Evaluation of Alternative Harvest Strategies for Bristol Bay Red King Crabs

By

Jie Zheng

Regional Information Report[1] No. 5J03-04
Alaska Department of Fish & Game
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P.O. Box 25526
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March 19, 2003

[1] The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series undergo only limited internal review and may contain preliminary data; this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or the Division of Commercial Fisheries.

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AUTHOR

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EXECUTIVE SUMMARY

The North Pacific Fishery Management Council's Crab Plan Team received requests from Industry in September 2002 to consider an intermediate step between 10% and 15% in the Bristol Bay red king crab (*Paralithodes camtschaticus*) mature male harvest rate. That request was supported by many members of the Pacific Northwest Crab Industry Advisory Committee. The Crab Plan Team unanimously requested the Alaska Department of Fish and Game to analyze the Bristol Bay red king crab harvest strategy relative to two alternatives: (1) an intermediate exploitation rate of 12.5% when the stock is between 34.75 and 55 million pounds of effective spawning biomass (ESB; Zheng et al. 1995); and (2) a continuous linear function for the mature male harvest rate, increasing from 10% at threshold to 15% when ESB is at or above 55 million pounds. Two more alternatives are also evaluated in this report: (3) a continuous linear function for the mature male harvest rate, increasing from 7% at threshold to 15% when ESB is at or above 55 million pounds; and (4) a continuous linear function for the mature male harvest rate, increasing from 9% to 13% when ESB is between threshold and 55 million pounds, and a mature male harvest rate of 15% when ESB is at or above 55 million pounds.

The status quo and these four alternative harvest strategies were compared through computer simulations in terms of mean annual yield, fishing opportunity, mature crab abundance and biomass, and probabilities below minimum stock size threshold and biomass at maximum sustained yield. Under the likely stock–recruitment relationship and handling mortality rate, the status quo and Alternatives 1 and 4 are preferred over Alternatives 2 and 3. Performance of both Alternative 1 and the status quo is very close. Alternative 1 has slightly higher mean yield than the status quo, but its ESB, mature biomass, and mature abundance are slightly lower than the status quo, and it also has a slightly higher probability of fishery closure. Overall, Alternative 1 may increase the yield marginally in the near future whereas the status quo may offer a slightly better protection of the stock. Alternative 4 offers a compromise between Alternative 1 and the status quo and has smoother harvest rates than these two strategies.

ISSUES AND PURPOSE

The North Pacific Fishery Management Council's Crab Plan Team received requests from Industry during their September 19–20, 2002 meeting to consider an intermediate step between 10% and 15% in the Bristol Bay red king crab mature male harvest rate. That request was supported by nine of the Pacific Northwest Crab Industry Advisory Committee members available for comment. The Crab Plan Team unanimously endorsed evaluation of this alternative and requested the Alaska Department of Fish and Game to analyze the Bristol Bay red king crab harvest strategy relative to two alternatives: (1) an exploitation rate of 12.5% when the stock is between 34.75 and 55 million pounds of effective spawning biomass (ESB; Zheng et al. 1995); and (2) a continuous linear function for the mature male harvest rate, increasing from 10% at threshold to 15% when ESB is at or above 55 million pounds (Minutes of the Bering Sea/Aleutian Islands Crab Plan Team Meeting, September 19–20, 2002, NPFMC, Anchorage, AK).

The purpose of this report is to evaluate these and other alternative harvest strategies for the Bristol Bay red king crab fishery. A brief history of the harvest strategies is presented. Then, the computer-simulated results for alternative harvest strategies are summarized and compared. Finally, merits for each alternative harvest strategy are discussed.

HISTORY OF HARVEST STRATEGIES

Harvest strategies for the Bristol Bay red king crab fishery have changed over time. The fishery is managed by the State of Alaska with federal oversight (NPFMC 1998). Two major management objectives for the fishery are to maintain a healthy stock that ensures reproductive viability and to provide for sustained levels of harvest over the long term (ADF&G 2000). In attempting to meet these objectives, guideline harvest levels (GHLs) are coupled with size-sex-season restrictions. Only males =6.5-in carapace width (equivalent to 135-mm carapace length, CL) may be harvested and no fishing is allowed during molting and mating periods (ADF&G 2000). Specification of GHLs is based on a harvest rate strategy. Before 1990, harvest rates on legal males were based on population size, abundance of prerecruits to the fishery, and postrecruit abundance, and varied from less than 20% to 60% (Schmidt and Pengilly 1990). In 1990, the harvest strategy was modified, and a 20% mature male harvest rate was applied to the abundance of mature-sized (=120-mm CL) males with a maximum 60% harvest rate cap of legal (=135-mm CL) males (Pengilly and Schmidt 1995). In addition, a threshold of 8.4 million mature-sized females (=90-mm CL) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings, the Alaska Board of Fisheries adopted the current harvest strategy in 1996. The current strategy has two mature male harvest rates: 10% when ESB is between 14.5 and 55 million pounds and 15% when ESB is at or above 55 million pounds (Zheng el al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. An additional threshold of 14.5 million pounds of ESB was also added. In 1997, a minimum threshold of 4 million pounds was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low.

