Efficiency and catch dynamics of collapsible square and conical crab pots used in the red king crab (*Paralithodes camtschaticus*) fishery

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Abstract—We compared the capture efficiency and catch dynamics of collapsible square and conical pots used in resource assessment and harvesting of red king crabs (*Paralithodes camtschaticus* [Tilesius, 1815]) in the Barents Sea. After two days of soaking, square pots caught three times as many crabs as conical pots, and their catches consisted of a higher proportion of male crabs and male crabs larger than 160 mm carapace length compared to the catches in the conical pots. Catches in the square pots did not increase as soak times were increased beyond two days, which indicates equilibrium between the rate of entries into and the rate of exits from the pots. Catches in conical pots, however, increased with increasing soak times up to eight days, the longest soak time examined in this study. These findings demonstrate the higher efficiency of square pots and the importance of understanding catch dynamics when making population assessments based on catch-per-unit-of-effort data. The favorable catch characteristics and handling properties of the collapsible square pot may make this pot design suitable for other crab fisheries, as well.

Manuscript submitted: 16 January 2007.
Manuscript accepted 3 August 2007.
Fish. Bull. 106:40–46 (2008).

The introduction of red king crab (*Paralithodes camtschaticus* [Tilesius, 1815]) (RKC) in the Barents Sea in the 1960s led to a commercial pot fishery in this area. In Norwegian waters, surveys conducted with conical pots in order to estimate population abundance on the basis of catch-per-unit-of-effort (CPUE) data began in 1993. In 2002, the first licenses for commercial fishing of RKC were issued. To harvest this new resource, an efficient, selective, and habitat-friendly fishing gear is required. Only small coastal fishing vessels (<15 m) are licensed in the Norwegian RKC fishery and these vessels are too small to effectively operate large rigid pots. Initially, conical pots were used because they have been used in the Russian and Japanese fishery for king crabs (Ivanov, 2002). Preliminary studies with a modified square, collapsible cod pot showed higher catches, and according to the fishermen, the square pot had better handling properties than the conical pot. The industry therefore requested adoption of this modified square pot design in the RKC fishery.

The introduction of new fishing gear in the commercial fishery, and subsequently in population assessments, requires a knowledge of its catching properties in order to ensure sustainable harvesting practices and to interpret changes in CPUE data (Hilborn and Walters, 1992; Nizyaev and Bukin, 2002). Thus, before the collapsible square pot was adopted, fishing trials had to be carried out to compare the catching efficiency and selection characteristics of the square pot with those of the conical pot.

Fishing with pots without escape-preventing devices (e.g., triggers or soft-eyed entrances) is a dynamic process, in which the ratio of crabs entering the pot to those escaping the pot usually decreases as soak time increases (Zhou and Shirley, 1997a; Watanabe and Yamasaki, 1999). Our fishing trials were therefore carried out with soak time as an explanatory variable.

The objectives of the experiment were to compare the two different pot designs with regard to 1) catch efficiency, 2) size distribution and sex ratio of the catch, and 3) the degree to which these characteristics (catch efficiency, size distribution, and sex ratio) are affected by soak time. Such

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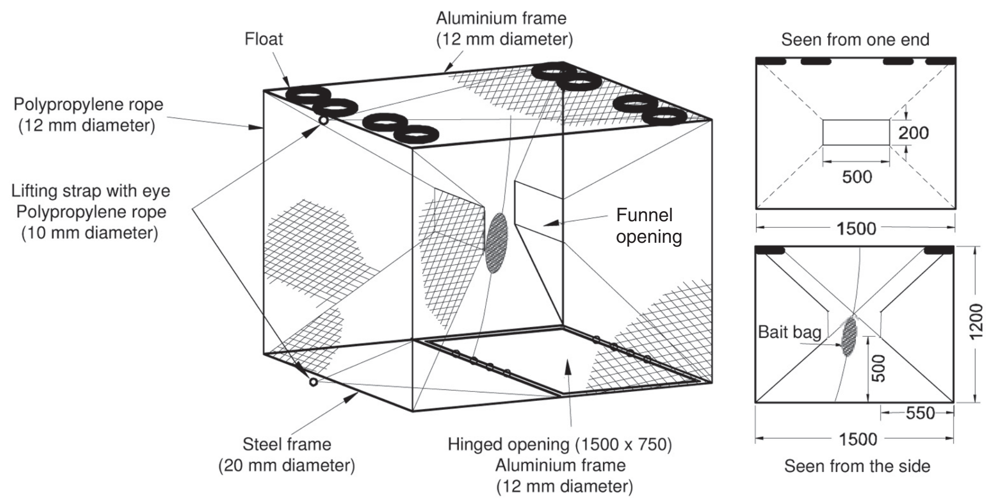

Figure 1

Drawing of the square pot design used to capture red king crab (*Paralithodes camtschaticus*). The frame is lined with 3-mm braided polyethylene netting with a mesh size of 100 mm. The 20-cm long bait bag is made of polyamide netting and has a mesh size of 22 mm. The pot weighs 37 kg out of water. All pot dimensions are in mm.

information is crucial for both improved population estimates and resource-friendly harvesting practices.

