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Bycatches of the red king crab in the bottom fish fishery in the Russian waters of the Barents Sea: assessment and regulations

Aleksei V. Stesko * and Sergey V. Bakanev

Laboratory of Marine Bioresources, Polar Branch of Russian Federal Research Institute of Fisheries and Oceanography, Academician Knipovich Str. 6, Murmansk 183038, Russian Federation

**Corresponding author: tel: + 7 8152 402614; e-mail: stesko@pinro.ru.*

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An analysis of red king crab bycatch in bottom-trawl fisheries in the Russian exclusive economic zone (EEZ) in the Barents Sea based on data collected from 2010 to 2019 shows an annual range of 2.2–9.8 thousand tonnes of crab bycatch from 2010 to 2018, which is 0.7–2.9% of the total biomass of red king crab in the EEZ. It was found that the catch of commercially valuable male crabs in the bottom-trawl fishery ranged from 1.4 to 6.5 thousand tonnes, which is ~0.7–3.3% of the total commercial stock. A protected area created in 2006 is estimated to prevent the catch of 1.1–4.8 thousand tonnes of crab; however, protective measures do not take into account the peculiarities of the current distribution of crab populations and the geography of the fishing area. This work offers suggestions for improving the regulatory measures to protect the king crab stock in Russian waters of the Barents Sea.

Keywords: Barents Sea, bottom fish, bottom-trawl fishery, bycatch, red king crab, regulatory measures

Introduction

Species bycatch in the Russian fishery is regulated by a special set of Russian fishery laws. Depending on the species composition, fishery bycatch may be processed or returned to the sea with the least damage. Such actions should be registered "in ship documents, fishing journal" and reported to special government services (Order of the Ministry of Agriculture No. 414, 2014). However, in practice, bycatch is often thrown overboard without any report, not only in Russia, but throughout the world (Alverson *et al.*, 1994; Sokolov, 2001, 2004; Ono *et al.*, 2013; Kolding *et al.*, 2016; Breivik *et al.*, 2017).

The red king crab (*Paralithodes camtschaticus*, Tilesius, 1815) is one of the bycatch species in the bottom-trawl fishery in the Barents Sea. *Paralithodes camtschaticus* was introduced into the waters of the Barents Sea in the 1960s (Orlov and Ivanov, 1978). At present, it is widespread in the southeastern part of the Barents Sea, in the coastal waters of the Kola Peninsula and the Scandinavian Peninsula, and in the White Sea Funnel and Throat (Sundet and Berenboim, 2008; Pinchukov and Sundet, 2011; Stesko and Manushin, 2017). The present distribution of the red king crab, based on research data from the Polar Branch of the Federal State Budget Scientific Institution Russian Federal Research Institute of Fisheries and Oceanography (PINRO, named after N. M. Knipovich) and published reports (Windsland *et al.*, 2014), is shown in Figure 1.

The densest accumulations of red king crab are located in the southern part of the Barents Sea where a significant part of the area has been closed to bottom trawling since 2006 (Pinchukov and Sundet, 2011; Order of Ministry of Agriculture No. 414, 2014; Figure 1). Crab trapping is carried out within the boundaries of this area. In areas where bottom trawling is allowed, sea flounder (*Pleuronectes platessa*) and haddock (*Melanogrammus aeglefinus*) are the main targets (Rudnev and Ajiad, 2011; Russkikn and Dingsor, 2011; Prozorkevich *et al.*, 2018). Crabs caught by trawls are damaged and inevitably die.

Assessment of crab bycatch in the bottom-trawl fishery and establishment of relevant crab stock protective measures are problematic. In Russian literature, authors usually raise the issue of the number of crabs caught by bottom trawls and the need for bycatch rates to be added to the regulations (Kuzmin and Pavlov, 2000; Pinchukov *et al.*, 2003). Globally, the issue of king crab mortality by trawling has been reviewed and measures created to protect crab stocks (Stevens, 1990, 1995; Alverson *et al.*, 1994; Kruse *et al.*, 2010; Stevens and Lovrich, 2014).

In the Russian part of the Barents Sea, bycatch of no more than ten crabs of any sex or size per tonne of the target species per trawl is allowed. If this amount is exceeded, the fishing vessel must register this fact in the ship's documents and change fishing position by five nautical miles. In addition, the fishing vessel should inform the local office of the Russian Ministry of Fisheries, which is responsible for this area—the "fishery basin". In Russia, separate rules have been worked out for each "fishery basin". The Barents Sea belongs to the Northern Fisheries Basin. By law, all crabs from bycatch must be returned to their habitat; they cannot be processed into commercial products (Order of the Ministry of Agriculture No. 414, 2014). However, in 2017, out of 119 bottom-trawl vessels operating in the south Barents Sea, none reported any crab bycatch. This did not correspond with the data collected by observers of the Polar Branch of the FSBSI VNIRO on fishing vessels and research surveys.