ALTERNATIVE HARVEST STRATEGIES

Five alternative strategies are evaluated in this report:

1. **Status quo**: a mature male harvest rate of 10% when ESB is between 14.5 and 55 million pounds and 15% when ESB is at or above 55 million pounds.

2. **Alternative 1**: a mature male harvest rate of 10% when ESB is between 14.5 and 34.75 million pounds, 12.5% when ESB is between 34.75 and 55 million pounds, and 15% when ESB is at or above 55 million pounds.

3. **Alternative 2**: a continuous linear function for the mature male harvest rate, increasing from 10% at threshold to 15% when ESB is at or above 55 million pounds.

4. **Alternative 3**: a continuous linear function for the mature male harvest rate, increasing from 7% at threshold to 15% when ESB is at or above 55 million pounds.

5. **Alternative 4**: a continuous linear function for the mature male harvest rate, increasing from 9% to 13% when ESB is between threshold and 55 million pounds, and a mature male harvest rate of 15% when ESB is at or above 55 million pounds.

The alternative strategies are illustrated in Figure 1. Except for the mature male harvest rates, all other elements of the current harvest strategy are the same for all five alternative strategies:

(1) Three thresholds: 8.4 million mature females, 14.5-million pound ESB, and 4-million pound minimum GHL; and
(2) Maximum harvest rate on legal males: 50%.

EVALUATION OF ALTERNATIVE HARVEST STRATEGIES

Approach

The length-based model (Zheng et al. 1995) was used in computer simulations to evaluate alternative harvest strategies for Bristol Bay red king crabs. Both male (=95-mm CL) and female (=90-mm CL) components of the stock were simulated in the model. Model parameters for simulations are those estimated during the 2002 stock assessment (Vining and Zheng 2003). Molting probabilities for males and natural mortality for both males and females are variable over time in the assessment model. Average of molting probabilities by size for males from 1980 to 2000 and the modes of estimates of natural mortality for both males and females were used for the simulations.

A stock-recruitment (S–R) relationship predicts likely recruitment of progeny from a given spawning stock size and has important implications for harvest strategies. The S–R relationship for Bristol Bay red king crabs was updated using the recruitment and ESB time series estimated in 2002 (Figure 2). Note that the strong recruitment primarily came from hatching years before 1976. It may not be realistic to expect such strong recruitment to occur in the near future because of the regime shift in climate and physical oceanography that occurred in 1976–77 (Hare and Mantua 2000). Note also that the Crab Plan Team does not consider levels of mature biomass prior to 1983 to be representative of that attainable under the current environmental conditions (NPFMC 1998). Therefore, the alternative harvest strategies were evaluated under the environmental conditions since 1976. A Ricker S–R curve (solid line) was fit to the S–R data (open circles) from hatching years after 1975 (Figure 2). Alternatively, a general S–R curve (dotted line) was optimally estimated using all S–R data from hatching years 1969–1995, and environmental noises modifying recruitments estimated from the S–R curve were derived from the S–R data from hatching years 1976–1995 (Figure 2). Both curves were used in the computer simulations.

The primary features of the simulation scenarios and options are as follows:

- The model was initialized with data on the population status for 2002.

- Natural mortality (*M*) is 0.2 for males and 0.35 for females based on the modes of estimates of natural mortality for both males and females from the length-based model.

- Selectivities for the directed pot fishery bycatch and retained males (Figure 3) were estimated by comparing survey abundance and estimated bycatch from 1991 to 2001.

- The current biomass at maximum sustained yield (B_{msy}, 89.6 million pounds, NPFMC 1998) is defined for both male and female red king crabs based on maturity schedule by CL. Because the model estimates abundance only for males ≥95-mm CL and females ≥90-mm CL and the current harvest strategy defines males ≥120-mm CL and females ≥90-mm CL to be mature, B_{msy} has to be approximated in the simulations. Based on the model estimates of crab abundances from 1983 to 1997, an equivalent B_{msy} was approximated as 77.0 million pounds of male crabs ≥120-mm CL and female crabs ≥90-mm CL.

- For each alternative strategy, the population and fishery were simulated for 35 years with 2000 replicates. The average population status, probability below the overfished level (the percentage of replicates below the overfished level), loss of fishing opportunity (the percentage of replicates with fishery closure), and mean yield from the simulations were summarized to compare the alternative harvest strategies.