Materials and methods

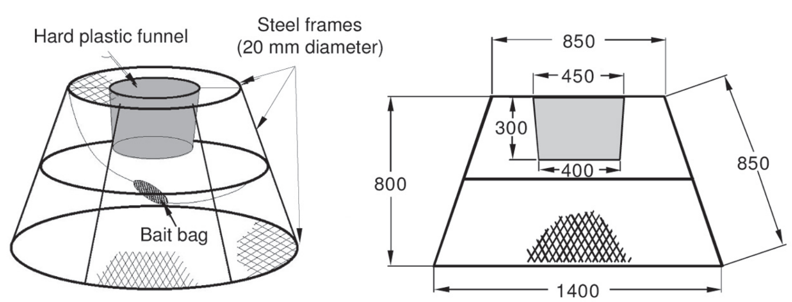

Figure 2

Drawing of the conical pot design used to capture red king crab (*Paralithodes camtschaticus*). The frames are made of 20-mm steel bars and lined with 4-mm polyethylene diamond netting with a mesh size of 150 mm. The 20-cm long bait bag is made of polyamide netting with mesh size of 22 mm. The pot weighs 17 kg in air. All pot dimensions are in mm.

The square pot (Fig. 1) had two funnel-shaped entrances with outer openings of 150×120 cm. The entrance area thus made up half of the pot's horizontal circumference. The netting used to line the frames had a mesh size of 100 mm. The 20-cm long bait bag was made of small-mesh netting (22 mm mesh size) and was placed in the center of the pot between the entrance openings. The weight of the pot out of water was 37 kg. The funnel of the conical pot (Fig. 2) was made of hard plastic, had an outer diameter of 45 cm, and was located at the top of the pot. The mesh size of the netting liner was 150 mm. A bait bag similar to that used in the square pots was located at the center of the pot, 10 cm below the inner funnel opening. The weight of the pot out of water was 17 kg.

The fishing trials were carried out between 19 October and 6 November 1998 in the Varangerfjord (close to the Russo-Norwegian border) (Fig. 3), which is the area with the highest density of RKC in Norwegian waters. Four commercial coastal fishing vessels of 10–12 m length were chartered for the experiment. The pots were set at depths of 50–250 m on silty and muddy bottom substrates.

Each vessel fished with 24 pots, arranged in six strings—each string consisting of two square and two conical pots (Fig. 4). The two types of pots were attached alternately to a 12-mm diameter rope at intervals of about 30 m, a between-pot distance commonly used by commercial fishermen. Each pot was baited with about 1 kg of chopped (~2 cm pieces), thawed Atlantic herring (*Clupes harengus*).

The analyses were based on the 112 string settings where there was catch in at least one of the four pots.

Four different categories of soak times were analyzed. The strings that were given a nominal two days of soak time (as is commonly used in commercial fishing) were physically in the water for 36 to 57 h (N = 61 string settings; mean=46.7 ±0.5 SE, standard error). The strings that were given three days of soak time were left out for 68 to 78 h (N= 30 string settings; mean=71.6 ±0.5 SE). Strings that were soaked for 90 to 120 h were classified as soaking for four to five days (N=8 string settings; mean=107.4 ±3.6 SE). A soak time of seven to eight days was ascribed to strings that were left to fish for 167 to 192 h (N=13 string settings; mean=176 ±3.0 SE).

During pot hauling, the sex of the crabs was identified and the carapace length (CL) was measured to the nearest millimeter with a caliper gauge (Zhou and Shirley, 1997b). The difference in mesh size between the square (100-mm mesh) and conical pots (150-mm mesh) may have contributed to differences in catchability of the smallest crabs. All crabs below 91 mm CL (a total of 54 crabs in the square pots and 16 in the conical pots) were therefore excluded from the length analysis because crabs with a CL of up to 90 mm are capable of escaping through a 152-mm mesh (Zhou and Shirley, 1997c).

