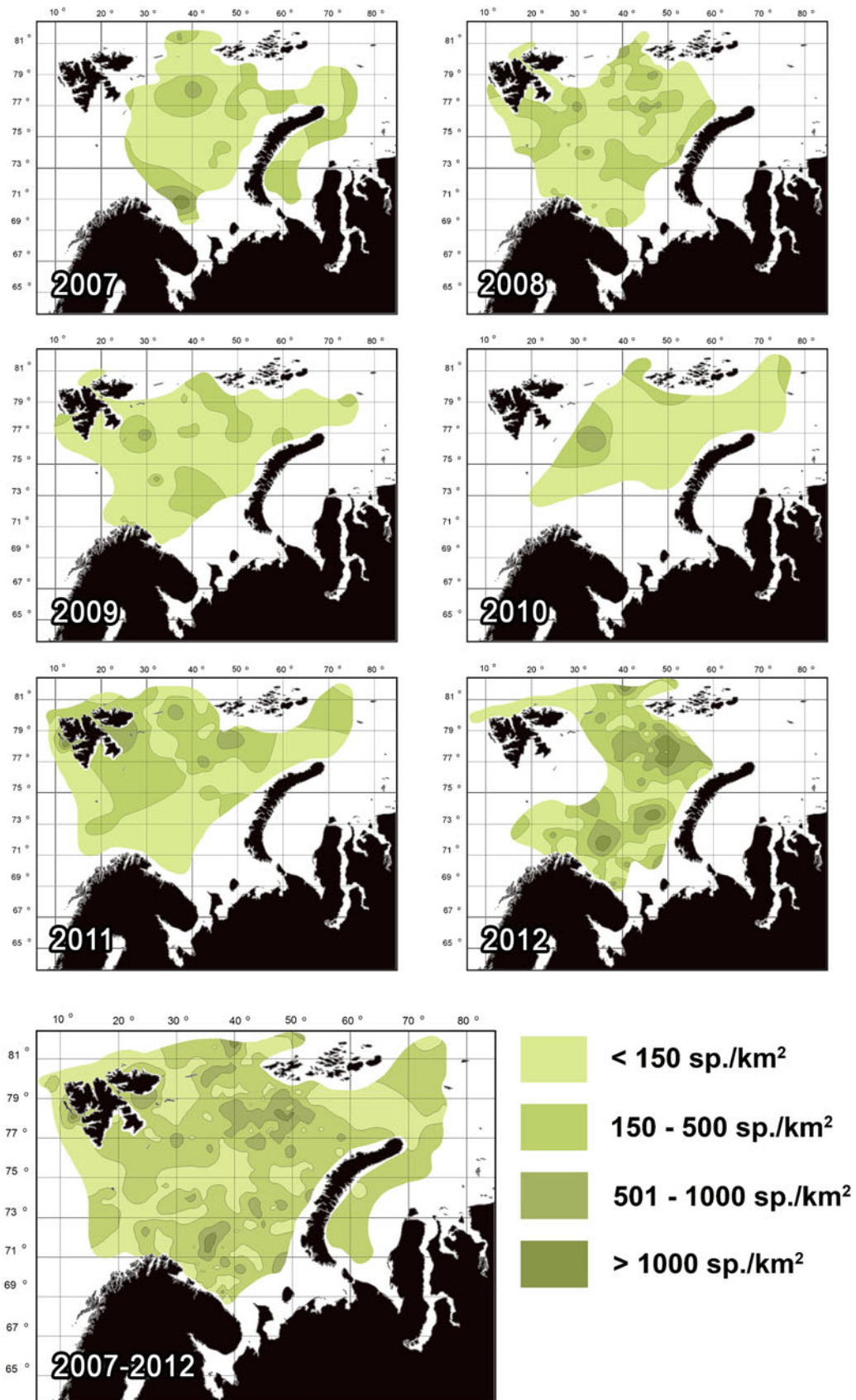**Fig. 2.** Biomass of *Rossia palpebrosa* in the Barents Sea and adjacent waters.

Fig. 3. Abundance of *Rossia palpebrosa* in the Barents Sea and adjacent waters.

