POPULATION SIZES AND HARVEST RATES OF RED KING CRABS IN SOUTHEAST ALASKA, 1993

By

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INTRODUCTION

This report describes the application of a population model to estimate the numbers and biomass of red king crabs (*Paralithodes camtshaticus*) in Southeast Alaska for 1993. The estimates were made to permit the first application of a harvest rate approach to setting commercial catch quotas for the red king crab fishery in Southeast Alaska. The harvest rate approach reflects the intent of the Alaska Department of Fish and Game to implement a conservative management policy that provides for a sustained yield (ADF&G 1993).

The commercial fishery for red king crabs was closed in Southeast Alaska in October, 1984 because of low abundance. By regulation, the fishery was to remain closed until the stock had rebuilt and there was a harvestable surplus of at least 300,000 pounds (ADF&G 1993). In addition to a population size estimate, this report provides guidelines for determining the size of the harvestable surplus.

METHODS

The Model

Population sizes were estimated using a modified DeLury method developed by Collie and Sissenwine (1983) for application to groundfish stocks, and most recently applied to Alaskan red king crab populations by Collie (1991) and by Kruse and Collie (1991). The model used here is the "all observation error" model of Kruse and Collie (1991), and relates the relative abundance of recruit and postrecruit crabs in year t to the relative abundance of postrecruits in year $t+1$ as

$$p_{t+1} = (p_t + r_t)e^{-M} - qC_t e^{-\tau_t M}$$

where p_t and r_t are the "true" survey catch rates of postrecruit and recruit crabs in year t, q is the catchability coefficient, C_t is the number of legal (recruit plus postrecruit) crabs caught in the commercial fishery in year t, M is the instantaneous rate of natural mortality, and τ_t is the fraction of the year between the time of the fishery in year t and the following survey in year $t+1$. Recruit crabs are defined as new shell male crabs $\geq$ 145 mm and $\leq$ 161 mm carapace length. Postrecruit crabs are all other legal male crabs. The survey catch rate is in units of crabs per pot per day.

The interpretation of the model is as follows. The first product on the right hand side of equation (1) represents a reduction in carry-over of legal crabs ($p_t + r_t$) by the expected annual survival rate (e^{-M}). The second term further reduces the carry-over by subtracting the number of legal crabs caught (C_t), which

is discounted by the fraction of the catch that would not have survived from the time of the fishery to the time of the next survey had the crabs not been caught ($e^{-\tau M}$). The catchability coefficient (q) scales the commercial catch to the same units as the survey catch rate data, allowing the total population sizes N in year t to be calculated as:

$$N_t = \frac{(p_t + r_t)}{q}$$

Harvest rates (fishing mortality rates) H in year t were calculated as:

$$H_t = \frac{C_t}{N_t}$$

Following the suggestion of Collie and Sissenwine (1983), the errors in survey catch rates were assumed to be log-normally distributed random variables, that is

$$\hat{p}_t = p_t e^{\eta_t}$$

and

$$\hat{r}_t = r_t e^{\delta_t}$$

where $\hat{P}_t$ and $\hat{r}_t$ are the observed catch rates of postrecruits and recruits in year t, and η_t and δ_t are normally distributed random variables (error terms). The lognormal assumption is made to reflect the observation that errors in count data are often multiplicative, and to reduce the influence of extreme values.

Assumptions

The model and methods used in this study assume:

1. Catchability is constant (the coefficient is estimated by the model).

2. The natural mortality rate is constant within and between years (the rate is estimated from data for Kodiak crabs, see below).

3. Commercial catches come from the same population that is sampled during the assessment surveys.

4. Commercial fishing and natural mortality are the only sources of mortality. Personal use (sport and subsistence) fishing mortality is assumed to be negligible.

5. The only error is in measurement of survey catch rates.

Input Data for the Model

Data for the model were taken from commercial catch and survey records for districts 10 to 15. These districts account for 92% of the commercial catch from all of Southeast Alaska from 1979 to 1984. Commercial catch data were reported in pounds (Table 1). The total number of crabs caught each year from 1979 to 1984 was calculated as the total pounds divided by the average weight, which was calculated from samples taken when crabs were sold.

Widespread and systematic surveys of red king crab populations have been conducted in most years since 1979 in Southeast Alaska by the Alaska Department of Fish and Game (Woodby et al., in prep.). The survey was made with pots in a systematic fixed station design from 1979 to 1985 and a stratified random design from 1986 to 1993. Average annual catch rates for recruit and postrecruit crabs were calculated from survey results for ten areas (mostly bays and referred to as bays from here on) that have been most consistently surveyed (Table 2; Figure 1). The 10 bays account for approximately 57% of the total commercial catch (in pounds) from 1979 to 1993 in all of Southeast Alaska (Woodby et al., in prep.), and are located in districts 10 through 15. Where data were unavailable for any year or area, simple linear interpolation was used to estimate catch rates from previous and later surveys. Catch rates for each district (Table 3) were calculated as an average of catch rates for all bays sampled in the district weighted by the surface area of the surveyed portion of each bay (Table 4). Districts 12 and 13 include surveys from only one bay each. The Eagle River area straddles the boundary of districts 11 and 15, and catch rates from that area were used for both districts.

The mortality rate was assumed to be 0.32, which is the expected mortality rate for legal males estimated from the data provided by Schmidt and Pengilly (1990, their Appendix B). This value is approximately the same as the value of 0.30 used by the North Pacific Fishery Management Council for Bering Sea red king crabs (NPFMC 1990).

Solution Method

Equation (1) was solved for q, p_{1979}, and r_t (t = 1979 to 1993) for each of districts 10 to 15. Solutions for each district are preferable to a single solution for all of Southeast Alaska because there are distinct differences between the districts in the relative abundances of the various size, sex, and maturity classes of crabs. District 11 was split into Seymour Canal and that portion not including Seymour Canal for the same reason, recognizing that District 11 covers a large area and variety of water bodies.