Aim and objectives

The present work aimed to estimate the actual bycatch of the red king crab in the southern part of the Russian exclusive economic zone (EEZ) in the Barents Sea and to discuss the effectiveness of current bycatch regulatory measures in Russia. Specific objectives were to:

(i) estimate the theoretically possible annual catch of red king crab in the bottom-trawl fishery based on data provided by observers in the fishery and research surveys;

(ii) determine the effectiveness of current borders of areas closed to trawl fishing in the south Barents Sea, taking into account the eastward migration of red king crab aggregations (Pinchukov and Sundet, 2011; Stesko and Manushin, 2017; Bizikov *et al.*, 2018);

(iii) analyse current red king crab bycatch and Russian standards in the bottom-trawl fishery and evaluate fishery-biological validity and effectiveness; and

(iv) make recommendations to improve the management of red king crab and bottom fish fisheries that equally reflect the interests of all stakeholders.

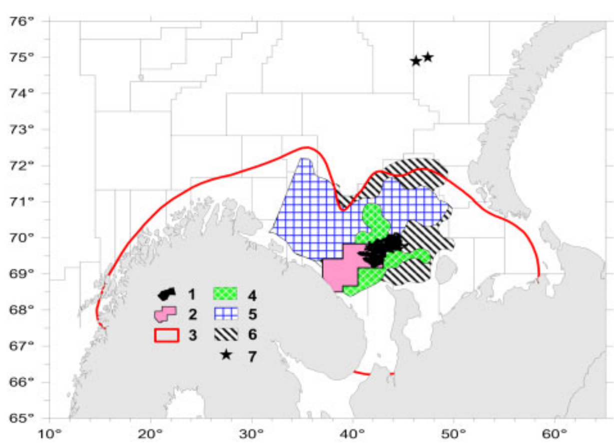

Figure 1. Current distribution of the red king crab in the Barents Sea, positions of commercial fishery of the red king crab in the Russian Economic Zone in 2018, and areas of Russian bottom trawling within red king crab habitat: 1—red king crab fishing position, 2—bottom trawls banned, 3—boundary of red king crab habitat, 4—sea flounder fishing, 5—cod fishing, 6—haddock fishing, and 7—red king crab registered in snow crab fishery.

Material and methods

The total research area was 16 100 km^2 and included the main accumulations of red king crab in the south Barents Sea, where it has been harvested in recent years. Areas within the boundaries of the Russian territorial sea were not included in these calculations because red king crab fishing has been prohibited there since 2010 and because a significant part of this area is closed to trawl fishing.

To assess the red king crab bycatch, the "effort" method was used (Walmsley *et al.*, 2007). To assess the fishing effort, the sum of hours of commercial bottom trawling in each section was determined for each year, after which the median effort for the period 2013–2018 was used in the assessment (1).

$$\text{annual bycatch} = \frac{\text{observed catch}}{\text{observed fishing effort}} (\text{annual fishing effort}). \quad (1)$$

The effort method was based on the results of specialized red king crab trawl surveys in August–September 2017–2019 on the vessel of the Polar Branch of FSBSI VNIRO MK-0520 "Professor Boyko". The work was carried out by a Russian-made trawl "22M"; the length of the rock hopper ground gear was 12 m, the average trawling speed was 2.5 knots, and the duration was 15 min. The number of trawls collected in 2017 was 107; in 2018, 130 trawls; and in 2019, 99 trawls. Carapace width, sex, shell condition, and presence or absence of injured limbs were recorded.

Data for annual fishery effort in the Barents Sea were obtained by the automatic Russian system "Fishery". This system collects fishery information from all fishing vessels in the Russian EEZ. Data from red king crab catches in research trawls and data of commercial effort (number of hours spent trawling) were divided by geographic area. The size of the area depended on the quantity of crabs in the bottom trawl catches, the boundaries of local fishing areas, and the depth of fishing (Figure 2).

The research vessel's catch per hour of red king crab in each section was replicated by the bootstrap method in the "boot" library of R (Davison and Hinkley, 1997; R Core Team, 2012). The number of bootstrap replicates was 9999. Confidence intervals of 50 and 95% of the research catch were calculated and used in (1) and multiplied by the median hours of trawling in each section to estimate the annual red king crab bycatch.

The red king crab catch coefficient on MK-0520 "Professor Boyko" was 1.0. Structural and design differences between research and fishery vessels were not considered. There are many types of bottom trawls and settings used in the Barents Sea. It is not our goal to standardize commercial and research trawl catches, but research trawls are smaller than commercial fishery trawls, so we believe our calculations do not underestimate king crab bycatch in the Barents Sea; if anything, they may overestimate it.

The total red king crab bycatch was divided into two groups: commercial-sized specimens (males with a carapace width >150 mm) and non-commercial, using data on the size and sex of catches in trawl surveys in 2017–2019. To estimate the proportion of red king crab taken from the entire stock by the bottom-trawl fishery, we estimated the dynamics of the commercial stock using a stochastic production model and data from 2019. In the Russian EEZ, only the commercial stock of red king crab was assessed; for this work, we estimated the stock according to the production model.