Table 1. Biomass and abundance of *Rossia palpebrosa* in the Barents Sea and western part of the Kara Sea.

Year	Climate index of the Barents Sea[a]	Biomass, tonnes		Abundance, million specimens	
		the Barents Sea[b]	Western part of the Kara Sea[b]	the Barents Sea[b]	Western part of the Kara Sea[b]
2007	5.97	6454.36	1054.23	304.90	75.93
2008	3.64	5161.91	–	287.24	–
2009	3.01	4010.06	1596.21	246.54	50.56
2010	3.21	6025.69	996.06	252.17	49.93
2011	4.00	5260.18	2821.65	342.28	76.82
2012	7.00	6216.29	–	521.47	–
2007–2012[c]	–	5873.85	1617.04	417.83	63.31

[a]Values of the Barents Sea climate index were taken from Boitsov *et al.*, 2012, and Trofimov, personal communication.
[b]Extrapolated for the whole area of the species' range in the sea;
[c]Mean data for all studied years.

relationship to each other, and Kendall's tau correlation between them (t = 0.466634, *P* = 0.1886) was not significant.

The areas with the highest density values of biomass (10.1–30.0 kg km^{-2}) were located mostly in the northern and eastern parts of the Barents Sea: from the Franz Victoria Trough to the North-Eastern Basin, North-Eastern Plateau, Novaya Zemlya Bank (except for the most shallow areas with depths of less than 100 m) and the northern part of the Central Basin (Figure 2). In addition, the maximum densities of biomass were recorded in the southern and south-eastern parts of the Central Basin in 2007, and at Isfjorden to the west of Spitsbergen in 2011. According to our data, most of the areas with maximum biomass lay within isotherms of −1.0 to 0.0°C at depths of 150–400 m. The areas with the minimum density of biomass (lower than 1.0 kg km^{-2}) were concentrated mostly in the western and occasionally in the south-eastern parts of the Barents Sea. They annually

Table 2. Biomass and abundance of *Gonatus fabricii* in the Barents Sea and western part of the Kara Sea.

Year	Climate index of the Barents Sea[a]	Biomass, tonnes		Abundance, million specimens	
		Barents Sea[b]	Western part of the Kara Sea[b]	Barents Sea[b]	Western part of the Kara Sea[b]
2009	3.01	5962.22	621.84	1397.39	96.05
2010	3.21	10,029.58	2185.17	1586.41	716.94
2011	4.00	24,796.79	4610.99	1705.00	96.09
2012	7.00	23,692.77	–	1551.40	–
2009–2012[c]	–	16,120.34	2472.67	1657.68	303.02

[a]Values of the Barents Sea climate index were taken from Boitsov *et al.*, 2012, and Trofimov, personal communication.
[b]Extrapolated for the whole area of the species' range in the sea;
[c]Mean data for all studied years.

represented up to 25% of the studied area. The patterns of abundance density distribution were quite similar to those described above. The areas with the maximum density of abundance (1–2 thousand specimens km^{-2}) were located in 2007 and 2011–2012 from the Franz Victoria Trough to the North-Eastern Basin, in the southern part of the Central Basin and at Isfjorden to the west of Spitsbergen. The depths were 200–450 m and the mean inter-annual bottom temperatures varied from −1.0 to +3.0°C. The biggest part of the studied area was usually characterized by low densities of abundance, with fewer than 150 specimens km^{-2} (Figure 3). Correlation analysis of the biomass and abundance of *R. palpebrosa* in relation to the climate index of the Barents Sea for the current and previous years showed that Kendall's tau correlation was not significant in all cases, except for abundance *vs* ongoing year's climate index, when *t* = 0.866667, *P* = 0.0411.

Data for the western part of the Kara Sea are still rather scarce and therefore showed only an approximate pattern. The maximum biomass there, about 2.8 thousand tonnes, was detected in 2011. The minimum biomass, less than 1 thousand tonnes, was detected in 2010 (Figures 2 & 3, Table 1). The maximum abundance in the Kara Sea was detected in 2007 and 2011, when it exceeded 75 million specimens, and it was 1.5 times less in all the other studied years, at about 50 million specimens (Table 1). The area with the maximum density of biomass with average values of abundance was located in St. Anna's Trough.