The solution was obtained by minimizing the sum of the squares of the measurement error using a Newton-Raphson method ("solver" algorithm, Microsoft 1992). The expected catch rates of postrecruits, p_t, for 1980 to 1993 were calculated from solutions for r_t for all years and p_t for 1979 using equation (1). When required, an offset value X was added to the catch rates to ensure that the arguments of the log functions were greater than 0:

$$\eta_t = \ln(\hat{p} + X)_t - \ln(p_t + X)$$

$$\delta_t = \ln(\hat{r} + X)_t - \ln(r_t + X)$$

The offset X was chosen as the smallest value, rounded to two decimal places, for which a solution was possible. Solutions of non-linear equations are sensitive to starting conditions, and starting conditions for all districts were standardized such that $p_{1979} = \hat{p}_{1979}$, and $r_t = \hat{r}_t$ (t = 1979 to 1993).

The number of legal males was estimated for each year using equation (2) for each district.

Size to Weight Conversion

A simple linear regression relationship between carapace length and weight was estimated for a sample of 258 legal crabs measured from districts surveyed in 1986 (ADF&G unpublished data). This relationship was used to estimate the average weight at the time of the summer survey given the average size of legal crabs caught.

Carapace length of all legal crabs captured in the 1993 survey were measured, and the average length for each bay was estimated as a simple average. Average length by district was calculated as a weighted average of the bays (areas) within each district, using surface areas of the surveyed portions of the bays as weights (Table 4).

RESULTS

The catchability coefficient in equation (1) was estimated to range from 1.25×10^{-4} to 3.77×10^{-4} for districts 10 to 15 (Table 3). Offset values (X) were 0 for all districts except 11 (excluding Seymour Canal) and 12, for which the values were 0.05 and 0.15, respectively.

The estimated error in observed catch rates for districts 10 to 15 can be seen in Figures 2 through 8, which show both predicted and observed catch rates from 1979 to 1993. Observed catch rates fit the predicted values best for districts 10 and 12, and there are varying degrees of lack of fit for the other districts.

Population sizes for legal males were estimated to range from a high of about 158,641 crabs in 1993 to a low of about 26,344 crabs in 1985 for districts 10 to 15 combined (Table 5). Harvest rates in that period for those districts were estimated to range from a low of 16% in 1993 to 61% in 1984 (Table 5 and Figure 9).

The regression relationship between carapace length and weight was found to be:

$$W = -13.45 + 0.13L$$

(slope significant at $p < 0.0001$, $r^2 = 0.86$). In 1993, the estimated average carapace lengths ranged from 155.9 mm to 165.0 mm for districts 10 to 15. Using the regression, the estimated average weight ranged from 6.88 to 8.07 pounds (Table 6). The total weight of legal red king crabs in districts 10 to 15 was estimated as 1,173,022 pounds. The total weight in districts 1 to 9, which were not surveyed, was estimated as 88,739 pounds (Table 6). That weight was calculated as a proportion of the total pounds for districts 10 to 15, based on the proportion of the commercial catch in districts 1 to 9 relative to the commercial catch in districts 10 to 15 from 1979 to 1984. The weight of legal males in Southeast Alaska, equal to the sum of weights for districts 1 to 15, was estimated as 1,261,761 pounds (Table 6).

DISCUSSION

Accuracy of the Estimates

There are several sources of error and variability that should be considered when evaluating the accuracy of the population estimates. The assumption that the natural mortality rate is constant and known is potentially a major source of error. It is possible for example, that mortality rates varied from year to year, and it is also possible that mortality rates were different for recruits and postrecruits. This is reasonable in light of the fact that postrecruits often include a large proportion of old shell crabs, which have higher rates of mortality (Schmidt and Pengilly 1990).

It may be unwarranted to assume constant catchability from year to year. The original development of the model by Collie and Sissenwine (1983), specifically calling for catch rates from research surveys, was motivated by the need for a constant catchability coefficient. Their model is an alternative to those using catch rates from commercial fishing boats, which typically see increasing efficiency, and therefore higher catchability, through time. Despite the fact that the surveys were conducted with the same type of gear and bait in all years, the vessel and pot deployment were supervised by various skippers, and it is plausible that the various abilities of these skippers led to biases in catch rates. Another concern is the possibility that catchability is density dependent. This may be more true for catch rates from pot data than

from trawl data, to which the model was originally applied by Collie and Sissenwine (1983), because pots may become saturated when crabs are at high densities.

A limitation of the methods used here is the assumption that the survey samples are representative of the population of red king crabs in districts 10 to 15 as a whole. It is not known if this is valid. For example, catch rates from the Lynn Sisters area are assumed to be representative of district 12 as a whole, yet district 12 includes numerous other relatively small areas which have been productive in the commercial fishery and have not been surveyed in recent years.

Survey area boundaries have been chosen to include those areas where crab are expected to be caught, but it is likely that the boundaries include poor crab habitat and exclude favorable habitat. This error is brought into the model by way of the estimates of catch rates and by way of the surface areas of bays, which are used as weights for calculating average district catch rates and carapace lengths.

If the survey is not representative, the estimates of population size might be biased high or low, depending on the distribution and behavior of crabs. For example, if the surveys occur in areas that are preferred habitat for crabs, it is possible that the removal of legal crabs by commercial fishing will be masked by immigration of crabs from less preferred areas. In this case, the population sizes will be overestimated (catch rates are higher than expected in surveys following fishing). On the other hand, if there is no crab migration, and the proportion of crabs removed is greater than in areas not surveyed, then the population sizes will be underestimated.

