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Trap survey on the fishing boats as a promising way to stock assessment of Red King Crab (*Paralithodes camtschaticus)* in the Barents Sea

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Red king crab was introduced into the Barents Sea by Soviet scientists in the 1960s and has developed a largest population in the world. Data on the stock abundance of red king crab in Russian waters of the Barents Sea are principally obtained via stratified, random trawl surveys, which have been conducted annually in August or September since 1997. Trawl surveys are generally associated with depths of more than 60-100 m in areas with predominately soft bottom. In 2004, commercial crab fisheries began in Russian Exclusive Economic zone. In 2003-2006, six diving surveys and four trap surveys were conducted by Russian Federal Research Institute of Fisheries and Oceanography (VNIRO) in cooperation with fishermen. Abundance in different sex-size groups was assessed on results of the trap surveys and with the help of new software developed in VNIRO and based on different mathematic methods for interpolation of spatially distributed data (Kriking, spline-approximation, the Delaunay triangulation and the Voronoi diagram). The resultant maps of the red king crab distribution were analyzed. Based on the results of trap and diving surveys in 2003-2005, the king crab stock in Russian waters of the Barents Sea was estimated to be approximately $100x10^6$ individuals, including $40\text{-}50x10^6$ mature crabs. It is shown that autumnal trawl surveys (August-September) led to a systematic error in the king crab stock assessment.

Key words: red king crab, survey, stock assessment, trap, fisheries, Kriking, approximation.

Commercial fishery for red king crab was started in Russian Exclusive Economic zone of the Barents Sea in 2004. This species was introduced into the Barents Sea in the 1960s and its successful acclimatization resulted in formation of a largest population in the world. The current area of the king crab distribution spreads from the Lofoten Islands in the west to Kolguev Island in the east (Kuzmin & Gudimova, 2002), and from the northern part of the Voronka in the White Sea (66°18'N) (Sokolov & Milutin, 2006) in the south to 72° N in the north.

Abundance surveys in the northern waters have been performed annually since 1993 (The Red King crab…, 2003). The Polar Research Institute of Fisheries and Oceanography (PNIRO) makes trawl surveys with the aim to give quantitative assessment of the king crab stocks in Russian waters. The abundance indices calculated with the trawl survey results showed a steady growth of the population during the entire period of studies, including 2003.

However, in 2004 and in 2005, the PNIRO trawl surveys revealed a decline in number of male individuals in the fishing stock while the catch per effort increased. Because of the high value of the king crab fishery, in 2003-2006, the status of the king crab stock was assessed using trap surveys. The essential feature of these large-scale studies was close cooperation with fishermen who made considerable contributions to organizing and financing the research activities.

MATERIALS AND METHODS

Assessment of the king crab abundance and distribution was made aboard fishing vessels during the trap surveys in 2003-2006. In 2003 (Oct.14 – Dec.5), the survey was undertaken at the site between 68°52 E - 69°41.6' E (Fig. 1). American-type rectangular traps were deployed either individually or collected in a set of 25 or 30 traps. The deployment time was in the range of 12 hours - 5 days. Mean catch per a trap was calculated for each set of traps based on assessment of a total catch taken with all the traps. Then, the mean catch per a trap was reduced to a mean catch per a 24-

hour deployment using the following formula:

$$z = x\frac{6{,}9049\ln(24)+15.604}{6.9049\ln(y)+15.604} \text{ or } z = x\frac{37{,}54814}{6.9049\ln(y)+15.604}$$

Where x is the actual mean catch per a trap; y is the deployment time for the given trap in hours; z is the mean catch per a trap for a 24-hour deployment.

This formula was derived from the equation (y=6.90491п(x)+15.604, where x is the catch per a trap and y is the deployment time in hours), developed on results of studying efficiency of the trap performance (The Red King crab…, 2003).

The crab density distribution and abundance were calculated with a ChartMaster software applying spline-approximation (Stolyarenko, 1987), the Delaunay triangulation, the Voronoi diagram and the Kriking method (Kanevski et al., 1998, Kanevski et al., 1999). Deviations were found with the Bootstrap method. While calculating density of the crab concentrations, we assumed that the area of efficient performance of one American trap totaled 31,400 m^2 (The Red King crab…, 2003).

In 2005, there were two trap surveys: (1) August 27 – September 16 and (2) October 1-16. Then, the surveyed area covered a larger part of the king crab distribution area in open waters. The research activities followed a network of stations (Fig. 1). American-type traps were deployed individually for 12 hours (August – September) and for 24-48 hours (October). In August, the abundance of large-sized males (the carapace width of >150 mm) was only taken. In October, the abundance survey covered all size and sex groups of crabs. Calculations followed the same scheme as in 2003.

In 2006 (February 14 – 28), the survey took place in the area from Rybachiy Peninsula till Svyatonossk Bay (Fig. 1), following the same methodology as in 2005. The results of this survey were used to analyze the crab distribution; due to the beginning of molt it was out of the question to obtain reliable abundance assessments.

Overall, in 2003, there were 189 stations performed; in 2005, 317 stations were made in September and 261 – in October; in 2006, there were 360 stations made. The crab abundance was calculated for the area bounded by the line connecting the extreme stations of the performed surveys (Fig. 1).