- Recruitment was modeled with two approaches: (1) the Ricker S–R curve estimated from the S–R data during hatching years of 1976–1995 with log-normal noises (solid line, Figure 2), and (2) the general S–R curve estimated from the S–R data during hatching years of 1969–1995 with environmental noises being random sampling from noise estimates from hatching years of 1976–1995 (dotted line, Figure 2). Assumption (1) was used as the base model and assumption (2) for sensitivity studies.

- Handling mortality rate of captured, but discarded sublegal males was assumed to be 20% for the directed crab fishery. The sensitivities of the results to handling mortality rates of 0 and 50% were also investigated.

- The annual groundfish trawl bycatch was assumed to be the upper bound on red king crab bycatch set for the Bering Sea groundfish fisheries in the simulations, i.e., 97,000 red king crabs annually when ESB is below 55 million pounds and 197,000 red king crabs annually when ESB is at or above 55 million pounds. Handling mortality rate of trawl bycatch was assumed to be 80%.

- Standard deviation for log-normally distributed measurement (assessment) error was assumed to be 0.2.

Results and Discussion

Simulated results are summarized in Table 1. With the base model (the Ricker S–R curve and 0.2 handling mortality rate), mean yields do not differ greatly among five alternative strategies; mean yields range from 8.17 million pounds for the status quo to 8.76 million pounds for Alternative 2. The mean yield for Alternative 1 is slightly higher than that for the status quo, but its annual yield is also more variable. ESB, mature biomass, mature female and male abundances are highest for the status quo and lowest for Alternative 2. Percentages of years with fishery closure are highest for Alternative 3 (7.5%) due to low harvest rates when the population abundance is low resulting in GHLs below the 4-million pound minimum. Percentages of years with total mature biomass below B_{msy} are highest (31.7%) for Alternative 2 due to relatively high harvest rates. Because of low recruitment levels used to estimate the S–R relationship, annual ESB is rarely above 55 million pounds for any of the alternative strategies. Under the given S–R relationship, percentages of years with the stock below minimum stock size threshold (MSST) are extremely low for any of the five alternative strategies.

The general S–R curve is more density-dependent and has higher overall recruitment levels than the Ricker S–R curve. Therefore, mean yield, ESB, mature biomass, and population abundance are much higher under the general curve than the Ricker curve. The general S–R curve makes the stock rebuild quickly and favors a harvest strategy with a low harvest rate when the population abundance is low. Under the general S–R curve, the status quo strategy performs best among five alternative strategies: highest mean yield, ESB, mature biomass and mature abundance, and lowest percentages of years with fishery closure. Overall, the results from five alternative strategies are not much different under the general S–R curve.

Handling mortality rate for crab bycatch from the directed fishery is not very well known. Bycatch catchability for large females =90-mm CL and sublegal males 95–134 mm CL was estimated as 50% (relative to 100% for legal males) using the observer data in 1990 and 1991 in previous harvest strategy studies for Bristol Bay red king crabs (Zheng et al. 1997a, b). Observer data since 1991 indicate that bycatch catchability for large females is much lower than 50%. The updated bycatch catchability (or selectivities, Figure 3) was used in this study. Because of low bycatch catchability for females, handling mortality had less pronounced effects in this study than the earlier studies. Overall, higher handling mortality rates decrease mean yield, ESB, mature biomass and mature abundance, and increase percentages of years with fishery closure and with mature biomass below B_{msy} (Table 1). Higher handling mortality rates also favor a more conservative harvest strategy, especially under the general S–R curve.

Based on the results in this study, which alternative strategy should be adopted? The answer to this question depends on the S–R curve and handling mortality rate. If we think that the general S–R curve is likely to prevail during the next two to three decades, then we believe that the current low harvest rate will allow the stock to rebuild quickly. The status quo strategy performed the best under this condition. If we expect the environmental conditions during the last two and half decades to continue into the future, then we believe that the Ricker S–R curve will prevail in the future. Under this condition, if the handling mortality rate is very high, say 50%, the overall performance of the status quo strategy is still the best. If the handling mortality rate is about 20%, as is commonly assumed in king crab studies, the mean yield is higher for Alternative 1, 2, or 4 than that for the status quo and the population abundance decreases only slightly under the Ricker S–R curve. Under this condition, Alternative 1 or 4 is preferred over Alternative 2 because the percentages of years with mature biomass below B_{msy} for Alternative 2 (31.7%) is much higher than that for Alternative 1 (24.4%) or 4 (23.7%). The overall fishing mortality for Alternative 3 is similar to the status quo. However, due to the minimum GHL, the low harvest rates when the population is low for Alternative 3 result in higher percentages of years with fishery closure. Performance of Alternative 4 is between those of the status quo and Alternative 1, yet Alternative 4 has smoother harvest rates than the status quo and Alternative 1.