The model did not account for sources of mortality other than natural mortality and commercial fishing. Personal use (sport and/or subsistence) fishing mortality were not included. The effect of this omission is that catchability is overestimated, and population sizes are underestimated. A similar effect is expected if commercial catches were under-reported, as is likely. Misreporting of catch locations is also likely for the commercial fishery. This type of error is a major concern only if there was a consistent bias in reporting error, such that catches were under-reported in particular districts. Biases are suspected but not known.

The regression relationship between size and weight is assumed to be valid for years other than 1986. This assumption may be false if, for example, the relationship is dependent on environmental conditions such as temperature that might vary annually.

Finally, population parameters, including size at maturity, recruit class boundaries, and mortality rates, were estimated from information for red king crab stocks in the vicinity of Kodiak. It is not known if these estimates are realistic for crabs in Southeast Alaska, with the exception of recruit class boundaries. In that case, growth information from Barlow Cove (ADF&G unpublished data) matches growth rates from Kodiak (McCaughran and Powell 1977), such that recruit class size boundaries are likely to be the same in both areas.

Harvest Rates

It is the policy of the Alaska Board of Fisheries that the harvest rate for red king crabs in Southeast Alaska should be based on information on the relative abundances of the various age classes of males and females, and on the percentage of females bearing eggs (ADF&G 1993). Female catch rates in 1993 were high relative to all years except 1979 and 1981 (Figure 10), and include large proportions of mature females (Figure 11) for which the average ovigerity was over 98% in the 1993 survey (ADF&G unpublished data). These factors point to a healthy crab population. The abundance of prerecruit 1 males (those within one molt of recruiting to the legal size class) is low relative to the legal segment of the population surveyed in 1993 (Figure 12), indicating that recruitment in 1994 will be low relative to that observed in 1993.

The decline of the red king crab population in Southeast Alaska from 1979 to 1985 (Figure 9) was coincident with harvest rates estimated to range from 44% to 61% (Table 5). Although it is not known if commercial harvests caused the decline, there are reasons to suspect that commercial harvests contributed to the decline. For example, red king crabs exhibit life history features that suggest that their populations are susceptible to overfishing and subsequent stock depletion (Kruse 1992). They are a relatively long-lived species (maximum age exceeds 20 years, Matsuura and Takeshita 1990), relatively slow to mature (mean age of 7 years, McCaughran and Powell 1977), and their populations in Southeast Alaska are characterized by sporadically strong year classes (ADF&G unpublished data).

A simulation study investigating harvest rate strategies for red king crabs in the Kodiak area suggests that harvests are likely to be more stable from year to year if a conservative exploitation rate is set for the breeding population[2] of males, instead of a fixed harvest rate[3] on legal crabs (Schmidt and Pengilly 1990). The proposed exploitation rate in the Kodiak area is 20% of mature male crabs, which results in a long-term average of 36% of legal male crabs when annual recruitment is constant. Red king crabs in the Kodiak area are estimated to become effective breeders at sizes larger than 130 mm carapace length (based on observations of grasping pairs), and become legal at approximately 145 mm length[4] (Schmidt and Pengilly 1990). The effectiveness of the simulated harvest strategy is that the breeding population is harvested at a conservatively low level. In contrast, a fixed harvest rate for legal males would allow high harvest rates on the breeding population if, in some years, there were few mature males which were not also legal. In the Kodiak area, this latter condition would occur if there were few prerecruit 1 males

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2 Exploitation rate for red king crabs is defined by Schmidt and Pengilly (1990) as the removal rate of sexually mature male crabs.

3 Harvest rate for red king crabs is defined by Schmidt and Pengilly (1990) as the removal rate of legal crabs.

4 Legal size is defined by regulation for Southeast Alaska and the Kodiak area as 178 mm (7 inches) carapace width. Carapace length, rather than width, is used as a standard index of size for the assessment surveys and for much of the scientific research on red king crabs. The relationship between length and width indicates that a legal width of 178 mm is obtained at an average size of 145 mm length.

(males within one molt of becoming legal). This condition appears to hold for crabs in Southeast Alaska in 1993 (Figure 12).

Simulation studies of the type just described have not been made for populations of red king crabs in Southeast Alaska; however, the results are expected to be similar if the rate of natural mortality and the frequency of strong year classes are similar. There are additional types of information needed before it will be possible to adequately estimate the optimal harvest rate in Southeast Alaska (or in Kodiak), including studies of stock-recruitment relationships.

The effective harvest rate on legal males in 1993 was expected to be 1.5 times the exploitation rate on breeders. This relationship was derived by comparison of the relative abundance of legals to the relative abundance of breeders, as shown in Figure 12 (ratio of breeding males to legal males = 1.5:1).

Given the observations that the red king crab population collapsed in the past decade when harvest rates are estimated to have ranged between 44% and 61%, and that the prerecruit 1 population is relatively low, it is advisable that harvest rates be conservative, not to exceed 40% of the legal population.

CONCLUSIONS

The population size estimates provided in this report are known to suffer from various sources of error. At present, there are no other estimates of population size for red king crabs in Southeast Alaska against which the current estimates can be compared. For this reason, the current estimates are the best available, and should be used only with appropriate cautions regarding their accuracy.

A practical method of obtaining independent estimates would be through a mark-recapture experiment. This would best be obtained from a geographically confined fishing area for which commercial catch data are reliable (thereby improving the reliability of the estimates from the model). Potential sites are Gambier Bay and Deadman Reach.

The population estimates can be improved by various means, some requiring more data and others requiring further analysis of current data. A significant improvement could be made in future estimates if reliable data, including numbers, dates, and locations, are collected on catches by non-commercial fishers. Also, it is important to record locations within districts for all commercial catches in future fisheries, so that the distribution of crabs within districts is more accurately known.