The pooled catch of crabs from the two pots of the same type within a string was used as a single observation in the statistical analyses to prevent inflation of tests by the use of pseudoreplicates (here: individual pots of the same type in the same string) and to minimize the effects of current (Sinoda and Kobayasi, 1969; Vienneau et al., 1993), and differences in depth, bottom conditions, and patchy distribution of the crabs (Wallace et al., 1949; Zhou and Shirley, 1998).

The catch and length observations were not normally distributed. Non-parametric statistics were therefore employed in the analyses. Paired comparisons (Wilcoxon test) of catch of RKC in square and conical pots in each string were carried out for each soak time. The Kruskal-Wallace one-way analysis of variance of ranks (Zar, 1999) was used to test for whether catch rates varied with soak time within each type of pot. The size composition of male and female crabs in the square and conical pots was com-

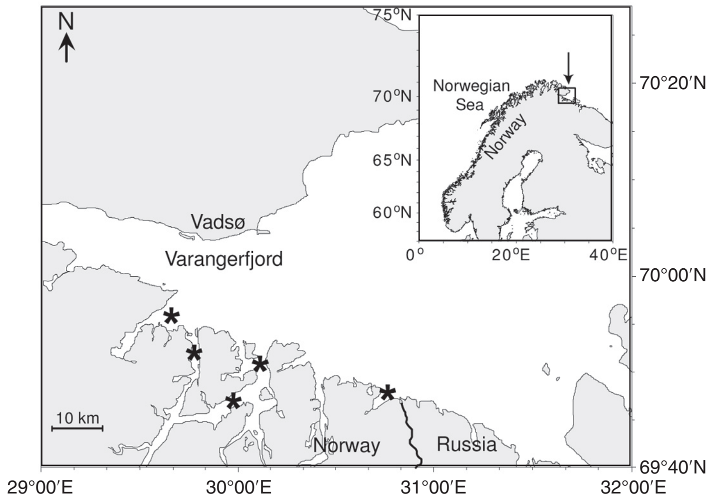

Figure 3

Map of the study area where the square and conical pots were used to capture red king crab (*Paralithodes camtschaticus*). Sampling locations are marked with asterisks.

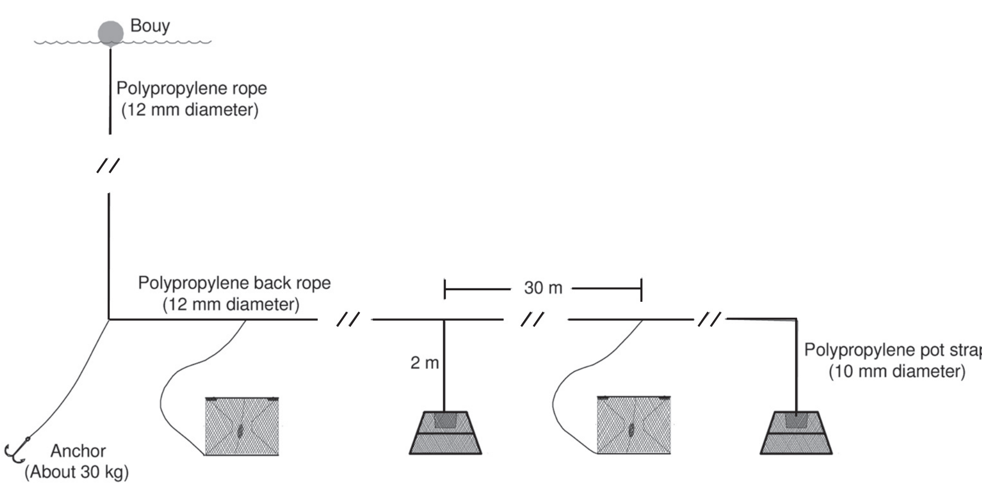

Figure 4

Drawing of the rigging formation used to capture red king crab (*Paralithodes camtschaticus*) in square and conical crab pots. Square and conical pots were arranged alternately along the string.

Table 1

Catch data from the comparative fishing experiment with square and conical red king crab (*Paralithodes camtschaticus*) pots. Total catch and catch by sex of red king crab (*Paralithodes camtschaticus*) at different soak times is shown. Within-string catches of red king crab for square and conical pots were compared by using a Wilcoxon paired comparisons test. n_p is number of pot settings for each type of pot, and N is the number of strings with nonzero catch. SE = standard error.