The production model was formulated as a Bayesian-state space model with explicit process and observation error terms (e.g. Meyer and Millar, 1999; Hvingel and Kingsley, 2006). The equation describing the state of transition from time t to $t+1$ was a discrete form of the logistic model of population growth including fishing mortality (e.g. Schaefer, 1954) and was parameterized in terms of maximum sustainable yield (MSY) rather than r (intrinsic growth rate, see Fletcher, 1978):

$$B_{t+1} = B_t - C_t + 4\text{MSY}\frac{B_t}{K}\left(1 - \frac{B_t}{K}\right), \qquad (2)$$

where K is the carrying capacity or equilibrium stock size in the absence of fishing, B_t is the stock biomass, and C_t is the total catch taken by the fishery.

The production model synthesized information from prior input, four independent series of crab biomass, and one series of crab catch. The four series of crab biomass indices were: a standardized series of annual commercial vessel catch rates (catch per unit effort: CPUE) 2006–2019, two trawl survey biomass indices for 1994–2012 and 2017–2019, and a coastal trap survey biomass index for 2009–2019.

Under the Bayesian paradigm, prior distributions are employed to quantify existing knowledge (or the lack thereof) of the likely value of each model parameter. In this context, the model parameters consist of the carrying capacity, MSY, catchability, initial biomass, and the process and observation error variances. In general, auxiliary information was incorporated into the prior distributions when it was available. The key parameter in the production model is K, the posterior distribution of which largely depends on the parameters of its prior. The lower boundary of prior K was determined taking into account the most pessimistic estimation of the commercial stock. The upper boundary was set high so that the biologically plausible posterior distribution of the parameter K fully entered into the prior distribution.

For total stock assessment, we used the proportion of the commercial and non-commercial stock in each sector.

Finally, the commercial stock of red king crab in the Barents Sea in 2017–2019 was assessed at 45–750 thousand tonnes in the 95% confidence interval. For crab bycatch calculations, we used a median of commercial stock or 200 thousand tonnes.

It should be noted that the stock assessment does not include any king crab bycatch.

The assessment of the effectiveness of the area closed to trawl fishing was calculated on the basis of hypothetical red king crab bycatch for 2006–2018. We calculated the amount of crab that might have been in the bycatch if the area had not been closed to trawl fishing. The assessment was carried out using methods similar to those used in areas open to trawling, but the basis for the calculations was data from fishing effort in 2003–2005 (i.e. 3 years before the area was closed). Data visualization and processing were performed in GIS MapViewer 7.0 (Golden Software, USA) and ggplot2 packet of the R programme (R Core Team, 2012).

Results

Estimates of potential red king crab bycatch

In the south Barents Sea, the primary targets of bottom-trawl fisheries are cod (*Gadus morhua*), haddock, and sea flounder. In 2013–2018, annual effort in bottom trawling in various parts of