A sensitivity analysis would be useful to determine the importance of obtaining estimates of biological parameters such as natural mortality and size at maturity from local stocks rather than using estimates derived for Kodiak stocks. Other analyses which would be useful include an investigation of alternative weighing schemes for estimating average catch rates and sizes. Also, it would be valuable to reformulate the model to incorporate prerecruit catch rates from the survey.

The optimal harvest rate for red king crabs in Southeast Alaska is not known. Until the appropriate research is conducted, the harvest rate should probably not exceed 40%. Where future recruitment is expected to be low, harvest rates should be reduced to provide for carry over of legal crabs to subsequent years.

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Table 1. Commercial catches in pounds for fishing districts in Southeast Alaska, 1979-1984.

Year	Districts: 1 to 9	10	11	12	13	14	15	Total
1979	49,455	168,363	220,199	39,545	79,434	89,083	11,838	657,917
1980	47,645	163,723	179,228	7,949	73,067	5,158	39,931	516,701
1981	39,410	114,378	135,354	32,716	116,707	32,782	52,551	523,898
1982	12,654	77,418	53,786	97,998	70,823	79,469	20,457	412,605
1983	36,440	79,463	35,199	30,222	46,747	50,139	1,854	280,064
1984	1,576	58,723	89,027	13,981	51,892	48,898	6,180	270,277
Total	187,180	662,068	712,793	222,411	438,670	305,529	132,811	2,661,462

Table 2. Survey catch rates of recruit and postrecruit red king crabs from 1979 to 1993. Rates are crabs per pot per day. Values in parentheses are interpolated from adjacent years. Underlined rates are averages from summer and fall surveys (1987 and 1988).

Recruits Year	Pybus Bay	Gambier Bay	Seymour Canal	Barlow Cove	Eagle River	St. James Bay	Lynn Sisters	Excursion Inlet	Port Frederick	Deadman Reach
1979	2.55	2.64	2.74	4.52	1.13	2.03	4.18	2.34	2.11	1.55
1980	1.51	6.85	1.10	6.73	1.05	2.73	5.36	1.21	1.31	1.86
1981	2.14	5.06	1.38	1.44	3.24	2.95	5.85	1.05	1.77	0.96
1982	2.26	2.34	0.35	0.64	0.54	0.47	0.24	0.61	1.69	2.01
1983	1.94	1.09	1.09	3.97	0.45	0.72	0.09	0.25	0.70	1.16
1984	0.48	0.22	3.24	0.87	1.83	0.46	0.32	0.75	2.20	2.21
1985	0.13	0.48	2.81	0.78	0.37	0.42	0.06	0.16	0.49	0.88
1986	0.00	1.52	0.89	1.66	0.45	0.60	0.49	0.33	0.39	1.51
1987	0.01	(0.98)	(0.95)	1.00	0.05	(0.46)	(0.32)	0.12	(0.34)	1.71
1988	0.00	0.45	1.01	0.92	0.06	0.31	0.15	0.25	0.30	0.20
1989	(0.11)	0.13	0.08	2.64	(0.33)	(0.88)	(0.63)	(0.28)	(0.26)	0.23
1990	(0.23)	(1.07)	(1.02)	(1.82)	(0.59)	(1.45)	(1.11)	(0.31)	(0.23)	(1.12)
1991	0.34	2.01	1.95	0.99	0.86	2.02	1.59	0.34	0.19	2.01
1992	0.39	1.99	1.61	3.15	1.26	2.45	2.99	1.02	0.25	2.23
1993	0.44	1.97	1.26	5.30	1.65	2.88	4.38	1.69	0.31	2.45

Table 2. continued.

Postrecruits Year	Pybus Bay	Gambier Bay	Seymour Canal	Barlow Cove	Eagle River	St. James Bay	Lynn Sisters	Excursion Inlet	Port Frederick	Deadman Reach
1979	1.59	1.38	0.45	1.06	0.03	1.28	2.91	0.42	1.27	0.94
1980	1.89	3.38	0.32	6.56	0.37	0.70	1.12	0.34	1.17	0.59
1981	0.56	1.78	0.57	2.23	1.35	0.39	2.65	0.43	1.18	0.56
1982	1.19	0.81	0.67	2.01	0.14	1.60	0.19	0.24	1.48	0.63
1983	1.90	1.05	0.38	0.76	0.44	0.18	0.00	0.13	0.71	1.03
1984	1.16	0.27	1.06	1.12	1.16	0.52	0.40	0.89	0.77	1.80
1985	0.43	0.20	1.84	0.62	0.26	0.68	0.08	0.14	0.69	0.57
1986	0.16	0.31	0.59	0.31	0.24	0.45	0.14	0.50	0.58	0.61
1987	0.11	(0.34)	(0.86)	0.67	0.06	(0.55)	(0.07)	0.12	(0.33)	0.52
1988	0.01	0.37	1.12	0.03	0.03	0.64	0.00	0.29	0.07	0.14
1989	(0.02)	0.11	0.09	0.20	(0.02)	(0.60)	(0.13)	(0.21)	(0.10)	0.12
1990	(0.03)	(0.42)	(0.29)	(0.43)	(0.02)	(0.55)	(0.27)	(0.12)	(0.12)	(0.15)
1991	0.04	0.72	0.49	0.66	0.01	0.51	0.40	0.04	0.15	0.17
1992	0.29	1.20	0.74	3.16	0.26	1.88	1.68	0.18	0.22	0.54
1993	0.53	1.68	0.99	5.65	0.51	3.25	2.95	0.32	0.29	0.90

Table 3. Input data and results of the population model for districts 10 to 15, 1979 to 1993.