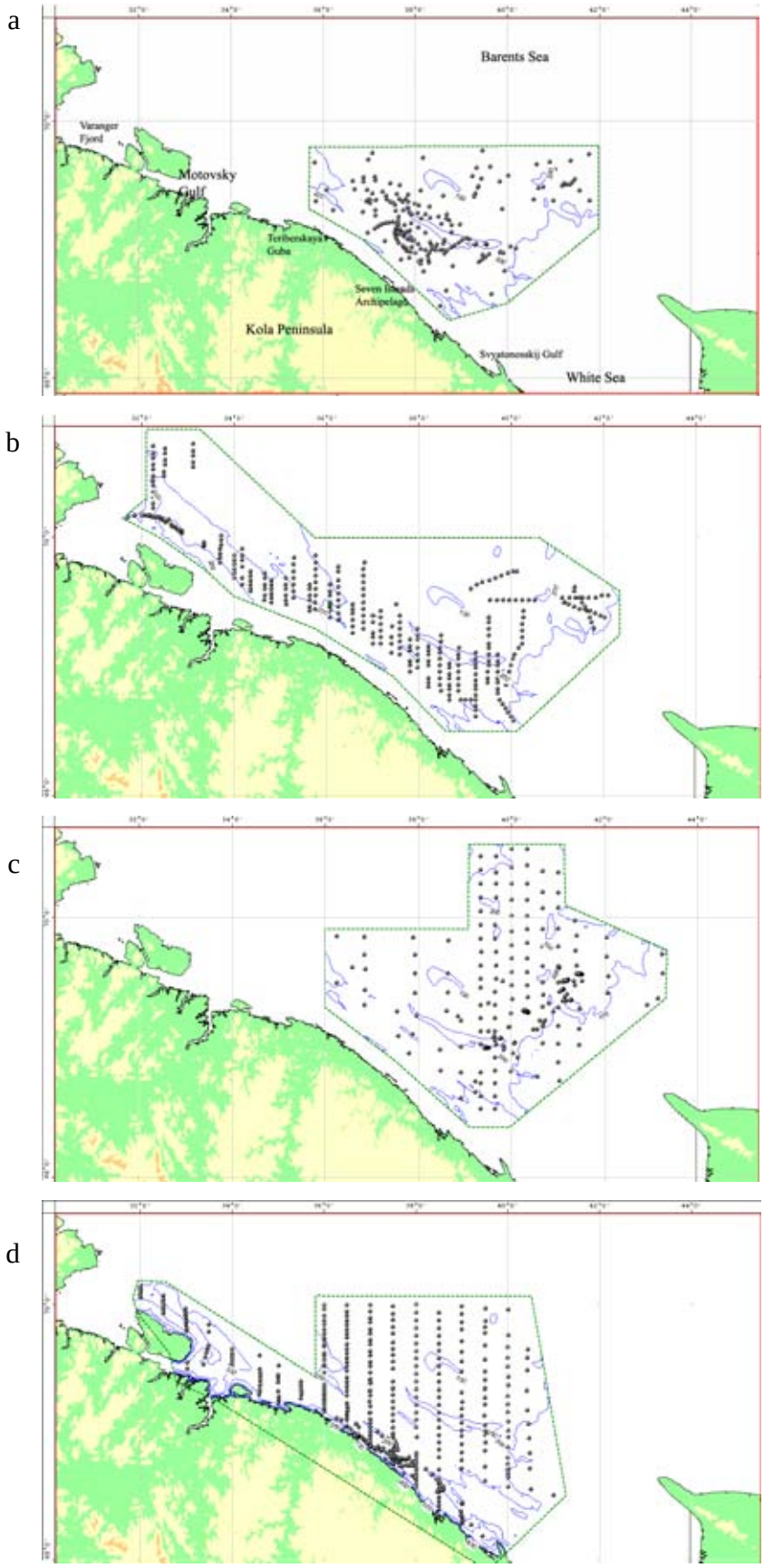

Figure 1. Arrangement of stations: a – October-November, 2003; b – August-September, 2005; c –October, 2005; d –February, 2006.

All crabs caught in the traps were classified into the following groups: large-sized males (the carapace width (cw) of >150 mm), mature males (cw = 130-149 mm), mature males (cw = 100-129 mm), mature females (cw >100 mm), immature individuals (males and females with the carapace width of <100 mm).

RESULTS

In 2003, catches from the surveyed area were dominated by large-sized males (cw>150 mm). In places of maximum concentrations the crab density attained 1600-1800 individuals/km, the male concentrations were found along the coastline at depths of 120-160 m. To the east of 39°00' E, density in concentrations of this sex/size group decreased and did not exceed 1400 individuals/km^2; during the autumn-winter time main concentrations of this group were found far off the coastal waters (Fig. 2a). In 2003, the mean density totaled 1041+13.9 individuals/km^2, and the abundance ranged from 24,000,000 – 33,630,000 individuals (Table 1).