Using the results of length-based assessments and observer data from 1996 to 2002 and assuming handling mortality rate to be 20% and selectivity, catchability, implementation errors, and abundance assessment errors to be the same for Alternative 1 as for the status quo, we can compare the performance of the status quo and Alternative 1 from 1996 to 2002 after the status quo strategy was adopted. Given that ESB estimated annually during 1996–1998 was either <34.75 million pounds or >55 million pounds, application of the status quo harvest strategy and Alternative 1 would have resulted in the same GHLs. However, for each year during 1999–2002 GHLs were determined under the status quo harvest strategy using a 10% harvest rate on mature males, whereas under Alternative 1 the GHLs would have been set using a 12.5% mature male harvest rate. As a result, during the period since the status quo harvest strategy was adopted in 1996, application of Alternative 1 would have increased mean annual yield by about 11% and decreased total male and female mature biomass by about 2%. Estimates of ESBs are below 34.75 million pounds from 1982 to 1996 (Vining and Zheng 2003), so there would have been no difference between the status quo and Alternative 1 during these years.

Spatial distributions of red king crabs in the eastern Bering Sea went through profound changes during the last three decades (Figure 4). Crab abundance in southern Bristol Bay was high during the 1970s and declined substantially over time after 1979. Female red king crabs were found primarily in central Bristol Bay during 1980–1987 and 1992–2001. Strong recruitment occurred from brood years in the late 1960s and early 1970s, a period when mature female abundance was high in southern Bristol Bay. It is not clear whether the strong recruitment and high mature female abundance in southern Bristol Bay are directly related. One possible cause of the northward movement of red king crabs is the regime shift in climate and physical oceanography that occurred in 1976–77 (Hare and Mantua 2000). Given the regime shift in 1976–77 and change in spatial distributions, the Ricker S–R curve estimated with data after 1975 is more suitable in the near future than the general S–R curve estimated with data from 1969 to 1995. Under the low productivity Ricker S–R curve, the status quo and Alternatives 1 and 4 are preferred over Alternatives 2 and 3 as reasoned in the above paragraph. Performance of the status quo and Alternative 1 is very close. Alternative 1 has slightly higher mean yield than the status quo, but its ESB, mature biomass, and mature abundance are slightly lower than the status quo. Thus, Alternative 1 may marginally increase yield in the near future whereas the status quo may offer slightly better protection of the stock. Alternative 4 offers a compromise between Alternative 1 and the status quo and has smoother harvest rates than both strategies.

Compared to historical high abundances in the 1970s, the current Bristol Bay red king crab population status is quite depressed (Vining and Zheng 2003) and the stock is very unlikely to rebuild to such high abundance quickly under the current low productivity environment. Thus, a conservative harvest strategy is appropriate to assure protection of the stock. The simulations presented here indicate that the chance for the stock to fall below MSST will be extremely low under any of the five alternative strategies if the future stock productivity is the same as the past. However, if the future stock productivity is much lower than we expect based on the past productivity, no harvest strategy will be able to completely prevent stock collapse. Still, a precautionary approach will reduce the chance of prolonged stock collapse.

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Table 1. Comparisons of mean yield (Yield), standard deviation of yield (SD), effective spawning biomass (ESB), total mature biomass (TMB), mature female abundance (Female), mature male abundance (Male), and mean percentages of years with fishery closure (Closure), below minimum stock size threshold (<MSST), below B_{msy} (<B_{msy}) and below 55 million pounds of ESB (<15%HR) during 35 years after year 2002 under five management alternatives with different levels of handling mortality rates (HM). Biomass is in million pounds and abundance in millions of crabs. The results from the base model are in bold font.