District 10

q=0.000125 ssq=1.62 offset X=0

Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.63	1.48	2.60	1.76	3.76	44,083	0.50
1980	0.64	2.65	4.22	1.77	3.16	39,398	0.59
1981	0.61	1.18	3.62	1.22	2.75	31,687	0.53
1982	0.67	1.00	2.30	1.17	2.29	27,602	0.38
1983	0.55	1.47	1.51	1.44	1.47	23,235	0.50
1984	0.67	0.71	0.35	0.90	0.38	10,260	0.74
1985		0.31	0.31	0.17	0.17	2,745	0.00
1986		0.24	0.77	0.25	0.26	4,046	0.00
1987		0.23	0.50	0.37	0.20	4,541	0.00
1988		0.19	0.23	0.41	0.13	4,322	0.00
1989		0.07	0.12	0.39	0.10	3,969	0.00
1990		0.23	0.66	0.36	0.46	6,537	0.00
1991		0.39	1.19	0.59	0.88	11,736	0.00
1992		0.75	1.20	1.07	1.03	16,754	0.00
1993		1.11	1.22	1.52	1.22	21,882	0.00

District 11 (excluding Seymour Canal)

q = 0.000163 ssq = 2.57 offset X = 0.05

Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.66	0.15	1.53	0.16	3.29	21,093	0.56
1980	0.66	1.10	1.72	0.94	2.65	21,982	0.56
1981	0.65	1.45	3.03	0.98	2.13	18,992	0.65
1982	0.70	0.36	0.55	0.61	0.93	9,418	0.61
1983	0.59	0.48	0.87	0.37	1.03	8,555	0.41
1984	0.75	1.16	1.72	0.54	0.75	7,932	0.78
1985		0.30	0.42	0.14	0.15	1,785	0.00
1986		0.25	0.59	0.21	0.14	2,139	0.00
1987		0.13	0.16	0.25	0.05	1,866	0.00
1988		0.03	0.16	0.22	0.06	1,738	0.00
1989		0.04	0.60	0.21	0.20	2,483	0.00
1990		0.07	0.74	0.29	0.31	3,723	0.00
1991		0.09	0.88	0.44	0.68	6,853	0.00
1992		0.60	1.48	0.81	1.24	12,576	0.00
1993		1.12	2.08	1.49	2.08	21,875	0.00

Table 3. continued.

District 11 (Seymour Canal)

q=0.000148 ssq=3.11 offset X=0

Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.65	0.45	2.74	0.46	3.20	24,694	0.78
1980	0.65	0.32	1.10	0.35	2.30	17,885	0.68
1981	0.62	0.57	1.38	0.46	1.29	11,751	0.50
1982	0.68	0.67	0.35	0.55	0.31	5,734	0.25
1983	0.58	0.38	1.09	0.45	0.88	8,953	0.12
1984	0.68	1.06	3.24	0.83	1.37	14,819	0.39
1985		1.84	2.81	0.90	0.78	11,290	0.00
1986		0.59	0.89	1.22	0.43	11,095	0.00
1987		0.86	0.95	1.20	0.41	10,818	0.00
1988		1.12	1.01	1.17	0.36	10,314	0.00
1989		0.09	0.08	1.11	0.07	7,971	0.00
1990		0.29	1.02	0.86	0.59	9,772	0.00
1991		0.49	1.95	1.05	1.09	14,449	0.00
1992		0.74	1.61	1.56	1.19	18,486	0.00
1993		0.99	1.26	1.99	1.26	21,914	0.00

District 12

q = 0.000194 ssq = 2.54 offset X = 0.15

Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.67	2.91	4.18	1.43	1.78	16,509	0.33
1980	0.67	1.12	5.36	1.48	2.03	18,041	0.06
1981	0.65	2.65	5.85	2.37	1.72	21,006	0.18
1982	0.70	0.19	0.24	2.38	0.23	13,395	0.89
1983	0.59	0.00	0.09	0.05	1.20	6,427	0.72
1984	0.76	0.40	0.32	0.16	0.30	2,365	0.78
1985		0.08	0.06	0.05	0.03	437	0.00
1986		0.14	0.49	0.06	0.15	1,084	0.00
1987		0.07	0.32	0.15	0.10	1,319	0.00
1988		0.00	0.15	0.19	0.09	1,413	0.00
1989		0.13	0.63	0.20	0.38	2,986	0.00
1990		0.27	1.11	0.42	0.71	5,826	0.00
1991		0.40	1.59	0.82	1.53	12,083	0.00
1992		1.68	2.99	1.71	2.80	23,159	0.00
1993		2.95	4.38	3.27	4.38	39,337	0.00

Table 3. continued.

District 13

	q = 0.00014		ssq = 3.94		offset X = 0		
Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.69	0.94	1.55	0.95	1.57	17,968	0.61
1980	0.70	0.59	1.86	0.60	1.96	18,295	0.56
1981	0.69	0.56	0.96	0.72	2.49	22,904	0.71
1982	0.75	0.63	2.01	0.50	2.42	20,896	0.50
1983	0.64	1.03	1.16	0.97	1.22	15,633	0.47
1984	0.80	1.80	2.21	0.76	0.87	11,621	0.63
1985		0.57	0.88	0.38	0.36	5,305	0.00
1986		0.61	1.51	0.54	0.38	6,542	0.00
1987		0.52	1.71	0.66	0.34	7,189	0.00
1988		0.14	0.20	0.73	0.12	6,080	0.00
1989		0.12	0.23	0.62	0.15	5,452	0.00
1990		0.15	1.12	0.55	0.46	7,229	0.00
1991		0.17	2.01	0.73	1.00	12,377	0.00
1992		0.54	2.23	1.26	1.46	19,438	0.00
1993		0.90	2.45	1.97	2.45	31,630	0.00