Gonatus fabricii

Interannual changes in the biomass of *G. fabricii* were much bigger than in previous species. The maximum biomass in the Barents Sea was detected in 2011, when it exceeded 24.5 thousand tonnes, while the minimum biomass of about 6 thousand tonnes was detected in 2009. At the same time, inter-annual differences in abundance varied slightly, from about 1.4 billion to more than 1.7 billion specimens (Table 2). A significant Kendall's tau correlation was not observed between biomass and abundance with the climate index of the Barents Sea for current and previous years. Data on the quantitative distribution of *G. fabricii* in St. Anna's Trough in the Kara Sea are still limited, and therefore showed only an approximate pattern. Biomass varied from about 0.6 thousand tonnes to about 4.6 thousand tonnes with abundance from about 100 million up to more than 700 million specimens (Table 2).

In most parts of the Barents Sea the density of biomass was about 10.0 kg km^{-2} with abundance of about 1 thousand specimens km^{-2} (Figures 4 & 5). The areas with high density of biomass (more than 100 kg km^{-2}) and abundance (more than 10 thousand specimens km^{-2}) were concentrated in deep-water troughs and trenches in the marginal parts of the Barents Sea and in adjacent deep-water areas: the north-eastern part of the Greenland Sea, the Bear Island Trough and its border with the Norwegian Sea, the Franz Victoria Trough and Orel Trough in the Barents Sea, and St. Anna's Trough in the Kara Sea (Figures 4 & 5). The first two areas were located above the big depths and mostly consisted of aggregations from epipelagic immature squids (maturity stages I–II) and meso-/bathypelagic maturing ones (late II and III–IV maturity stages). The maximum values of biomass and abundance were recorded in the upper
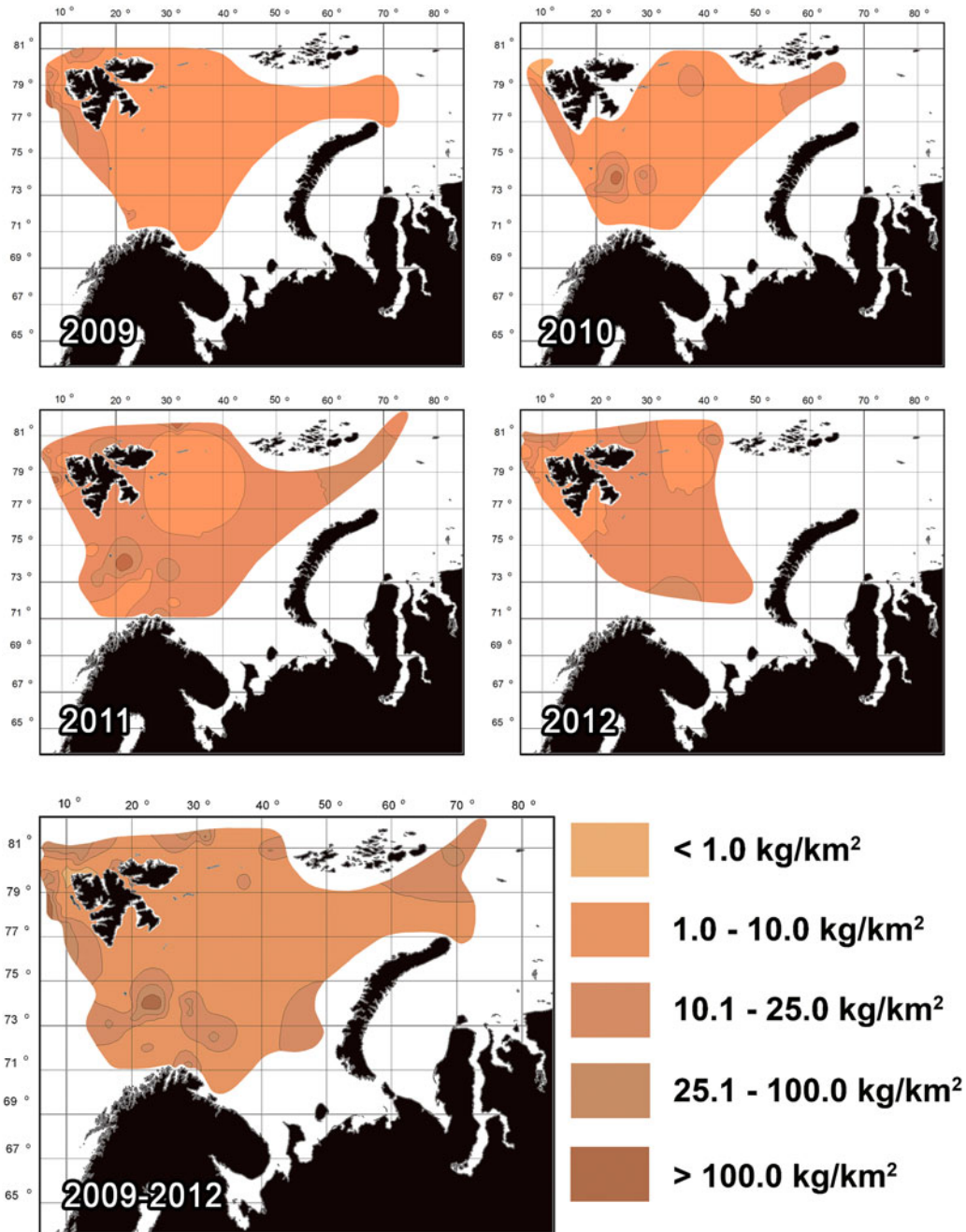
Fig. 4. Biomass of *Gonatus fabricii* in the Barents Sea and adjacent waters.