Alternative	HM	Yield	SD	ESB	TMB	Female	Male	Closure	<MSST	<B_{msy}	<15%HR
					Ricker S–R Relationship						
Closure	0	0	0	34.39	152.08	18.05	20.78	100	<0.01	0.6	95.5
Status q.	0	9.12	4.65	33.76	105.84	17.91	14.20	3.3	<0.01	13.0	96.6
Status q.	**0.2**	**8.17**	**4.12**	**31.29**	**97.74**	**16.74**	**13.03**	**4.9**	**<0.01**	**21.1**	**98.1**
Status q.	0.5	6.93	3.58	27.95	86.98	15.15	11.48	8.5	<0.01	37.2	99.3
Alter. 1	0	9.62	4.90	33.58	102.64	17.87	13.73	3.3	<0.01	14.6	96.9
Alter. 1	**0.2**	**8.46**	**4.37**	**30.80**	**94.06**	**16.55**	**12.49**	**5.1**	**<0.01**	**24.4**	**98.5**
Alter. 1	0.5	6.98	3.83	27.17	83.15	14.83	10.93	9.4	<0.01	43.2	99.5
Alter. 2	0	10.12	4.86	33.33	99.40	17.81	13.25	3.4	<0.01	18.8	97.1
Alter. 2	**0.2**	**8.76**	**4.36**	**30.16**	**89.98**	**16.33**	**11.90**	**5.6**	**<0.01**	**31.7**	**98.7**
Alter. 2	0.5	7.04	3.90	26.09	78.31	14.40	10.23	11.1	<0.01	53.9	99.7
Alter. 3	0	9.50	5.27	33.62	103.27	17.88	13.82	4.9	<0.01	12.3	96.9
Alter. 3	**0.2**	**8.28**	**4.76**	**30.94**	**95.31**	**16.60**	**12.67**	**7.5**	**<0.01**	**20.6**	**98.5**
Alter. 3	0.5	6.78	4.24	27.58	85.61	15.00	11.29	13.2	<0.01	36.8	99.5
Alter. 4	0	9.54	4.84	33.62	103.17	17.88	13.80	3.5	<0.01	14.2	96.9
Alter. 4	**0.2**	**8.41**	**4.32**	**30.90**	**94.72**	**16.59**	**12.59**	**5.4**	**<0.01**	**23.7**	**98.4**
Alter. 4	0.5	6.96	3.81	27.34	83.97	14.90	11.05	9.9	<0.01	41.9	99.5
					General S–R Relationship						
Closure	0	0	0	74.49	314.39	39.92	43.18	100	<0.01	0.2	31.2
Status q.	0	22.73	12.53	70.50	204.57	39.28	27.34	0.2	<0.01	1.0	34.9
Status q.	0.2	19.43	10.81	62.35	181.55	35.71	23.99	0.3	<0.01	1.5	42.8
Status q.	0.5	14.77	8.33	50.46	149.43	30.08	19.41	0.8	<0.01	3.4	60.7
Alter. 1	0	22.93	11.97	69.81	201.30	39.07	26.86	0.2	<0.01	1.2	36.1
Alter. 1	0.2	19.37	10.13	60.76	175.77	35.06	23.17	0.4	<0.01	1.9	45.8
Alter. 1	0.5	14.29	7.43	47.30	139.30	28.57	18.00	0.9	<0.01	4.8	68.4
Alter. 2	0	23.01	11.58	69.13	198.50	38.83	26.46	0.2	<0.01	1.5	37.1
Alter. 2	0.2	19.23	9.66	59.23	170.65	34.41	22.44	0.4	<0.01	2.6	48.7
Alter. 2	0.5	13.74	6.81	44.23	129.99	27.06	16.72	1.3	<0.01	8.0	74.9
Alter. 3	0	23.01	11.89	69.73	200.76	39.06	26.78	0.4	<0.01	1.0	36.2
Alter. 3	0.2	19.41	10.05	60.51	174.82	34.99	23.03	0.7	<0.01	1.6	46.3
Alter. 3	0.5	14.24	7.38	46.84	137.97	28.40	17.81	1.6	<0.01	4.0	69.8
Alter. 4	0	22.91	12.03	69.92	201.75	39.11	26.93	0.2	<0.01	1.1	35.9
Alter. 4	0.2	19.40	10.21	61.01	176.61	35.17	23.28	0.4	<0.01	1.8	45.3
Alter. 4	0.5	14.38	7.54	47.81	140.89	28.82	18.22	1.0	<0.01	4.4	67.1