District 14

	q = 0.000132		ssq = 1.99		offset X = 0		
Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.68	0.79	2.24	0.74	1.90	20,043	0.61
1980	0.68	0.70	1.25	0.62	0.92	11,650	0.06
1981	0.66	0.76	1.37	1.04	1.14	16,513	0.27
1982	0.71	0.78	1.08	1.10	1.20	17,439	0.60
1983	0.60	0.38	0.45	0.56	0.96	11,508	0.56
1984	0.78	0.84	1.39	0.40	0.79	9,009	0.65
1985		0.38	0.30	0.26	0.19	3,436	0.00
1986		0.54	0.36	0.33	0.16	3,728	0.00
1987		0.21	0.22	0.36	0.12	3,604	0.00
1988		0.19	0.27	0.35	0.13	3,617	0.00
1989		0.16	0.27	0.35	0.13	3,646	0.00
1990		0.12	0.27	0.35	0.15	3,762	0.00
1991		0.09	0.27	0.36	0.19	4,182	0.00
1992		0.20	0.68	0.40	0.46	6,547	0.00
1993		0.31	1.08	0.63	1.08	12,975	0.00

Table 3. continued.

District 15

	q = 0.000377		ssq = 2.68		offset X = 0		
Year	tau	p_hat	r_hat	p_est	r_est	N	H
1979	0.66	0.27	1.30	0.26	1.16	3,775	0.43
1980	0.67	0.43	1.37	0.54	3.09	9,618	0.61
1981	0.65	1.17	3.18	0.85	3.05	10,333	0.70
1982	0.70	0.42	0.53	0.60	0.89	3,952	0.69
1983	0.59	0.39	0.50	0.26	0.39	1,731	0.15
1984	0.75	1.04	1.57	0.39	0.40	2,114	0.39
1985		0.34	0.38	0.34	0.17	1,346	0.00
1986		0.28	0.48	0.37	0.18	1,444	0.00
1987		0.15	0.13	0.40	0.08	1,265	0.00
1988		0.15	0.11	0.35	0.07	1,116	0.00
1989		0.13	0.43	0.31	0.19	1,324	0.00
1990		0.12	0.76	0.36	0.32	1,819	0.00
1991		0.11	1.08	0.50	0.74	3,293	0.00
1992		0.57	1.48	0.90	1.19	5,549	0.00
1993		1.03	1.88	1.52	1.88	9,028	0.00

Table 4. Surface areas of bays and other study areas surveyed from 1979 to 1993. Surface areas were used as weights to calculate average catch rates and average size frequencies for each district.

Bay	District	Surface area (km^2)
Pybus Bay	10	38.3
Gambier Bay	10	39.6
Seymour Canal	11	26.4
Barlow Cove	11	5.4
Eagle River	11,15	39.8
Lynn Sisters	12	20.9
Deadman Reach	13	43.8
Excursion Inlet	14	84.9
Port Frederick	14	66.4
St. James Bay	15	9.4

Table 5. Population sizes and harvest rates of legal male red king crabs for districts 10 to 15 combined, 1979 to 1993. C is the catch in numbers and is equal to the catch in pounds divided by the average weight (catch and weight data are from the commercial catch) H is the estimated harvest rate (fishing mortality) calculated as C divided by N.

Year	Catch (lbs)	Average weight (lbs)	C	N	H
1979	608,462	7.25	83,891	148,165	0.57
1980	469,056	7.19	65,241	136,867	0.48
1981	484,488	7.23	66,967	133,187	0.50
1982	399,951	7.54	53,078	98,435	0.54
1983	243,624	7.24	33,671	76,042	0.44
1984	268,701	7.56	35,526	58,120	0.61
1985	0		0	26,344	0
1986	0		0	30,078	0
1987	0		0	30,601	0
1988	0		0	28,599	0
1989	0		0	27,831	0
1990	0		0	38,668	0
1991	0		0	64,973	0
1992	0		0	102,508	0
1993	200,192	8.04	24,907	158,641	0.16

Table 6. Estimated biomass (lbs) of legal male red king crabs for districts 1 to 15 in 1993. Population sizes are from Table 3. Average weights were calculated using the regression equation (8) and average lengths sampled during the survey. Total weight is a product of average weight and population size.

District	N	Length (mm)	Average weight (lbs)	Total weight (lbs)
10	21,882	165.0	8.07	176,488
11 (not Seymour	21,875	162.5	7.74	169,204
11 (Seymour Canal)	21,914	156.9	7.01	153,699
12	39,337	160.7	7.51	295,305
13	31,630	155.9	6.88	217,573
14	12,975	160.1	7.43	96,395
15	9,028	157.8	7.13	64,358
Subtotal	158,641		7.39	1,173,022
1-9	12,449[1]			88,739[2]
Total	171,090			1,261,761

[1] population size for districts 1 to 9 is calculated as the total weight for districts 1 to 9 divided by the average weight for districts 10 to 15 (= 7.39 pounds), which is weighted by the population size for each district.

[2] total weight for districts 1 to 9 in 1993 is an estimate based on historic catch data and is calculated as the total commercial catch for districts 1 to 9 from 1979 to 1984 (Table 1), divided by the total commercial catch for districts 10 to 15 for the same period, multiplied by the total estimated weight for districts 10 to 15 in 1993 (this table).