In August-September, 2005, there were practically no dense concentrations of large-sized males outside the 12-mile zone. Density of the crab concentrations did not exceed 800 individuals/km^2 over the entire surveyed area. At the site located between 35°40' E and 39°30' E, concentrations of crabs elevated in the direction to the coast. At open sea (the area between 38° E -39° E), there was a marked patch with a relatively high density in the crab concentrations (round 400 individuals/km) (Fig. 2b). Calculations applying spline-approximation, the Kriking method, the Delaunay triangulation, and the Voronoi polygon produced the abundance values of commercial-sized males 11.522+0.783, 12.204+0.867, 10.934, and 11.069 mln. individuals, respectively.

In October 2005, surveys in open waters revealed dense concentrations of mature males mainly with the carapace width of >170 mm (Fig. 2c). High concentrations occurred at depths of 170-230 m. Compared to the same period in 2003, dense concentrations of king crabs shifted significantly to the east and to the north. Maximum density values were slightly lower than in 2003 and did not exceed 1600 individuals/km^2. Mean density for the surveyed area was also less than in 2003 and totaled 537+8.3 individuals/km^2. The large-sized male abundance in the surveyed area was estimated to be 21.875-26.849 mln. individuals and depended on the applied calculation method (Table 2). In February, 2006, the general distribution pattern changed little (Fig. 2d). However, due to the beginning of molt a trap survey was less efficient, compared to the autumnal time. Moreover, male concentrations were found to shift in the direction of coastal waters.

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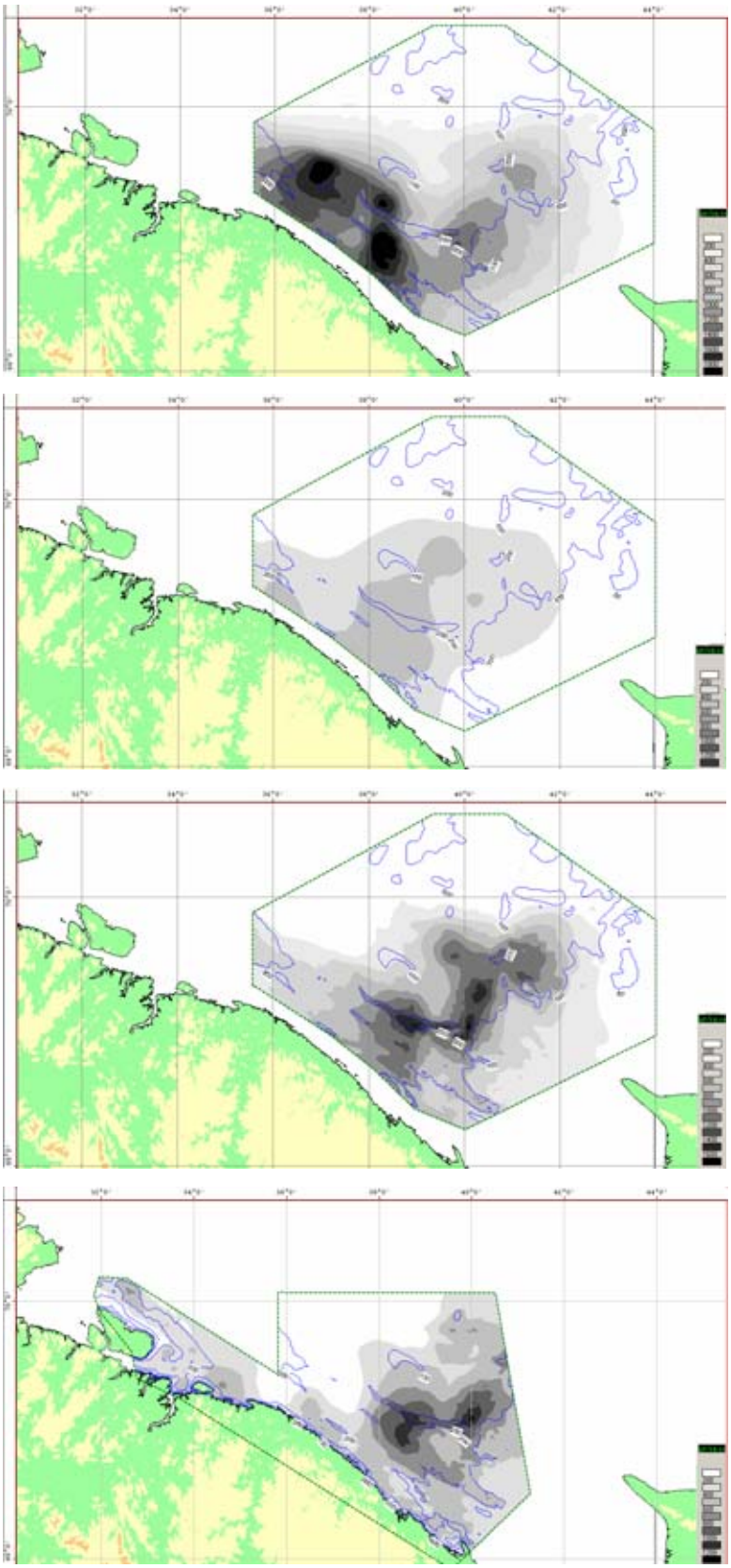