		Number of crabs caught							
		Square pots			Conical pots			Paired comparisons	
Soak time (days)	n_p	Median	Mean	SE	Median	Mean	SE	N	P value
Males									
2	122	12.0	14.9	0.86	2.0	3.5	0.37	61	<0.001
3	60	14.0	13.9	1.04	5.0	6.2	0.66	30	<0.001
4–5	16	10.0	10.9	1.26	5.0	6.0	0.90	8	<0.05
7–8	26	13.0	14.0	1.68	9.0	9.7	1.43	13	>0.05
Females									
2	122	15.0	16.1	1.02	5.0	6.2	0.53	61	<0.001
3	60	18.0	17.4	136	12.0	11.5	1.08	30	<0.001
4–5	16	20.5	19.6	3.57	11.0	10.6	1.10	8	>0.05
7–8	26	20.0	21.2	1.56	18.0	17.8	1.69	13	>0.1
Total catch									
2	122	29.0	31.0	1.66	7.5	9.7	0.79	61	<0.001
3	60	32.0	31.3	1.81	15.5	17.6	1.43	30	<0.001
4–5	16	29.0	30.5	3.90	15.5	16.6	1.33	8	<0.05
7–8	26	34.0	35.2	2.83	26.5	27.5	2.54	13	<0.05

pared by means of the Mann-Whitney U-test for each soak time.

A Wilcoxon test was used to test for differences between the pot types in the proportion of male crabs and males that were larger than 160 mm CL (the smallest commercial size in the Norwegian RKC fishery). In order to reduce the effect of small sample size (Zar, 1999), proportions equal to zero were replaced by $1/4n$ (where n is the denominator in the calculation of the original proportion) and proportions equal to one were replaced by $1-(1/4n)$. Only observed data on strings with catches in both types of pots were included in these analyses. All statistical tests were performed with Statistica, vers. 8.0 (StatSoft Inc., Tulsa, OK).

Results

The square pots caught significantly more crabs than the conical pots at all soak times (Table 1). At the shortest soak times, the catch ratio of square to conical pots exceeded 3:1, whereas the mean ratio (square:conical) for the two longest soak times was close to 3:2. Except for the longest soak time, the square pots caught more of both male and female crabs (Table 1, Fig. 5). Total catches and the catches of both male and female crabs in the conical pots increased with increasing soak time ($P<$ 0.001), but catches in the square pots did not increase beyond two days of soak time.

The percentage of male crabs in the catch was higher in the square than in the conical pots after the two, three, and four to five days of soak time (Table 2). The difference was greatest for the shortest soak times because the proportion of female crabs in the square pots increased with increasing soak time ($P<0.05$). No significant changes were found in the percentage of female crabs taken in conical pots over time.

The overall percentages of male crabs larger than 160 mm were 60% (SE=3) and 50% (SE=3) in the square and conical pots, respectively. At all soak times, the proportion of male crabs larger than 160 mm was significantly higher in the square pots ($P<0.001$, Fig. 5). The median length of males was larger in the square pots for all but the longest soak time tested (Table 3). There were no differences between the types of pots with respect to the size of female crabs caught.

Discussion

The square pots caught up to three times more red king crab than the conical pots, but the difference decreased with increasing soak time. Provided that the two types of pots attracted equal numbers of crabs (identical bait was used), the differences in catches must be due to different rates of entry versus exit. Because escape rates from the conical pot have been shown to be low (Godøy et al., 2003), the low catch rate for the conical pot was presumably due to low entry rates. RKC and other species of crabs have been shown to restrict their horizontal search movement to the area suffused by the odor plume from the bait (Miller, 1980; Zhou and Shirley, 1997c; Archdale et al., 2003). However, the differences in the probability of crabs finding their way into the two pots is not explained by the size of the horizontal entrance sector (area available for entry) because the less efficient conical pots had an entrance sector of 360°, whereas only half of the perimeter of square pots led to a funnel opening. Vertical search behavior of chemically stimulated RKC has also been observed to be limited to the extent of the odor plume (Stiansen, 2004). In the square pot, the bait and funnel were at the same vertical height, whereas the entrance of the conical pot was located above the plume. Crabs were seldom observed to search for the source of the odor outside the odor plume (Miller, 1978; Vienneau, 1993; Stiansen, 2004), which they have to do to locate the entrance of conical pots.