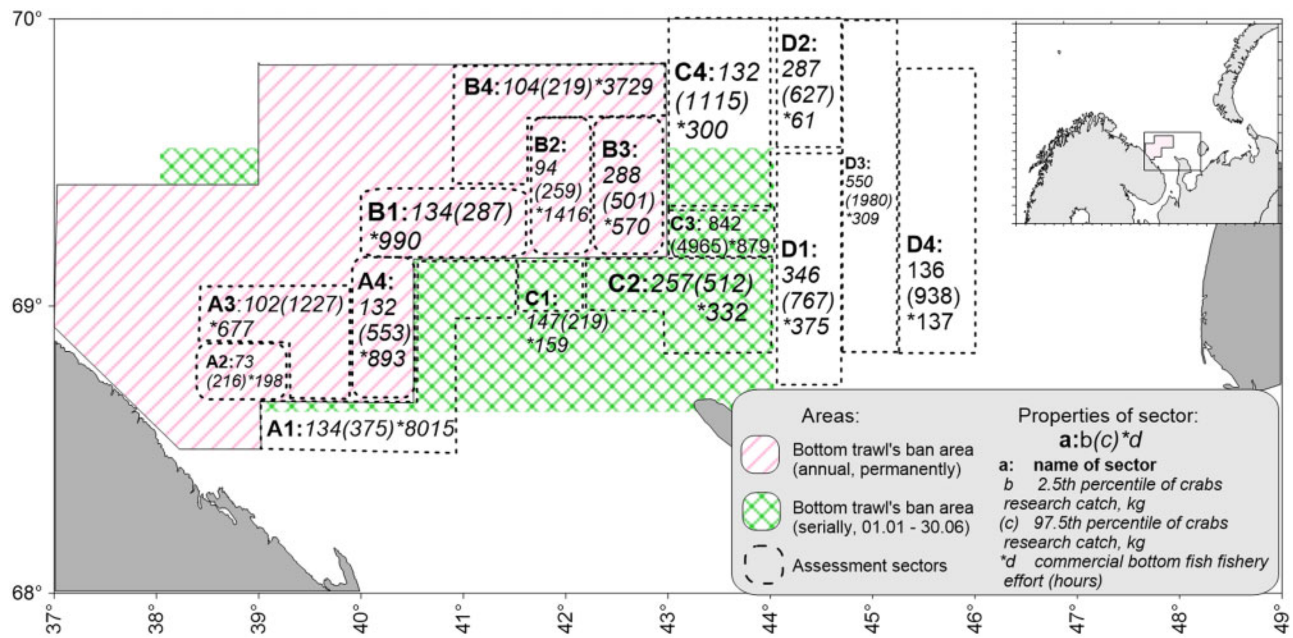

Figure 2. Areas for estimating red king crab bycatch relative to the trawl survey of MK-0520 "Professor Boyko" and effort (number of hours) in bottom-trawl fishing, 2017–2019 (2003–2005 for annual bottom-trawl's ban area).

the region ranged from 80 to 9900 h year^{-1}. The greatest fishing effort was registered in sections A1 and C3, while effort in other areas did not exceed 2000 h year^{-1} (Figure 3).

In research trawl surveys conducted in August–September 2017–2019, the red king crab bycatch reached a maximum of 18.7 tonnes h^{-1} of trawling. However, research trawl catches were often no more than 1.0 tonnes h^{-1} of trawling. The largest fluctuations in amount of crab bycatch in trawl catches were observed in areas A1, A4, C3, and D3 (Figure 4a).

The total annual red king crab bycatch in the research area was estimated to be 2.2–9.8 thousand tonnes in the 95% confidence interval and 3.6–6.6 thousand tonnes in the 50% confidence interval. The highest amount of crab in the bycatch was observed in areas C1–C4 (0.2–4.5 thousand tonnes per area). In some areas, the estimated red king crab bycatch in the bottom-trawl fishery did not correspond with the crab catch in the scientific survey. This is due to the inequality of the effort by fishing vessels during the year in different areas. For example, the logarithmic index of crab bycatch in area A1 correlates with the index from other areas. However, the estimated annual bycatch in the bottom-trawl fishery in area A1 is similar to the bycatch in areas C3 or D3, where catches reached record highs due to higher fishing intensity in area A1 compared to other areas (Figures 3 and 4).

Similarly, the spatial dynamics of the red king crab catch in the survey does not correspond with the estimated crab bycatch. When the research vessel shifted east, both the catch and its variability increased. Nevertheless, bycatch was reduced and reached its minimum in the eastern part of the research area (area D4), creating a dual situation. In the western part of the study area, the red king crab bycatch was high due to more intensive efforts in the bottom-trawl fishery; in the east, it was high due to the density of the crab populations.

Results of research trawl surveys in 2017–2018 showed that the average percentage of commercial crab specimens in all areas was 69 ± 2 by weight of the total red king crab bycatch. Considering this, the biomass of the total crab stock in the research area may reach 338 ± 4 thousand tonnes. Accordingly, the annual red king crab bycatch in the bottom-trawl fishery may be 0.7–2.9% of the total crab biomass in the Russian EEZ. Bycatch of commercial crab varied between 1.4 and 6.5 thousand tonnes year^{-1}, which was 0.7–3.3% of the total commercial crab stock, if the 95% confidence interval is used. If the 50% interval is used, the biomass of the bycatch could be 2.4–4.4 thousand tonnes year^{-1}.

The annual official catch of the bottom-trawl fishery in the research area in 2013–2018 fluctuated between 15.2 and 20.3 thousand tonnes. Consequently, within the 2.5% percentile of the calculated crab bycatch (2.2 thousand tonnes), each fishery vessel could catch 42–56 crabs per tonne of total catch, and based on the 97.5% percentile, the calculated crab bycatch (of 9.8 thousand tonnes) for each fishery vessel could be 186–248 crabs per tonne of total catch, much more than Russian fishery rights permit (ten crabs per tonne).

Effectiveness of current borders of area closed to trawl fishing in the South Barents Sea

According to calculations based on the data from research trawls in 2017–2019, the annual red king crab bycatch within a closed area could be 1.1–4.8 thousand tonnes, and a significant part of the bycatch would be represented by males (0.8–3.2 thousand tonnes). Accordingly, the total red king crab catch in the area closed to bottom trawling in the period 2006–2018 (13 years) could vary from 14.3 to 62.4 thousand tonnes for all crabs and 10.4–41.6 thousand tonnes for males. If we use the 50% confidence interval, results indicate that 26.2–43.7 of all crabs and 17.4–28.8 of males were saved from harvest in 2006–2018.