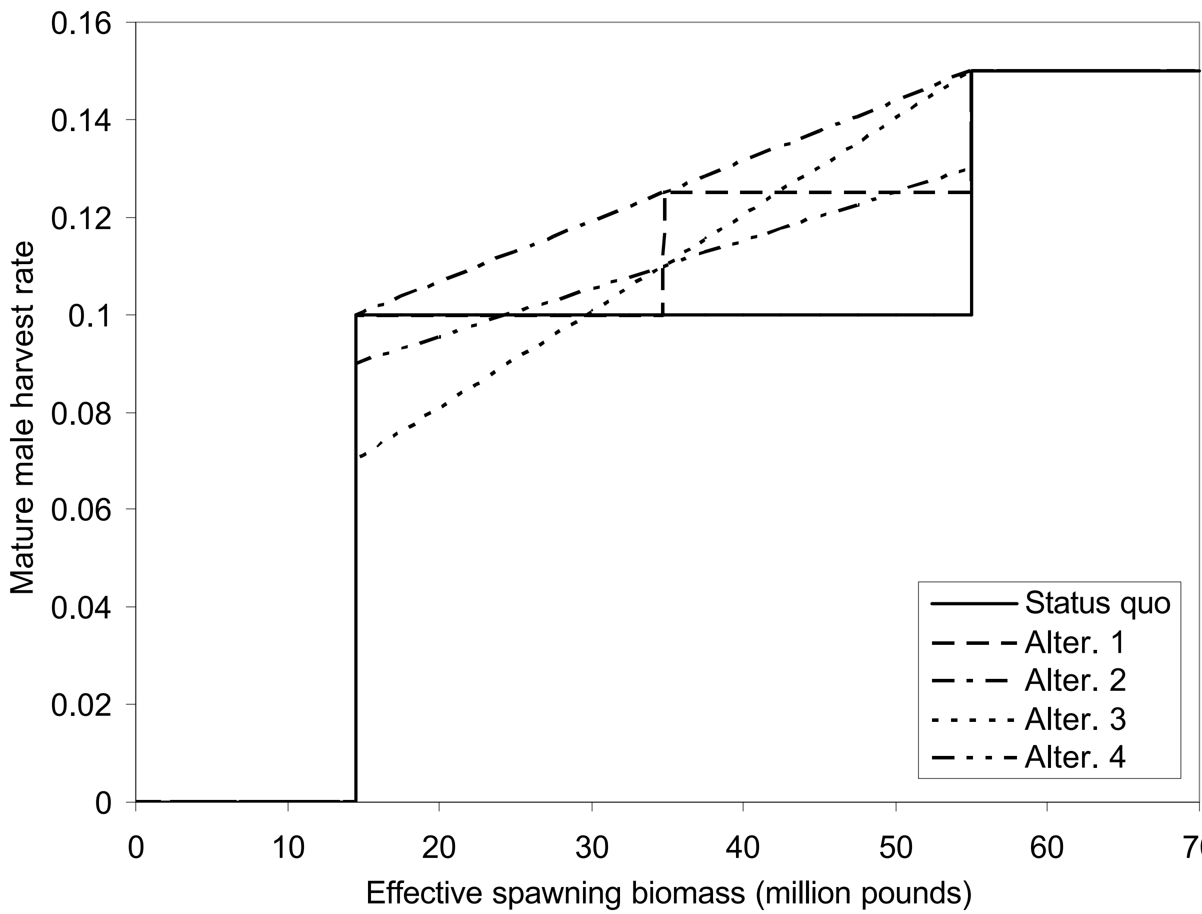

Figure 1. Five alternative harvest strategies for Bristol Bay red king crabs.