100-metre layer in the north-eastern part of the Greenland Sea, where the density of epipelagic immature squids reached 279 kg km^{-2} and 96 thousand specimens km^{-2}. The mean ML of the squids in the area was 19 $\pm$ 3.3 mm. In the western part of the Barents Sea, the mean ML was significantly ($P = 0.0047$) higher and reached 47 $\pm$ 1.9 mm. In the eastern part of the Barents Sea and the western part of the Kara Sea, including two remaining areas with high densities of biomass and abundance, only meso-/bathypelagic specimens were sampled. In the eastern part of the Barents Sea, the mean ML increased up to 83 $\pm$ 4.4 mm ($P = 0.0036$) and reached 91 $\pm$ 2.8 mm ($P = 0.0042$) in St. Anna's Trough in the Kara Sea.

DISCUSSION

Species biomass and abundance in the Barents Sea

Values of biomass and abundance densities of *R. palpebrosa* assessed in the Spitsbergen area, along the southern shore of Greenland and in the western part of the Baffin Sea (Frandsen & Wieland, 2004; Lubin & Sabirov, 2007; Treble, 2007) were lower than our mean values of densities (4.06 $\pm$ 0.22 kg km^{-2} and 278 $\pm$ 13.07 specimens km^{-2}) in the Barents Sea. Thus the environmental conditions in the north-eastern parts of the Barents Sea with mean inter-annual