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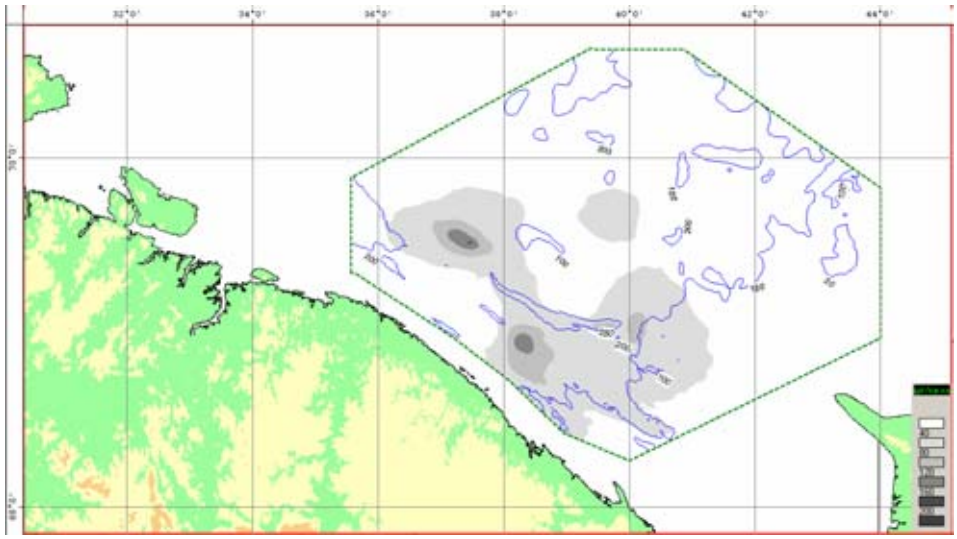
Figure 2. The distribution of commercial males (CW>150 mm) of red king crabs (specimens per square kilometer): a – October-November, 2003; b – August-September, 2005; в –October, 2005; г –February, 2006.

Abundance of males with the carapace width of 130-149 mm was significantly less than that of large-sized males, meanwhile distribution patterns of these two sex-size groups were similar in 2003 (Fig. 3a). Patches with relatively high density of males with the carapace width of 130-149 mm were found at depths of 100-140 m, meanwhile, in some places, this sex-size group of king crabs was rather numerous also at depths of ≈ 200 m and lower. In the eastern part of the surveyed area dense concentrations occurred closer to the coast. Overall, in the area, there were two concentrations of king crabs with density attaining 168 individuals/km^2. Mean density of this sex-size group of crabs for the total area made 44.2+1.73 individuals/km^2. Depending on the calculation method, abundance of the group was assessed in the range from 1.054 to 1.572 mln. individuals (Table 1).

During the October survey in 2005, mature males with the carapace width of 130-149 mm were found still scarcer than in 2003. The area of concentrations was also considerably smaller, compared to 2003 (Fig. 3a, b); besides, it was closer to the coast. The core of the crab concentrations was found at longitude 38° E; the crab concentrations with a relatively high density were also found at the depth of ≈ 230 m westward of the core. Maximum concentrations of this sex-size group of crabs occurred at depths of 140 -250 m. Relatively large catches were also taken at several stations with depths of 110-120 m. At sites of maximum concentrations, the density values approached 166 individuals/km with mean density of 19+1.12 individuals/km^2, which is twice less than in 2003. The king crab abundance estimated on the survey results obtained in 2005 varied in the range from 0.571 mln. individuals - 951 mln. individuals (Table 2). In February, 2006, this sex-size group of crabs was virtually absent in the eastern areas, while in the Motovsk Bay and adjacent waters there was a sharp increase in the mean density of concentrations of this group (Fig. 3c).

In 2003 and in 2005, males with the carapace width of 100-129 mm were found in samples oftener than those with the carapace width of 100-139 mm, but significantly scarcer than large-sized males. In the autumn of 2003, mature male crabs with the carapace width of 100-129 mm were found mainly in the south-eastern part of the surveyed area. Overall, there were three little patches with elevated density of these king crabs (Fig. 4a); the maximum density value in these concentrations was around 259 individuals/km^2. Over the rest of the surveyed area, this sex-size group was found very rarely. Mean density of this group in the area totaled 35.9+2.35 individuals/km^2. The abundance estimates ranged from 0.46 -1.8 mln. individuals (Table 1).