Discussion

Analysis of red king crab bycatch and Russian standards in bottom-trawl fishery

Management of the red king crab fishery in the Barents Sea is carried out through the following mechanisms:

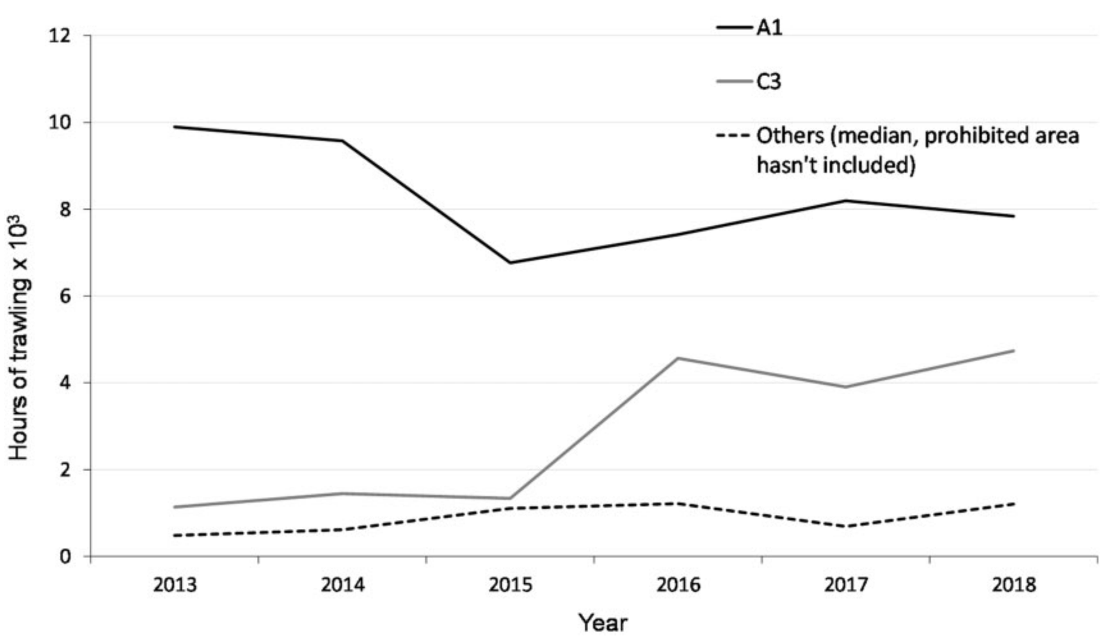

Figure 3. Fishing effort in the research areas in the south Barents Sea, 2013–2018.

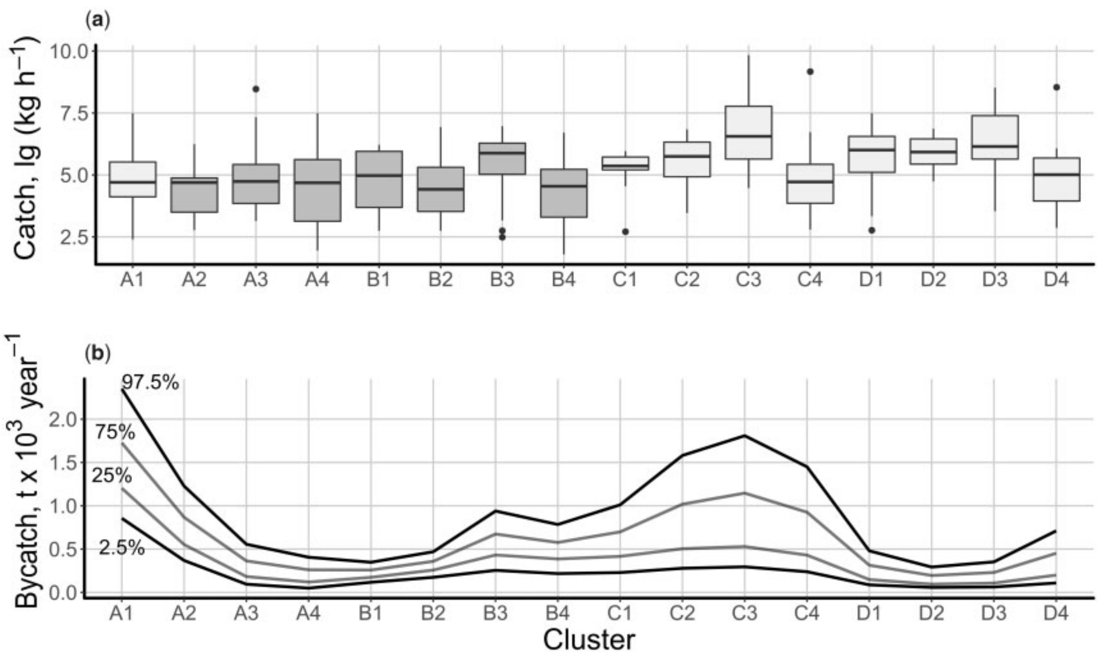

Figure 4. Variability in red king crab catch in research trawl surveys, 2017–2019 (a) and assessments of red king crab bycatch (b) by bottom fish commercial fisheries in different research areas by confidence intervals (light boxplot—outside the closed area, dark boxplot—inside the closed area).

(i) scientifically based prognosis of the stock biomass,

(ii) establishing the total allowable catch,

(iii) restrictions on fishing areas and timing, and

(iv) establishing requirements for fishing gear and limits on non-fishing specimens in bycatch (juveniles, females).