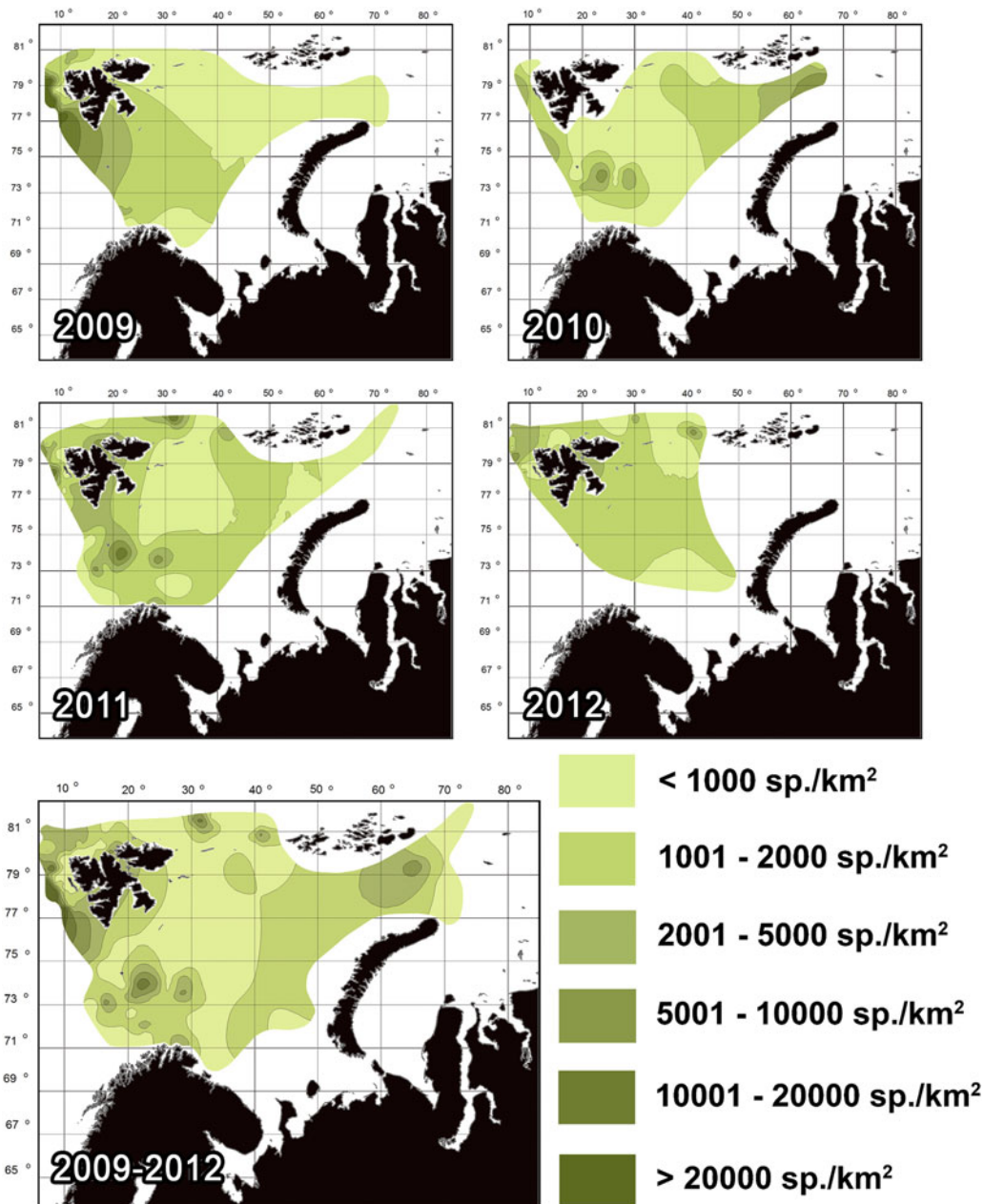
Fig. 5. Abundance of *Gonatus fabricii* in the Barents Sea and adjacent waters.

temperatures ranging from −1.0 to 0.0°C at depths of 200–400 m fitted most perfectly for *R. palpebrosa* to reach maximum concentrations. In other parts of the World Ocean, the density of Sepiolida abundance was assessed in the Mediterranean Sea (Lefkaditou *et al.*, 2001; Lefkaditou & Kaspiris, 2005) and Porcupine Seabight and Porcupine Abyssal Plain in the north-east Atlantic (Collins *et al.*, 2001). Different bottom trawls without any catchability coefficients shown (most probably they are different) were used in those reports, resulting in lower values than ours from the Barents Sea. The most abundant species in the north-eastern Atlantic were *Sepiola atlantica* Orbigny, 1839 and *Sepietta oweniana* (Orbigny, 1839) with an abundance of up to 116 specimens km^{-2} (Collins *et al.*, 2001) and *S. oweniana* in the Mediterranean Sea with an abundance of up to 44 specimens per unit effort (Lefkaditou *et al.*, 2001; Lefkaditou & Kaspiris, 2005).