a



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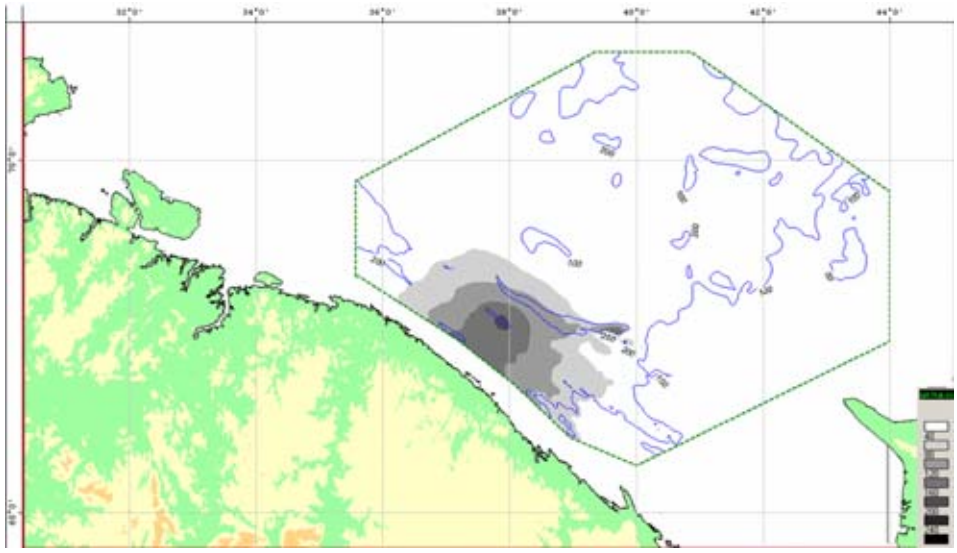

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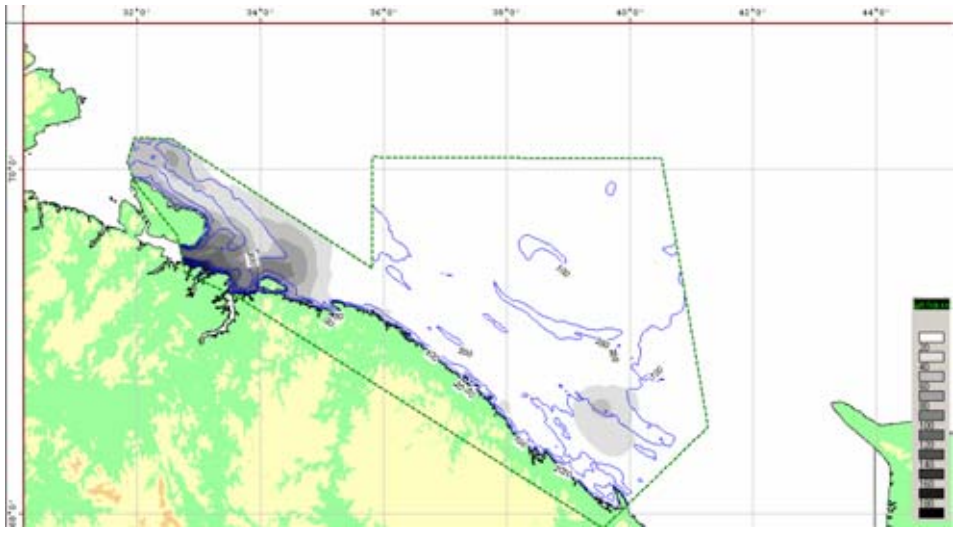

Figure 3. The distribution of red king crab's males with CW 130-149 mm (specimens per square kilometer): a – October-November, 2003; b – October, 2005; г –February, 2006.

In October, 2005, concentrations of male crabs with the carapace width of 100-129 mm covered larger areas, compared to 2003. Moreover, in 2005, this group concentrations were found at greater depths and were characterized by a higher density than in 2003 (Fig. 4b). Thus, in 2005, the maximum density value totaled 415 individuals/km, that was 1.5 times higher than in 2003. Mean density of this group in the area was also higher, compared to 2003, and totaled 60.5+1.99 individuals/km^2. The abundance estimates for this sex-size group of king crabs was in the range from 2.47 - 3.37 mln. individuals, depending on the calculation method (Table 2). In February, 2006, this sex-size group of crabs was virtually absent in traps. Obviously, this was the time when this group migrated to shallower areas not covered by the survey.

In the autumn of 2003, mature females did not form dense concentrations in the surveyed area. Their concentrations were found at depths of 100-260 m in the area within 37°40' E and 40°10' E, far from the coastal waters. Maximum concentrations of mature females occurred in the deep-water part of the surveyed area (Fig. 5a). Mean density for this sex-size group totaled 69.65+4.15 individuals/km^2 and the maximum density was 700.6 individuals/km. In 2003, the number of mature females varied from 1.865 - 3.282 mln. individuals, depending on the calculation method (Table 1).

Table 1. Number crabs of different sex-size groups in 2003 (S= 26464 км^2).

Sex	Carapace width (mm)	Stock assessment, thousand specimens.			
		spline-approximation	Kriking method	Delaunay triangulation	Voronoi diagram
♂	>150	27701±167.9	33630±228.4	24000	26695
	130-149	1176±22.32	1572±22.47	1054	1239
	100-129	1802±42.4	997±29.6	460	570
♀	>100	1865±46.3	3151±76.29	3282	2705
♀ и ♂	<100	61.9±3.1	62.2±2.7	40	102
Total		32605.9	39412.2	28836	31311

In October, 2005, the survey revealed only one, but rather dense concentration of females. The majority had egg-laying. This concentration was found at depths of 100-140 m in the south-eastern part of the surveyed area (Fig. 5b). There were no concentrations of mature females over the rest of the area. The maximum density for concentrations of the group totaled 1188.4 with the mean of 88.9+2.46 individuals/km^2 for the entire surveyed area. The group abundance estimates varied from 3.35 - 4.437 mln. individuals.