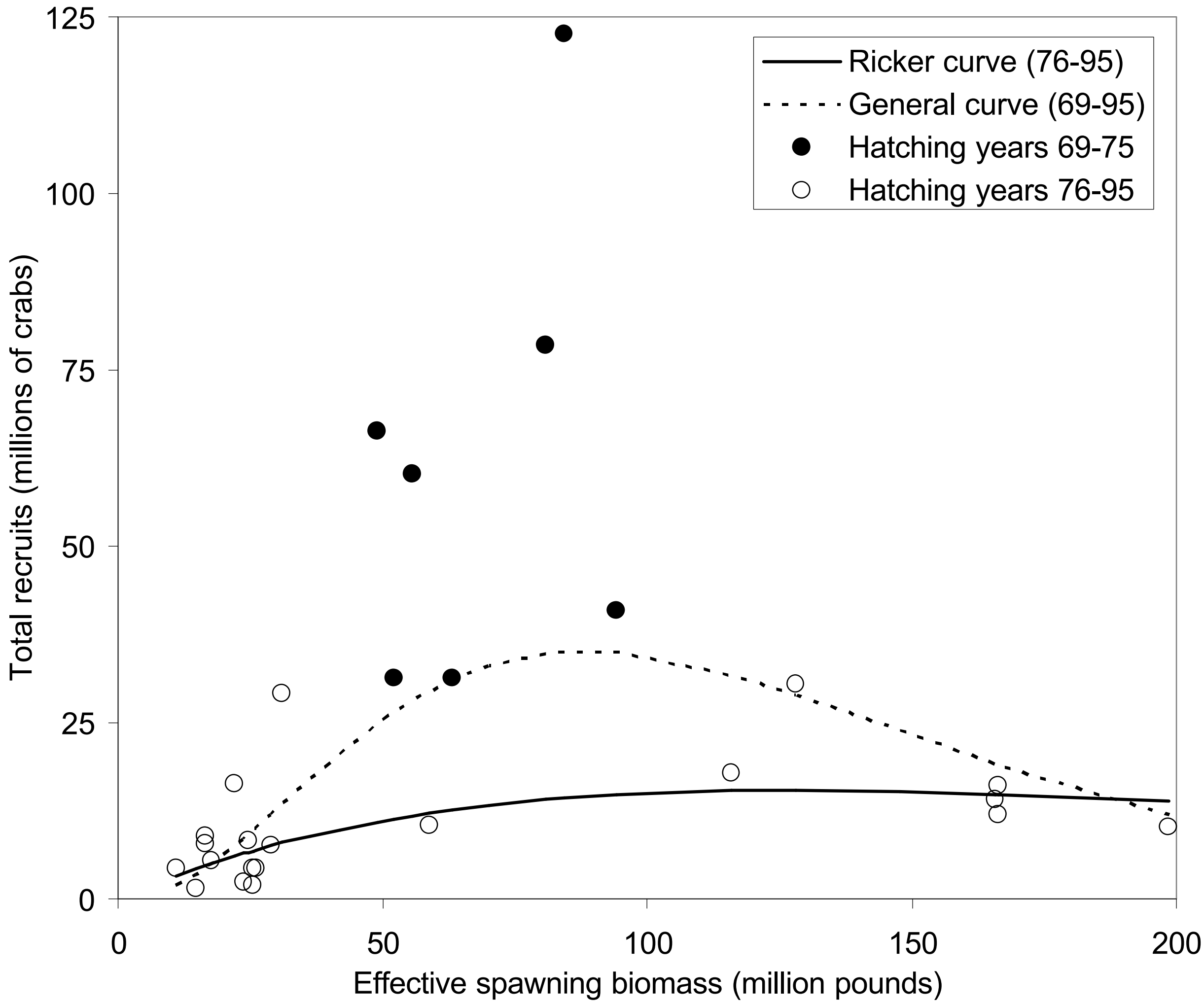

Figure 2. Relationships between total recruits at age 7.2 years (i.e., 8-year time lag) and effective spawning biomass for Bristol Bay red king crabs.