For example, the main objective of creating a closed area in the south Barents Sea is to protect red king crab females and juveniles, which are forbidden to be caught. The second objective is to prevent conflict between fisheries using trawls and fisheries using traps because these types of fishing gear can be damaged when they try to fish together in the same locations.

The closed area has existed for >10 years. During this period, the main accumulations of red king crab migrated east and south (Pinchukov and Sundet, 2011; Bakanev, 2016; Bizikov *et al.*, 2018). Some individuals were caught in the Vaigach area of the Barents Sea and in the White Sea Throat (Stesko and Manushin, 2017).

Red king crab populations are distributed in areas open to bottom-trawl fishing (A1, C1–C4, D1–D4). In areas A1 and C1–C4, the European plaice catch totals 5 thousand tonnes annually. In areas D1–D4, the haddock catch reaches 3–4 thousand tonnes annually.

As the observations and calculations of the present study show, bottom-trawl fisheries are most likely associated with red king crab bycatch. Moreover, red king crab bycatch in the bottom-trawl fishery in the south Barents Sea may be similar to the annual commercial catch, which is about 9 thousand tonnes. Most of the bycatch occurs in areas C1–C4 (Figure 2) where the densest aggregations of red king crab were recorded. In the western part of the study area, high bycatch was due to high crab density, while in the eastern part, it was due to high bottom trawling intensity.

The problem of assessment of allowable red king crab bycatch in the bottom-trawl fishery in the Barents Sea was actively discussed in the Russian literature in the late-1990s and early-2000s (Kuzmin and Pavlov, 2000; Pinchukov *et al.*, 2003) because, at that time, an increasing catch of red king crab was correlated with an increasing amount of crabs in trawl bycatch. Current limits on bycatch of red king crab in Russia are ten crabs per tonne of total catch. This regulation was set for the Far East seas of the USSR in 1989 (Order of the Ministry of Fisheries of the USSR No. 458, 1989) and has no biological basis for the Barents Sea. In this regulation, the allowable red king crab bycatch is 2% by weight of the permitted catch (Kuzmin and Pavlov, 2000). The 2% were converted to absolute values, which amounted to "kg, or ten specimens, of which seven males and three females averaged" (Pinchukov *et al.*, 2003). The main reason for the introduction of a bycatch rate of ten individual crabs per tonne of total catch was to protect the red king crab stock during an explosive growth in the crab population and the absence of any protected areas.

To approve the measures of ten specimens, Kuzmin and Pavlov (2000) and Pinchukov *et al.* (2003) referred to US fishing regulations. The bycatch limit indicated the total annual allowable amount of red king crab in bycatch for a given area, as well as the bycatch rate standard—the recommended average amount of crab bycatch per tonne of allowable catch, which amounted to 2.5 specimens in 1996 (Federal Register, 1996). At present, the Fishery Rules for the Far Eastern Fisheries Basin [Order of the Ministry of Agriculture of the Russian Federation No. 385, 2013 (as of 4 June 2018)] have not established a quantitative limit for crab bycatch in other fisheries. According to Article 25 of these rules, the bycatch of objects for which a total allowable catch is established "shall be no more than 2% by weight per one operation for the catch of the total allowable species catch". Unlike the 1989 rules, current rules completely prohibit mammals, crabs, and shrimp bycatch. They are required to be returned to their habitat immediately. This regulation also covers the Barents Sea.

The term Bycatch Standard Rate (Federal Register, 1996) of biological resources in similar US regulations for the period 2014–2018 is absent (Federal Register, 2014, 2018). The regulations define the terms prohibited species catch (PSC-limit) and Prohibited Species Quota within the "Crab Protection Area" (Red King Crab Saving Areas). Bycatch is distributed over specific areas and limited in amount, which is calculated based on the status of the red king crab spawning stock, as well as the characteristics of the fishing regime in the area (Zheng and Siddeek, 2018). For example, with a spawning biomass of 6.7 thousand tonnes and less, the limit in "zone 1" (the eastern part of the Bering Sea shelf) is 32 thousand red king crab individuals. If the spawning stock is >6.7 thousand tonnes, but <24.9 thousand tonnes, the limit will equal 97 thousand individuals. The highest bycatch threshold is set at 197 thousand red king crabs. Upon reaching this limit, bottom trawling in the area will be closed until the end of the year or season.

As in Russia, the red king crab trawl bycatch in the United States cannot be processed and should be returned to its habitat. The control of PSC is carried out using technical means or by observers on board (Fishery management, 2017; Federal Register, 2018; Zheng and Siddeek, 2018; Electronic Code of Federal Regulations, 2019).

With the average weight of a male king crab in the Bering Sea at 2.9 kg (Stevens and Lovrich, 2014), the total weight of permitted bycatch in the United States in "zone 1" in 2018 was about 281 tonnes. Compared with the crab bycatch in the Barents Sea, estimated on the order of thousands of tonnes, such an allowable amount seems small. The United States approach to managing fisheries in the red king crab congestion areas is based primarily on the current state of the stock, not arbitrary norms taken from other documents.