Macrozoobenthos of the Barents Sea as a whole is quite well studied, often with usage of Campelen 1800 bottom trawl gear (reviews: Wassmann *et al.*, 2006; Jakobsen & Ozhigin, 2012). In the north-eastern parts of the sea, where the biggest aggregations of *R. palpebrosa* were found, inter-annual values of total macrozoobenthos density of biomass are usually below average, which is about 147 tonnes km^{-2}. Moreover, the main areas with maximum densities of macro-zoobenthos biomass were mostly located in the southern, south-eastern and north-central parts of the Barents Sea, where the biomass density of *R. palpebrosa* did not reach more than 5.5–7 kg km^{-2}, which is 5.5–6 times below the maximum assessed values. This all shows that even if *R. palpebrosa* is quite abundant for the bobtail squid compared with other studies (Collins *et al.*, 2001; Lefkaditou *et al.*, 2001; Frandsen & Wieland, 2004; Lefkaditou & Kaspiris, 2005; Lubin & Sabirov, 2007; Treble, 2007), it is definitely

not very abundant in comparison to the major taxa of benthic invertebrates of the Barents Sea (reviews: Wassmann *et al.*, 2006; Jakobsen & Ozhigin, 2012).

The total stock of *G. fabricii* biomass in the Norwegian and Greenland Seas based on Harstad pelagic trawl catches was previously assessed as 1.5 million tonnes of epipelagic immature squids (Bjørke, 2001), 2 million tonnes of epipelagic immature squids and 6.4 million tonnes of meso-/bathypelagic squids with a mean interannual density of 2.63 tonnes km^{-2} (Bjørke, 1995; Bjørke & Gjøsaeter, 1998) or 4.1 million tonnes (Dalpadado *et al.*, 1998). All the mentioned assessments are much bigger than our values for the Barents Sea. The main reason for the difference is that the bottom relief of the Norwegian and Greenland Seas mostly consists of deep-water trenches and troughs, where four out of seven *G. fabricii* reproductive spots are located (Bjørke, 1995, 2001). The squid is supposed to live in these seas throughout its life cycle (Bjørke, 1995, 2001; Arkhipkin & Bjørke, 2000). The Barents Sea in its marginal westernmost part is comparable to the Norwegian and Greenland Seas due to its primary production values (Sakshaug *et al.*, 2009; Dalpadado *et al.*, 2014). In these parts of the Barents Sea the areas with maximum densities of *G. fabricii* are located. Considerable densities of abundance of immature epipelagic stages of this squid in the border area of the Barents, Norwegian and Greenland Seas have been known since the 1980s (Wiborg, 1979, 1980, 1982; Wiborg *et al.*, 1982, 1984; Sennikov *et al.*, 1989). But the rest, the main part of the Barents Sea, its shelf, is far less productive (Sakshaug *et al.*, 2009; Dalpadado *et al.*, 2014). The values of *G. fabricii* biomass and abundance there were low and aggregations were formed only in deep-water troughs and trenches in the marginal parts of the Barents Sea and in adjacent deep-water areas. The aggregations found on the western side of the studied area were much bigger. The density of *G. fabricii* biomass and abundance in Greenland waters outside the Greenland Sea (Nesis, 1965; Kristensen, 1977, 1984; Piatkowski & Wieland, 1993; Frandsen & Wieland, 2004) is less than in aggregations we found, but bigger than mean values from the main shelf parts of the Barents Sea. The biomass of scyphozoan jellyfish and major commercial fish species in the Barents Sea was also assessed with Harstad pelagic trawl gear (Eriksen *et al.*, 2011, 2012; Jakobsen & Ozhigin, 2012; Johannesen *et al.*, 2012). Mostly the values varied from 900 thousand tonnes up to several million tonnes and more. The stock of *G. fabricii* biomass we found was comparable only to lumpfish, *Cyclopterus lumpus* L., 1758, which had a mean interannual biomass in the Barents Sea of about 48 thousand tonnes (Eriksen *et al.*, 2014).