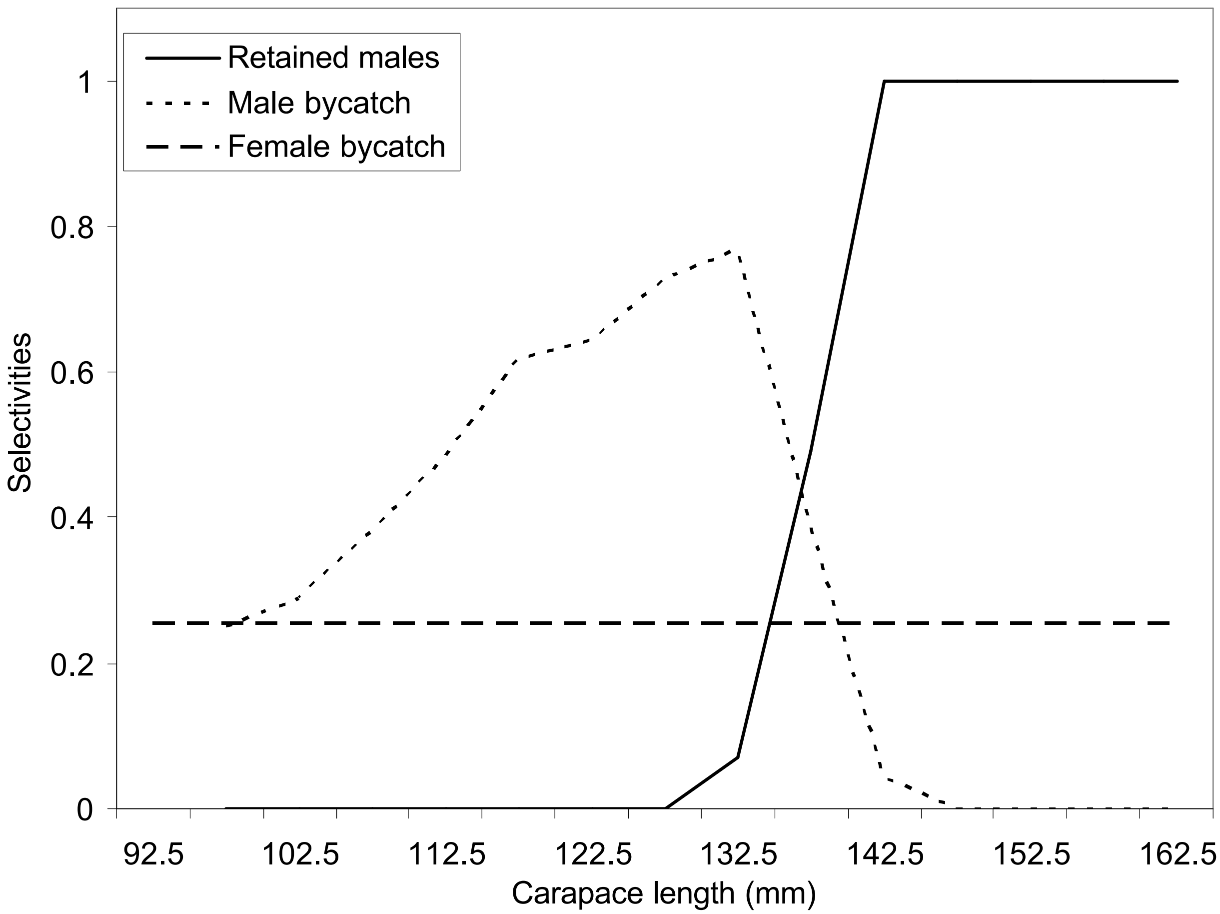

Figure 3. Estimated selectivities for male bycatch, female bycatch, and retained males for Bristol Bay red king crabs.

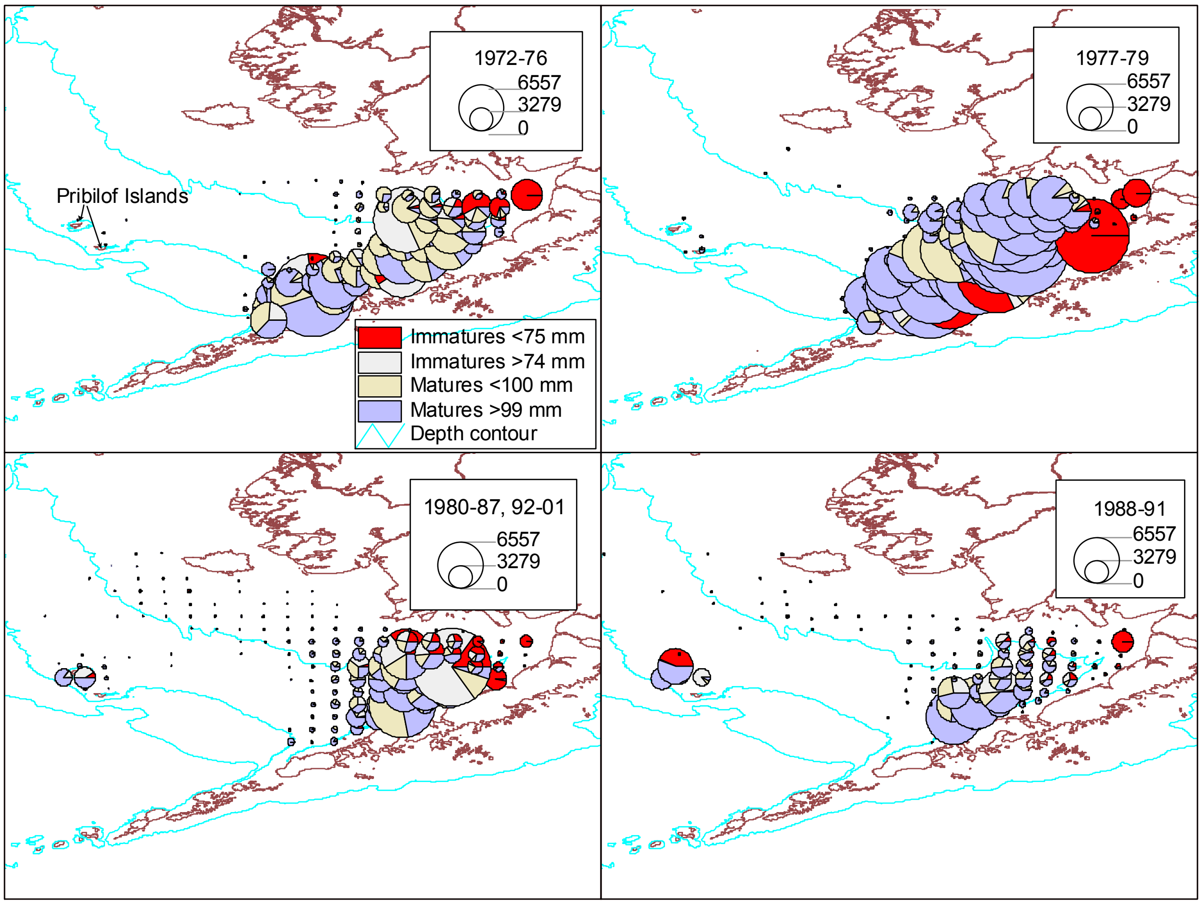

Figure 4. Distributions of female red king crabs from 1972 to 2001 in the eastern Bering Sea derived from NMFS summer trawl survey data. Crab density is expressed as the number of crab per square nautical mile. The three depth contour lines are 50, 100, and 200 m.