If standards for red king crab bycatch in the Barents Sea were strictly followed, it would interfere with fishing vessels trawling in areas where dense crab aggregations occur. In our opinion, the bycatch rate should be estimated on the spatial distribution and stock status of the current red king crab population and, if necessary, adjust the rates. There is no reason to keep areas closed in which the red king crab fishery has been long absent; however, bottom trawling in areas of mass aggregations of females and juveniles should be restricted or prohibited. We assume that fishing in areas of high or medium red king crab density is unprofitable for a fishing vessel because if a crab injures a fish, it can render the fish unsuitable for processing (Kuzmin and Pavlov, 2000; Pinchukov *et al.*, 2003). Furthermore, it is difficult to remove crabs from the trawl, which delays operations and can damage gear. Thus, recommendations for changing red king crab bycatch standards for bottom trawling in the Barents Sea should come, in our opinion, from the following positions:

(i) The concentration of red king crab has shifted eastwards, and crab fishing vessels have followed them.
(ii) Concentrations of red king crab occupy a significant area in the south Barents Sea, and crabs are distributed in areas with different fishery regulations.
(iii) In areas where significant concentrations of commercial and non-commercial red king crab males and females occur, bottom trawling occurs.
(iv) Fishing vessels, if possible, will avoid dense aggregations of red king crab so as not to damage the gear or the allowable catch.

The commercial stock of red king crab outside the closed area experiences twice the amount of exploitation due to legal trap fishing and bottom trawling. According to Stevens's (1990) estimations, 20–100% of the red king crab bycatch in commercial flounder trawls die. Currently, American experts hold the opinion that 80% of the crabs in the bottom-trawl catch die (Crab Bycatch Overview, 2018).

Nevertheless, even significant red king crab bycatch in bottom trawling does not always threaten crab stocks or fisheries. Stevens (1995) noted that the annual red king crab bycatch varied between 0.1 and 2.9% of the total stock in Bristol Bay and rarely exceeded 0.5%. Armstrong *et al.* (1993) noted that, in some years, red king crab bycatch reached 22% of the total catch in the crab's special fishery. According to the North Pacific Fishery Management Council (USA), the estimated bycatch of king crab in the Bristol Bay trawl fishery in 2013–2017 was 1–3% of the total commercial trap catch of this species.

In the Russian EEZ of the Barents Sea, bottom-trawl bycatch of red king crab can comprise up to 2.9% of the commercial stock and up to 3.3% of the total stock. It should be noted that the results presented here are based on estimations using the production model of 2019 (the most current data at this time). In previous works (Stesko and Bakanev, 2019a, b), the biomass of the red king crab commercial stock was estimated at 90 thousand tonnes using the catch survey analysis model, which did not take into account the data from crab surveys in 2017–2019. Accordingly, the percentage of all crabs and the bycatch of commercial males was about 6 of the total and commercial stocks, respectively. In absolute terms, crab bycatch in the bottom-trawl fishery can equal the catch by the Russian commercial fishery. However, considering that the crews on fishing vessels try to avoid crab aggregations, we suggest that the results of our calculations in the 50% confidence interval have the best probability, but there is no other proof.

Recommendations to improve the management of red king crab and bottom fish fisheries

One of the options for regulating red king crab bycatch in the Barents Sea may be the designation of special areas where the densest accumulation of crabs occurs. Within the area of dense crab accumulation, it is possible to create a protected zone divided into sections. For each section, the number of commercial crab males that can be caught (as bycatch) without loss to the fishery stock in the south Barents Sea can be determined.

Based on data from the trawl surveys, the following measures can be taken:

(i) Classify areas according to the average red king crab catch per hour of trawling.
(ii) Identify areas with "low" red king crab bycatch where the use of trawling fishing gear is favourable.
(iii) Designate two levels of protected areas with fishing restrictions:
    (a) First-level areas are protected areas where the notification principle should operate. Red king crab