So our estimated values of the biomass and abundance of *R. palpebrosa* and *G. fabricii* are much lower than those of major groups of pelagic and bottom fishes and invertebrates in the Barents Sea (Wassmann *et al.*, 2006; Eriksen *et al.*, 2011, 2012; Jakobsen & Ozhigin, 2012; Johannesen *et al.*, 2012). It was concluded that even if *R. palpebrosa* and *G. fabricii* are quite abundant in the Barents Sea, they obviously are not the major components of the Barents Sea ecosystems according to their biomass and abundance. Thus, it was suggested that the importance of cephalopods in the Arctic ecosystems, at least in terms of quantitative distribution, could be somewhat lower than in the Antarctic (Collins & Rodhouse, 2006) or tropical parts of the World Ocean (Jereb *et al.*, 2010).
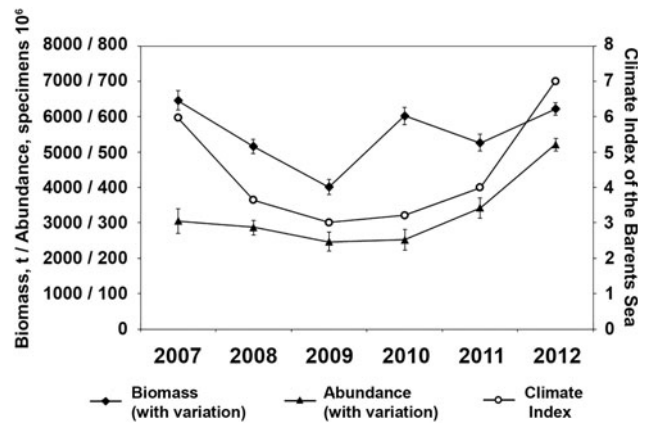

Fig. 6. Biomass and abundance of *Rossia palpebrosa* in the Barents Sea in relation to its climate index.

Influence of climate change

The impact of the ongoing warming of the Arctic (Walther *et al.*, 2002; Boitsov *et al.*, 2012) on the distribution of cephalopods there has already been recorded repeatedly: the range of *G. fabricii* has increased and three new boreal-subtropical species have appeared in the Arctic (Sabirov *et al.*, 2009, 2012; Golikov *et al.*, 2013b, 2014). The previously known border of the *G. fabricii* range was at ∼40°E in the Barents Sea (Kristensen, 1984; Gardiner & Dick, 2010; Roper *et al.*, 2010). It was established that its range has increased to the whole eastern part of the Barents Sea, except the margins of Novaya Zemlya Bank, and the western part of the Kara Sea, St. Anna's Trough (Golikov *et al.*, 2012, 2013b). Its quantity inside the new parts of the range is low, except inside the deep-water trenches and troughs in the north-eastern part (Figures 4 & 5). But does climate change really affect the abundance and biomass values of *R. palpebrosa* and *G. fabricii* in the Barents Sea? It is unknown what the values of studied species' biomass and abundance in the Barents Sea were before climate change. The climate index of the Barents Sea was higher than the average values throughout the studied period, 2007–2012 (Boitsov *et al.*, 2012; Trofimov, personal communication), which means that these were warm years. The warmest of them were 2007 and 2012, the same years as when the maximum biomass of *R. palpebrosa* was recorded (Figure 6). Also, there was a point of view that the biomass of some benthos taxa in the Barents Sea can 'respond' to changes in climate conditions with a lag of up to a few years, according to the taxa's life cycle duration (Matishov *et al.*, 2012). To check this assumption with our species we performed a correlation analysis of the biomass and abundance of the studied cephalopod species in relation to the climate index of the Barents Sea for the current and previous years, because the exact duration of the species' life cycles in the Barents Sea is not known for sure; it is only known for other close species or areas (von Boletzky & von Boletzky, 1973; Arkhipkin, 1995; Arkhipkin & Bjørke, 2000). The climate of the current and previous years showed no significant impact on the biomass and abundance of the studied species in the correlation analysis performed. The only exception was the abundance of *R. palpebrosa*, which correlated with the current year's climate conditions. This is also noticeable from the

graph presented (Figure 6). This could be explained by suggesting greater survival of juveniles due to larger amounts of food available to them, because during the warmer years the total macrozoobenthos biomass is usually bigger (Jakobsen & Ozhigin, 2012).

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