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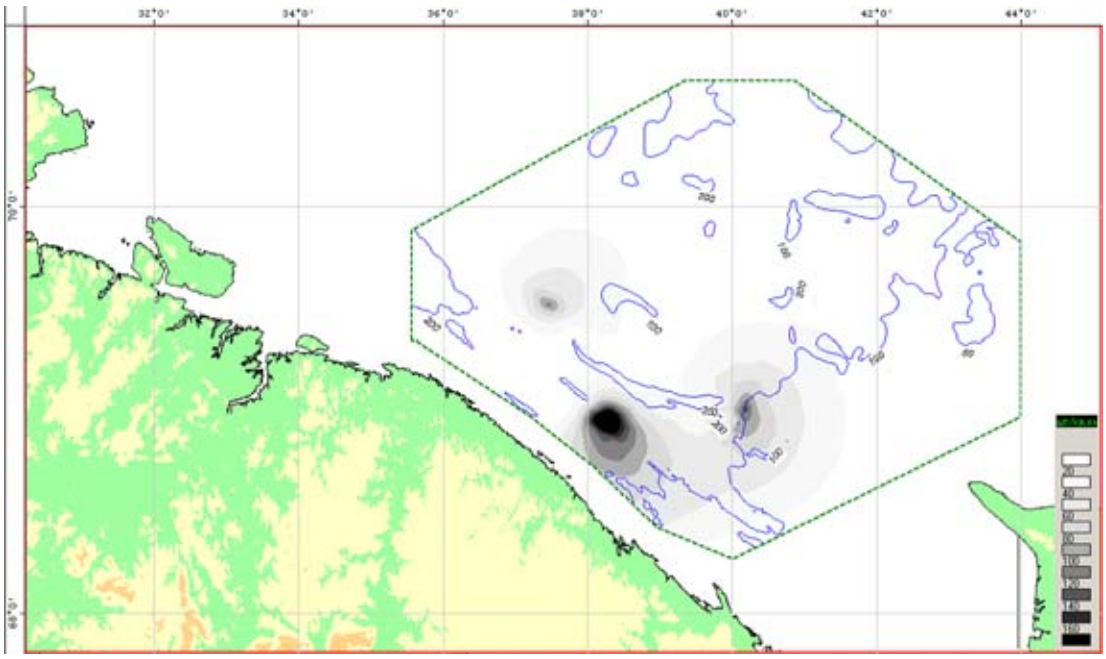

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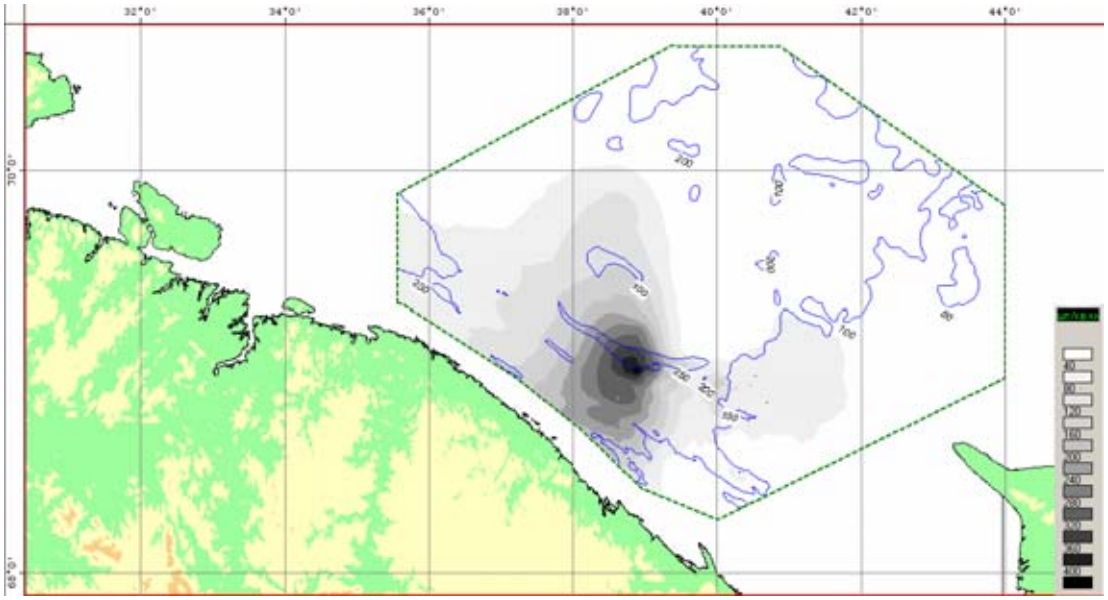
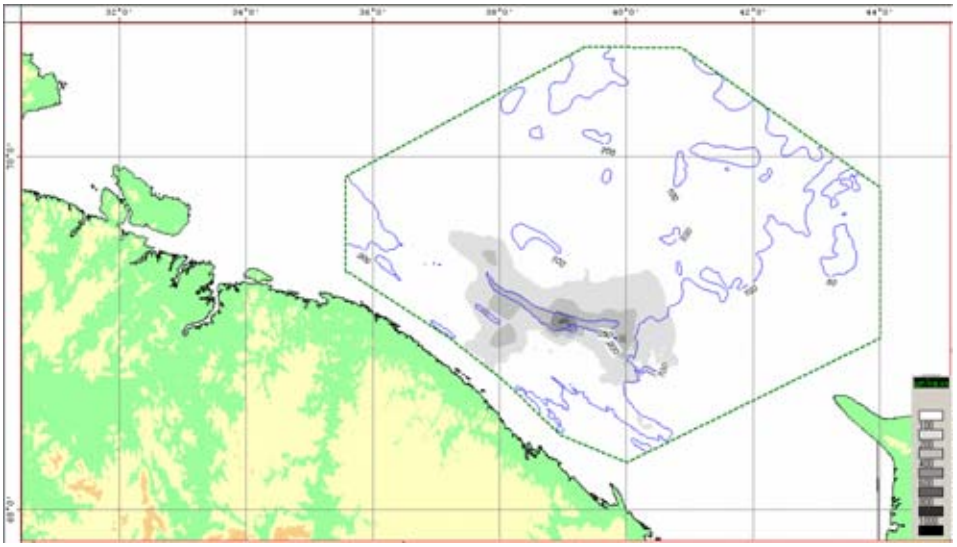