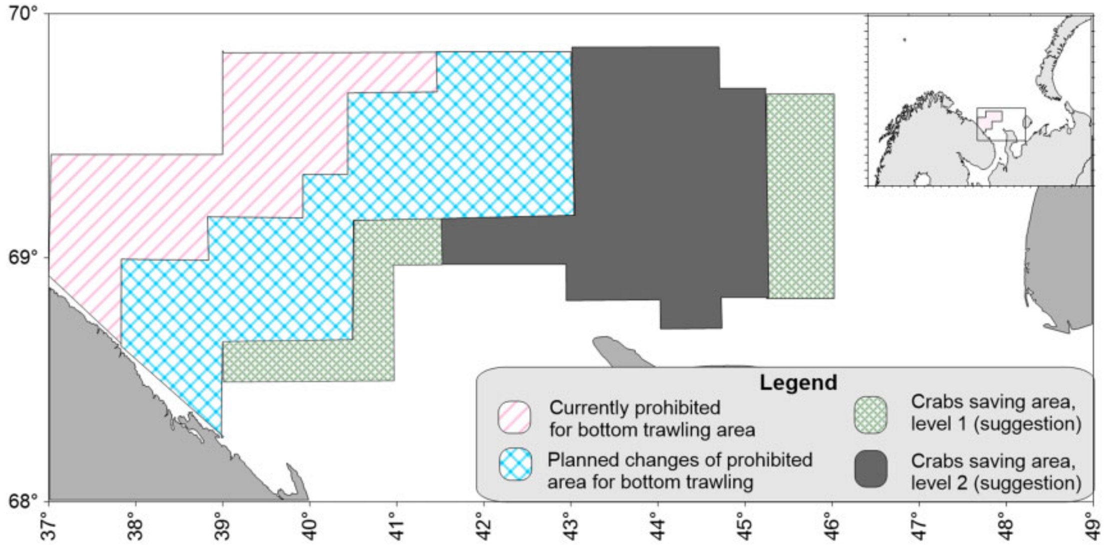

Figure 5. Areas of the Barents Sea that require a special regime for bottom trawling.

bycatch in these areas is classified as "average". The crab catch amount is limited and based on the results of research proposed by research institutions. The total bycatch is calculated on the basis of catch standards (trawling per hour) and on the vessels' daily reports. Upon reaching 90% of the catch limit, fishing vessels will be warned, and upon reaching 100%, they must leave the fishing area. Due to crab migration, the catch limit can be calculated for each season. Another option would be direct limitation of total trawling hours or restriction of the presence of vessels in the area. Thus, the catch limit can be calculated two ways: (i) based on daily catch reports and (ii) by calculating trawling hours based on data from technical control means and daily reports. The second way seems more reliable because it reduces the possibility of reporting false catch information.

(b) Second-level areas are areas with "high" red king crab bycatch. In this case, fishing should be allowed only if an objective scientific observer is on board the vessel. In our opinion, it would be useful to require the observer to take photographs and/or video recordings of every catch taken aboard. The necessity of such measures is dictated by the high probability of crab bycatch, which can significantly exceed any established standards and require direct registration by the observer or control by inspectors.

The bycatch of red king crab juveniles and female should be registered. For example, if their percentage in a catch is >50%, it may force closure of the area to trawling or establish a given area as a special protected regime. The complete closing of an area is unwelcome due to the sea flounder fishery in the south Barents Sea.

At the present time, the assessment of red king crab bycatch in the bottom-trawl fishery is not taken into account in biomass prognosis. In the future, king crab bycatch should be assessed and included in the calculations along with the other parameters. Based on foreign research, the red king crab mortality rate in trawls is 80%. The mortality rate should be clarified for the Barents Sea as well.

As an additional measure, we can propose the use of selective gears (devices) for bottom trawls to be used in areas with red king crab accumulations. Experimental fisheries have shown their effectiveness, and further improvement of such devices will help to minimize bycatch of invertebrates. Vessels using this selective fishing gear should be provided with incentives, such as fishing without an observer on board or reducing the limit of trawling hours in certain areas. It is our opinion that all areas currently adjacent to the present area closed for trawling (A1, C1–C4, D1–D3) also need protection (Figure 5).

To increase the efficiency of the bottom-trawl fishery in 2020, the boundaries of the closed area are planned to be changed. The area will be reduced in the west. Expansion of the area to the east is not yet planned. In the future, it is possible to stop the practice of a year-round trawling ban across much of the area, with the exception of areas where accumulations of red king crab juveniles and females are registered. Special measures of fishing regulations will probably replace year-round bans in the future.

Conclusions

Annual red king crab bycatch in 2016–2018 in the bottom-trawl fishery was estimated in the range of 2.2–9.8 thousand tonnes, which comprises 0.7–2.9% of the total biomass of the red king crab stock in the Russian EEZ in the Barents Sea. The catch of commercial males can reach 3.3% of the total commercial crab stock in the EEZ.

Annually, in the period 2006–2018 in the area closed to bottom trawling, 1.1–4.8 thousand tonnes of crab could have been caught if it had been opened to fishing, and the total catch could have been 14.3–62.4 thousand tonnes. However, the largest calculated red king crab bycatch is registered in the Kaninskaya Bank area (C1–C4), where bottom trawling is currently permitted across most of the area. The effectiveness of the current borders of the area closed to trawl fishing is not as high now as it was before the main crab stock migrated eastward into the closed area. Nonetheless, the practice of closing areas to bottom trawling in the Barents Sea works well.

Current Russian standards for red king crab bycatch in the bottom-trawl fishery are not effective. It does not save crab stock and interferes with the bottom fish fishery.

Measures to protect the red king crab stock should be based on scientific data of commercial and total crab stock including spatial distribution, abundance, size, and composition.

In addition, banning the practice of year-round closure of certain areas in the Barents Sea and replacing it by conservation areas with special fishery regimes can be considered. The control of the fishery can be done by limiting the effort or time spent by vessels in a particular area, as well as by the presence of an objective scientific observer on board documenting catches with photographs and video recordings.

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