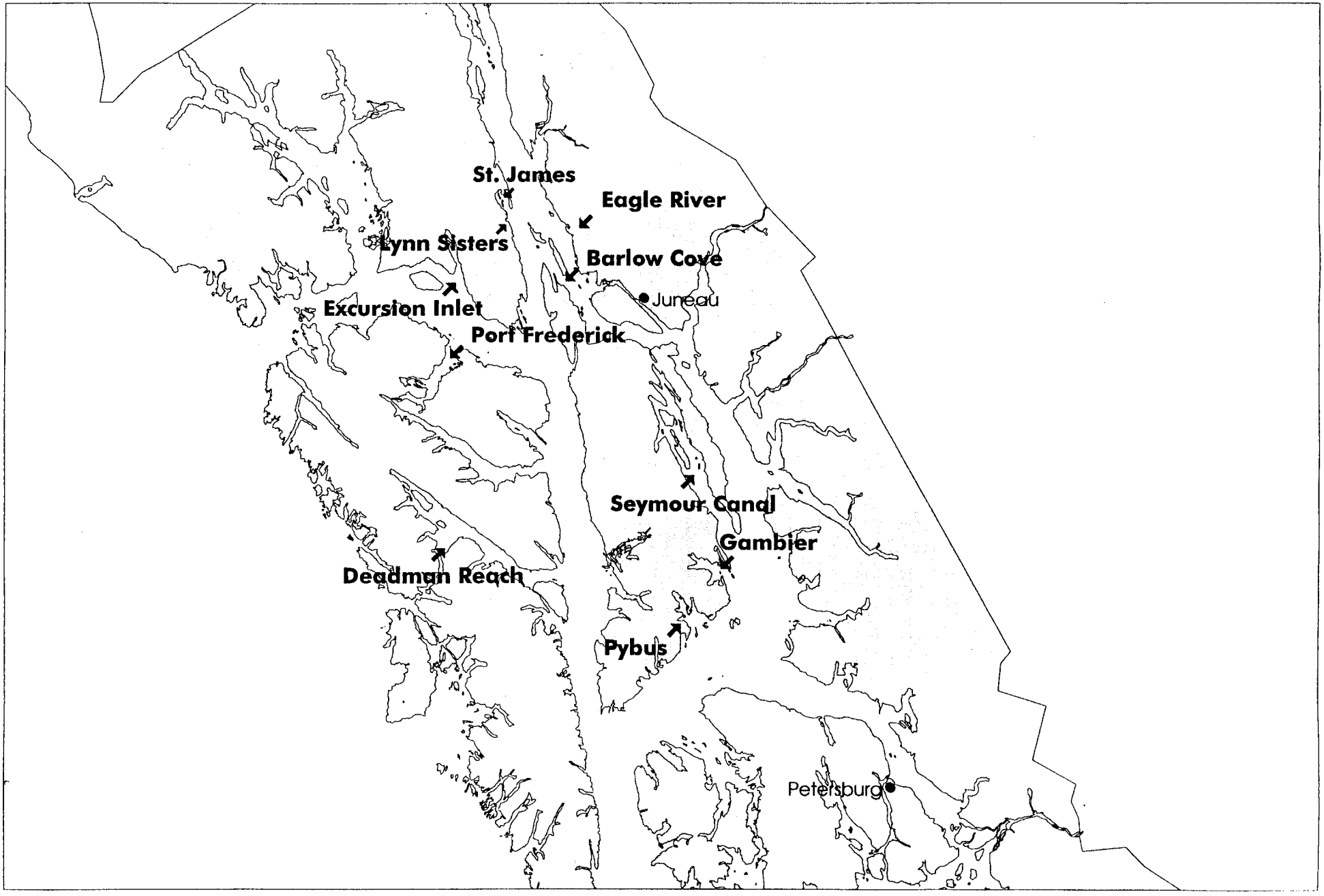

Figure 1. Map of Southeast Alaska showing the 10 bays where sampling was conducted in 1993.