Figure 4. The distribution of red king crab's males with CW 100-129 mm (specimens per square kilometer): a – October-November, 2003; b – October, 2005.

In February, 2006, the female group formed relatively dense concentrations along the entire Murman coast (Fig. 5c). Minimum concentrations occurred at depths exceeding 190 m along the western Rybachiy Peninsula, in the Motovsky Bay, westward of the Teriberskaja Gulf, and in the waters of Bolshoi Oleniy Island. There were no concentrations of females between 35°00' E and 35°30' E. Further to the east, density of the female crab concentrations increased once more and attained its maximum at longitude 36°30' E, then gradually declined by 40° E.

a



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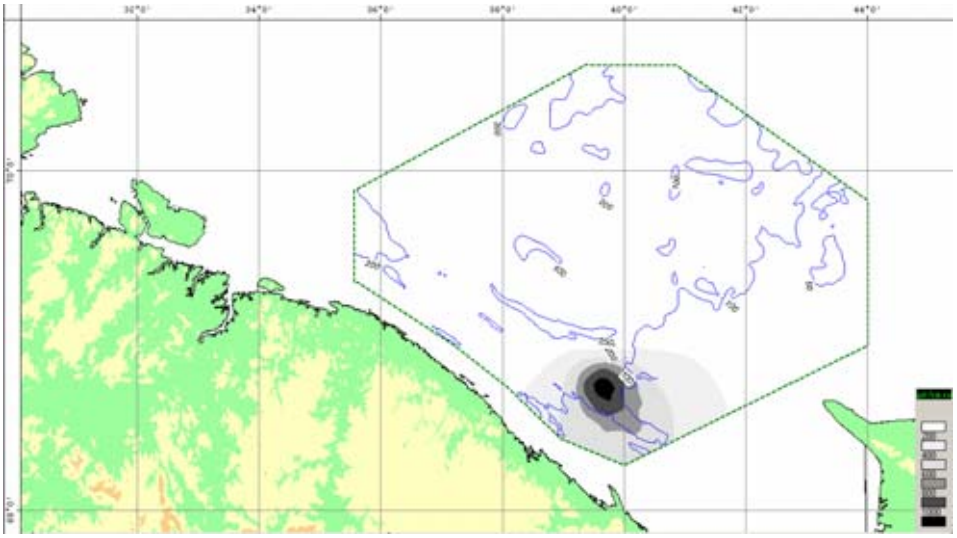

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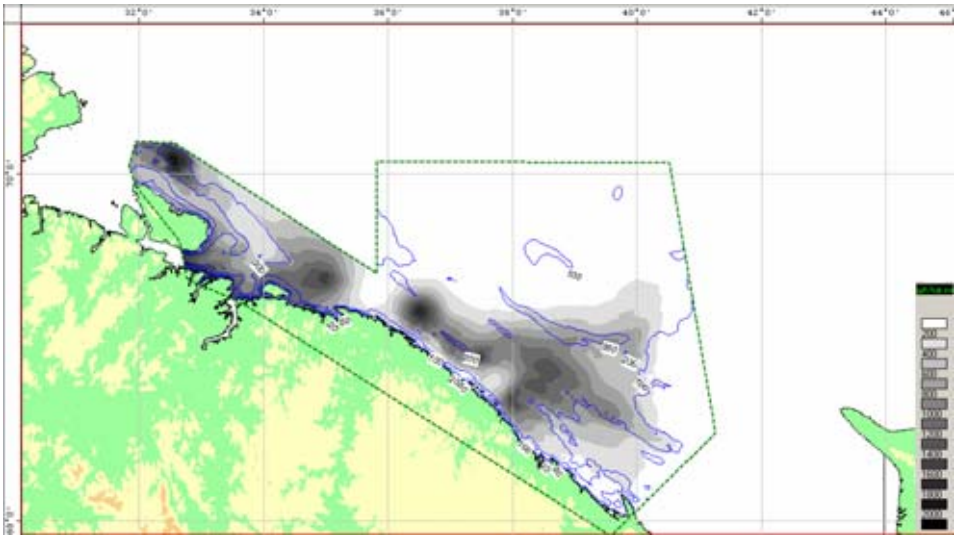

Figure 5. The distribution of red king crab's mature females with CW 130-149 mm (specimens per square kilometer): a – October-November, 2003; b –October, 2005; г –February, 2006.