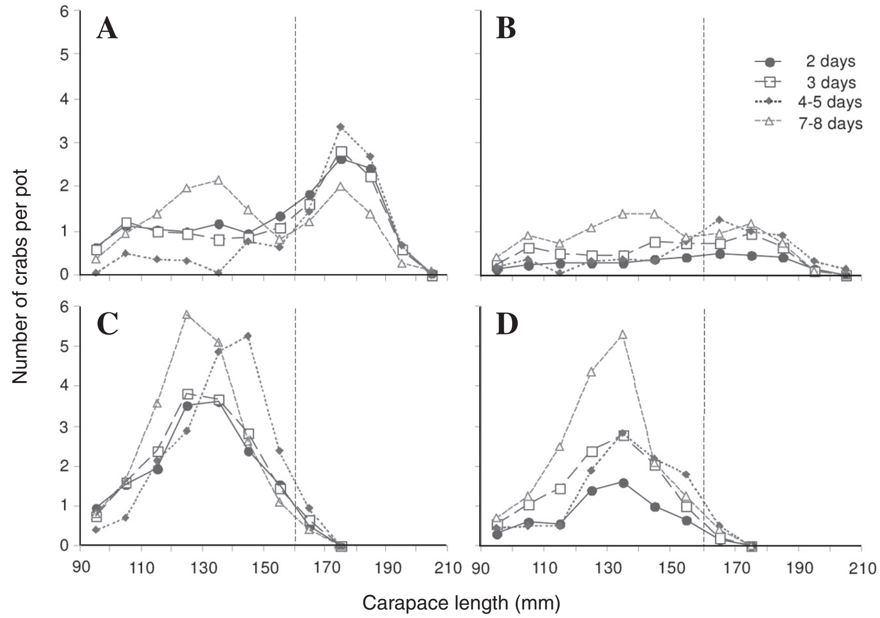

Figure 5

Size distribution of red king crabs (*Paralithodes camtschaticus*) caught in the comparative fishing experiment. The four panels give the size distribution of (**A**) male crabs in square pots; (**B**) male crabs in conical square pots, (**C**) female crabs in square pots, and (**D**) female crabs in conical pots. The *x*-axis is divided by size intervals of 10-mm carapace length. Note that the minimum commercial landing size of male crabs is 160 mm, marked with a vertical dashed line.

Although the catches in the conical pots continued to increase beyond two days of soak time, the catch appeared to stabilize in the square pots, indicating that the two pot types were at different phases of the catch cycle even after two days of soak time. An approximately linear increase in catches with time in the conical pots indicates that the ratio of entries to exits was relatively constant throughout the period of observation. The vertical plastic funnel used in the conical pots effectively prevents crabs from escaping (Miller,

Table 2

Catch data from the comparative fishing experiment with square and conical red king crab (*Paralithodes camtschaticus*) pots. Median and mean percentages of female red king crabs in catches taken by square and conical pots at different soak times are shown. Calculations were made on a string basis, i.e., the pooled catch from the two pots of the same type within a string was used as a single observation. The hypothesis of no difference in percentage of females in square and conical pots was tested by a Wilcoxon paired comparisons test. Only string settings with catch in both types of pots were used in the test. N is the number of strings with nonzero catches, SE is the standard error, and N_b is number of strings with catch in both types of pot.

	Percentages of female crabs caught								Statistical test	
	Square pots				Conical pots				Paired comparisons	
Soak time (days)	N	Median	Mean	SE	N	Median	Mean	SE	N_b	P value
2	57	53.4	51.0	2.17	52	66.7	63.8	2.46	51	<0.001
3	29	56.5	52.0	4.21	27	71.0	66.4	3.76	26	<0.005
4–5	8	65.9	58.2	8.31	8	69.8	63.3	6.82	8	<0.05
7–8	13	62.9	62.2	2.82	13	65.3	67.0	4.30	13	>0.5

Table 3

Catch data from square and conical pots used to capture red king crab (*Paralithodes camtschaticus*). Median and mean carapace length of male and female red king crabs caught by the two types of pot at different soak times are shown. The length distributions were compared by means of a nonparametric Mann-Whitney *U* test for each soak time. *n* is the number of crabs caught, SE is the standard error.

	Carapace length of crabs caught (mm)								
	Square pots				Conical pots				
Soak time (days)	*n*	Median	Mean	SE	*n*	Median	Mean	SE	*U* test *P* value
Males									
2	1797	161	154	0.69	412	154	150	1.38	<0.01
3	823	164	154	1.04	369	151	148	1.44	<0.001
4–5	232	174	168	1.46	95	166	159	2.37	<0.01
7–8	364	142	146	1.42	250	142	143	1.65	>0.2
Females									
2	1954	131	130	0.39	755	132	131	0.60	>0.1
3	1030	130	130	0.53	683	131	130	0.63	>0.7
4–5	312	139	137	0.85	170	137	136	1.22	>0.6
7–8	548	129	128	0.62	463	131	130	0.67	>0.05

1990; Cyr and Sainte-Marie, 1995), and it is not until catches are large, and crabs (by climbing on top of each other) can reach to the funnel top, that the entry and exit rates reach equilibrium (Zhou and Shirley, 1997a). The linear increase in catches, the relative low catches, and the stable sex ratio (60% females) until seven to eight days of soak time indicated that the exit rate was low for the conical pots.

Unlike the catch in the conical pots, the amount of catch taken by the square pots did not increase after two days of soak time as was also observed by Zhou and Kruse (2000) who used a different square-pot design. The initially high rate of entry into pots may lead to the bait being eaten within a short time and to the result that few additional crabs are attracted into the pot. In addition, the likelihood of escape should be higher for square pots that have two horizontally orientated funnels, which are placed lower and made of netting that enable crabs to climb up the funnel and escape (Zhou and Shirley, 1997c).

The square pots caught a higher proportion of male crabs and male crabs larger than 160 mm CL than did the conical pots. If the largest crabs take longer to escape than small crabs, large crabs will accumulate in the square pots over the course of time. Sexual dimorphism, where the two sexes have different probabilities of leaving the square pot, would result in more males in the catch. Although large crabs accumulated in the square pots over time, the proportion of female crabs increased from 50% to 60% with longer soak time. This increase may also be explained by sex-dependent escape probability. Generally, total body length and height (critical dimensions in entering and escaping) are greater for females than for males of the same carapace length (Zhou and Shirley, 1997b), and the differences increase with increasing carapace length. Thus, at a carapace length of 100 mm, Wallace et al. (1949) found female crabs to be 6 mm longer and 11 mm taller than male crabs with the same carapace length. Moreover, in the autumn (the season of this study) most female crabs larger than 100 mm CL were carrying external eggs, which would further increase body length and height. Motivational differences related to sex and condition may also have influenced the ability of RKC to climb into and out of pots (Zhou and Shirley, 1997c).

The catch characteristics and design (collapsible) of the square pots make them highly suitable for commercial fishing. This pot design may also prove to be efficient and practical in other regions, e.g., in the Alaskan king crab and Tanner crab (*Chionoecetes bairdi*) fisheries. The size selection of the square pots resulted in them taking five times as many large male crabs (>160 mm CL, approximately 3.5 kg) as the conical pots after two days of soak time. The selectivity and catch efficiency of the square pots also resulted in a 50% reduction in the catch of females and males smaller than 137 mm CL (minimum legal landing size). Even though discard mortality should be minimal with correct on-deck handling, there is nevertheless the likelihood that some crabs are injured, e.g., spines, rostrum, and limbs can be damaged during handling (Zhou and Shirley, 1995). RKC without all legs intact are of no commercial value and have to be discarded. This problem would be mitigated with the use of square pots. A further advantage of the square pot over the conical pot is that the higher escapement rate afforded by the square pot reduces crab mortality at sea when pots that are lost at sea continue to fish (ghost fish); the pots used in the

Norwegian fishery do not at present contain a degradable escapement panel. Such panels are mandatory in some regions, such as Alaska.

Catch rates, sex ratio, and size distribution were clearly different for square and conical pots. CPUE data from the square pots will provide much higher estimates of the exploitable part of the population (i.e., large male crabs) than data from conical pots. Large differences were also observed in the catch dynamics; the square pot reached equilibrium at much shorter soak times than did the conical pot. Gear saturation may lead to underestimation of population abundance at high densities of crabs. In an area with high crab density, no effects of increasing soak time beyond two days were found (Zhou and Kruse, 2000), and smaller pots underestimated population density to a higher extent than did the larger pots (Nizyaev and Bukin, 2002). The relationship between pot design, catch dynamics, and selectivity observed in the present study demonstrates the importance of adjusting for and standardizing the duration of soak time when CPUE data from pots are used in population assessments. Most importantly, when using effective pots like the square pot tested in this study, soak time needs to be short in order to prevent underestimation of population size and biased sex and size distributions.

Acknowledgments

The authors are grateful for the invaluable comments and advice from the referees and the editorial staff. We also thank B. K. H. Ulvestad and A.-B. S. Tysseland for preparing the figures.

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