Table 2. Number crabs of different sex-size groups in 2005 (S= 39930 км^2).

Sex	Carapace width (mm)	Stock assessment, thousand specimens			
		spline-approximation	Kriking method	Delaunay triangulation	Voronoi diagram
♂	>150	21875±123.7	26849±170.4	21965	26832
	130-149	787±34.6	529±22.5	571	951
	100-129	2472±36.83	3343±63.7	3319	3376
♀	>100	3764±56.6	4437±54.6	3350	3763
Total		28898	35158	29205	34922

Immature males and females were virtually absent from the trap catches. Density of concentrations and abundance of this age group (without division into male and female groups) were assessed only in 2003. Individuals from this group were present at depths of 100-180 m. The maximum density of immature individuals totaled only 27.3 individuals/km^2; mean density of this age group was 2.3+0.1 individuals/km^2 (Table 1). The total abundance of all the described above groups of king crab was 28.836-39.412 mln. individuals in 2003 and 28.898-35.158 mln. individuals in 2005.

DISCUSSION

In recent years, distribution analysis for the large-sized males has indicated that concentrations of this group shifted eastward. This tendency was revealed both by trawl surveys, and trap surveys. In 1999-2000, maximum concentrations of the large-sized mature males were found in Warangerfiord and in the Motovsk Bay. Besides, patches with concentrations of high density were found at the entrance to the Kola Bay, in the waters of Kil'din Island, and at the entrance to the Teribersk Gulf. In the area between 38° E and 40° E, density of male crabs with the carapace width of > 150 mm was low (The Red king crab…, 2003).

According to the data of trawl surveys made in 2001, maximum densities occurred in the western areas, however, smaller patches with relatively high density of the male crab concentrations were also found eastward of longitude 38° E. In 2002, the area of dense concentrations westward of the Kola Bay decreased, meanwhile the crab concentrations appeared in the eastern part of the distribution area. On the whole, the king crab distribution area increased in the direction north-east (The Red

king crab…, 2003). A similar pattern emerged from analysis of the king crab bycatch at bottom trawl fisheries in 1996 - 2002 (The Red king crab…, 2003).

Recent studies with the help of traps indicate persistence of this tendency for concentrations of mature male king crabs to shift eastward along the Murman coast. In 2003, the densest concentrations of male crabs were found in the area between 36° E and 39° E. Then, highly dense concentrations of the fishing stock only started to form in open waters, taking the direction north-east along the 100-m isobath (the general direction of this isobath in the area eastward of 39° E is almost perpendicular to the coastline).

In 2005, concentrations of large-sized males obviously shifted eastward, compared to previous years. In autumn and winter, this sex-size group kept to depths of 120-190 m at the Voronka of the White Sea between 39° E and 42° E. This area is characterized by large stocks of benthic biomass (100-300 t/m^2) (Zenkevich, 1963) and is very attractive to male crabs during winter feeding.

Comparison of distribution of the density values for the fishing stock of king crab which were calculated on results of trawl surveys (PINRO) and trap surveys (VNIRO) in the area bounded by the line connecting points 69°10'N - 39°30'E, 69°35'N - 39°30'E, 69°35'N - 42°00'E, 69°10'N - 42°00'E showed that while the catchability coefficient of a bottom trawl was 0.75, the area of efficient performance of an American trap only totaled 36, 000 m^2 ; this was very close to our chosen area of 31,400 m^2.

CONCLUSIONS

1. In 2003-2005, the king crab population in Russian waters of the Barents Sea was estimated to be ≥ 100 mln. individuals, including 40-50 mln. mature crabs. The king crab population in the Barents Sea was at the abundance level close to that of the West Kamchatka king crab population in its best years.

2. Appearance of dense concentrations of large-sized males in the south-eastern waters of the Barents Sea is principally associated with active migration of crabs from the western waters (the Motovsk Bay, the Kola Bay, the Teribersk Gulf, and the Dal'nezelensk Gulf).

3. In 2006-2009, there will be a natural decrease in number of mature crabs in the south-eastern waters of the Barents Sea. This decrease will continue until migration of growing males from the western areas increases which can be expected by 2007-2009. Meanwhile, in the western areas, particularly, in the Motovsky Bay, there could be an increase in number of mature individuals, which then could start to migrate actively to the south-eastern waters of the basin.

4. We think that summer trawl surveys (August) led to a systematic

error in the king crab stock assessment because in the Barents Sea a lot of crabs lives in August and early September on depths not accessible to trawl researches.

5. Trap survey on the fishing boats permit to carry out investigations of distribution and stock assessment of Red King Crab (*Paralithodes camtschaticus)* in the Barents Sea. The collaboration between scientists and fishermen is very promising for Red king crab investigation.

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