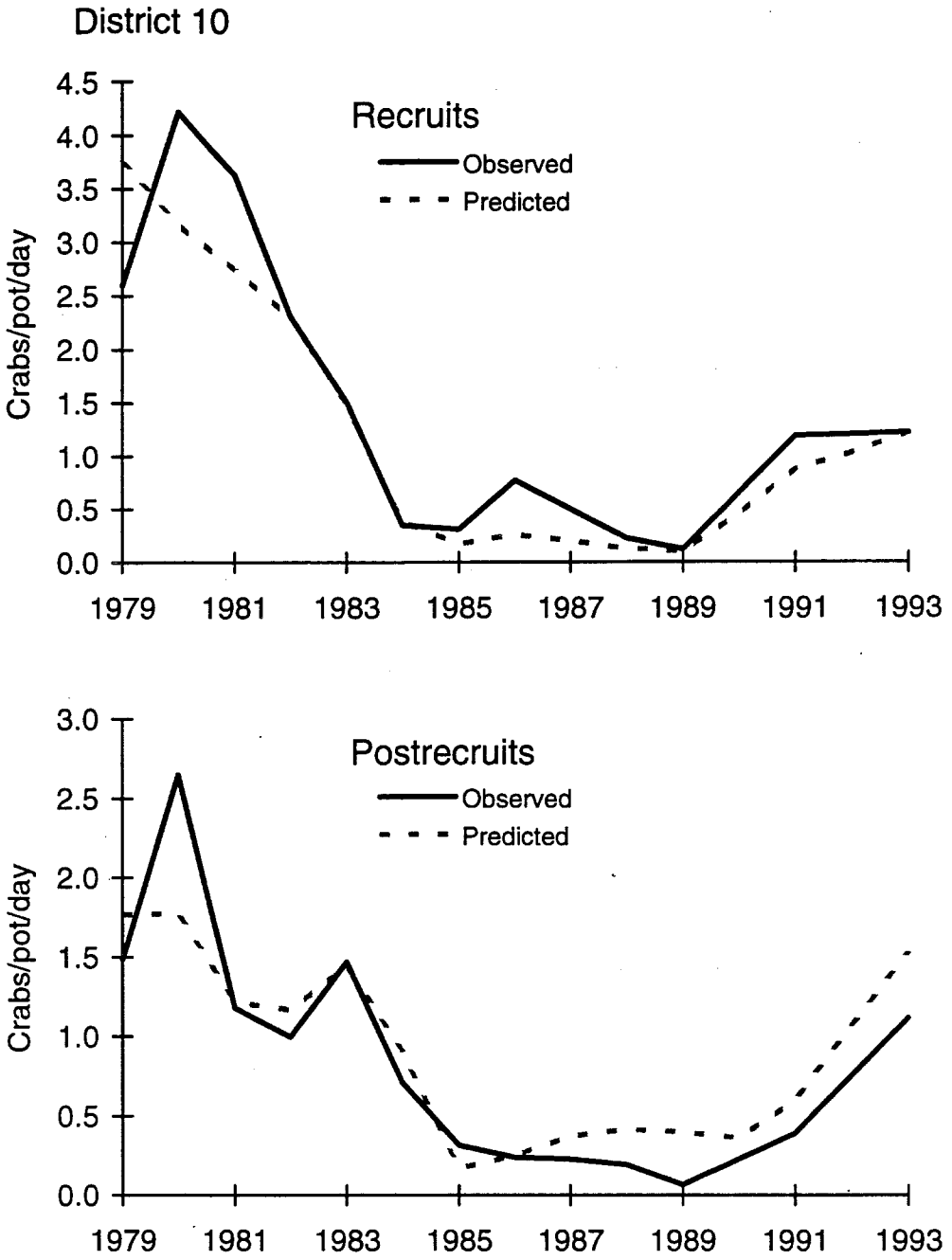

Figure 2. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 10, 1979 to 1993.

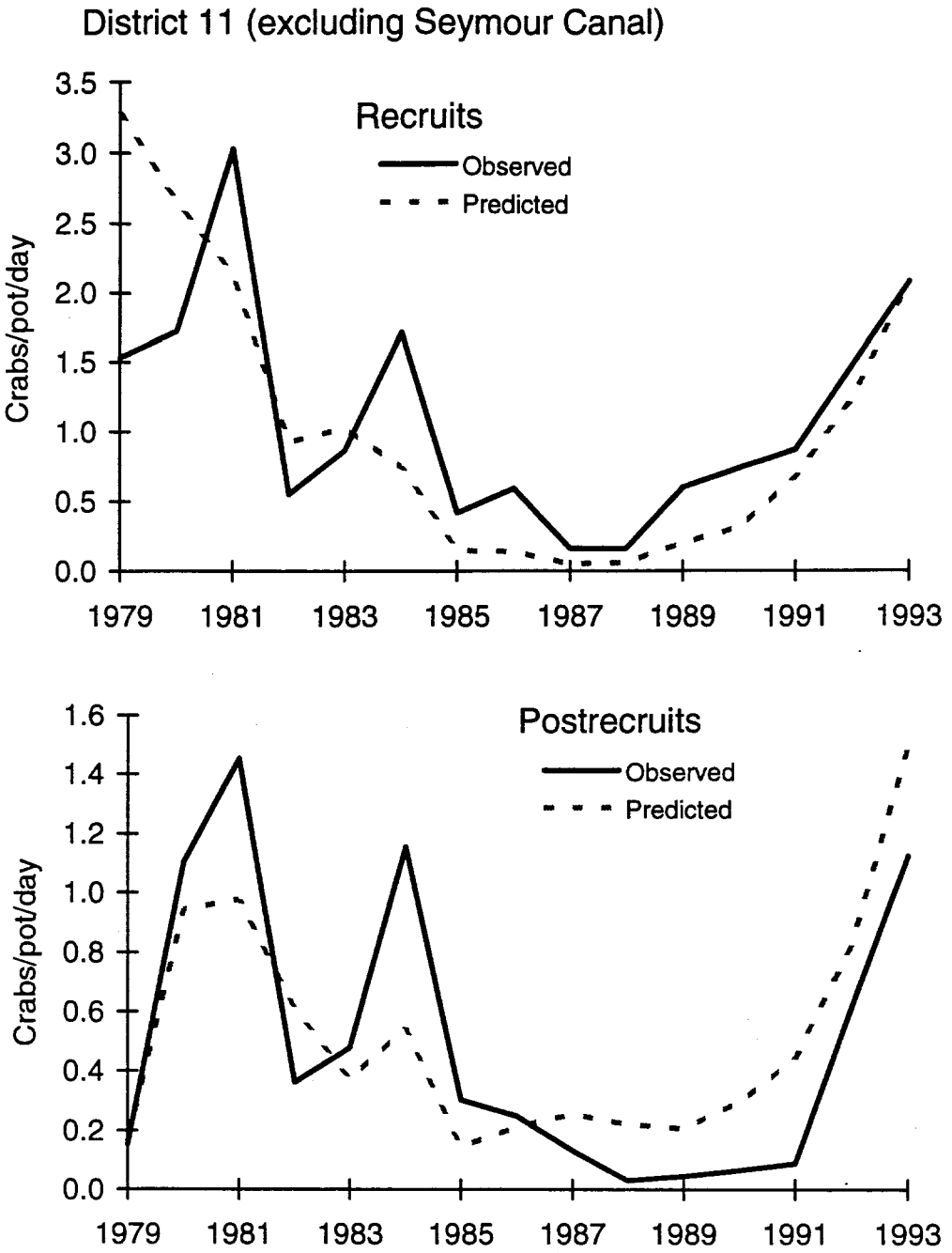

Figure 3. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 11 (excluding Seymour Canal), 1979 to 1993.

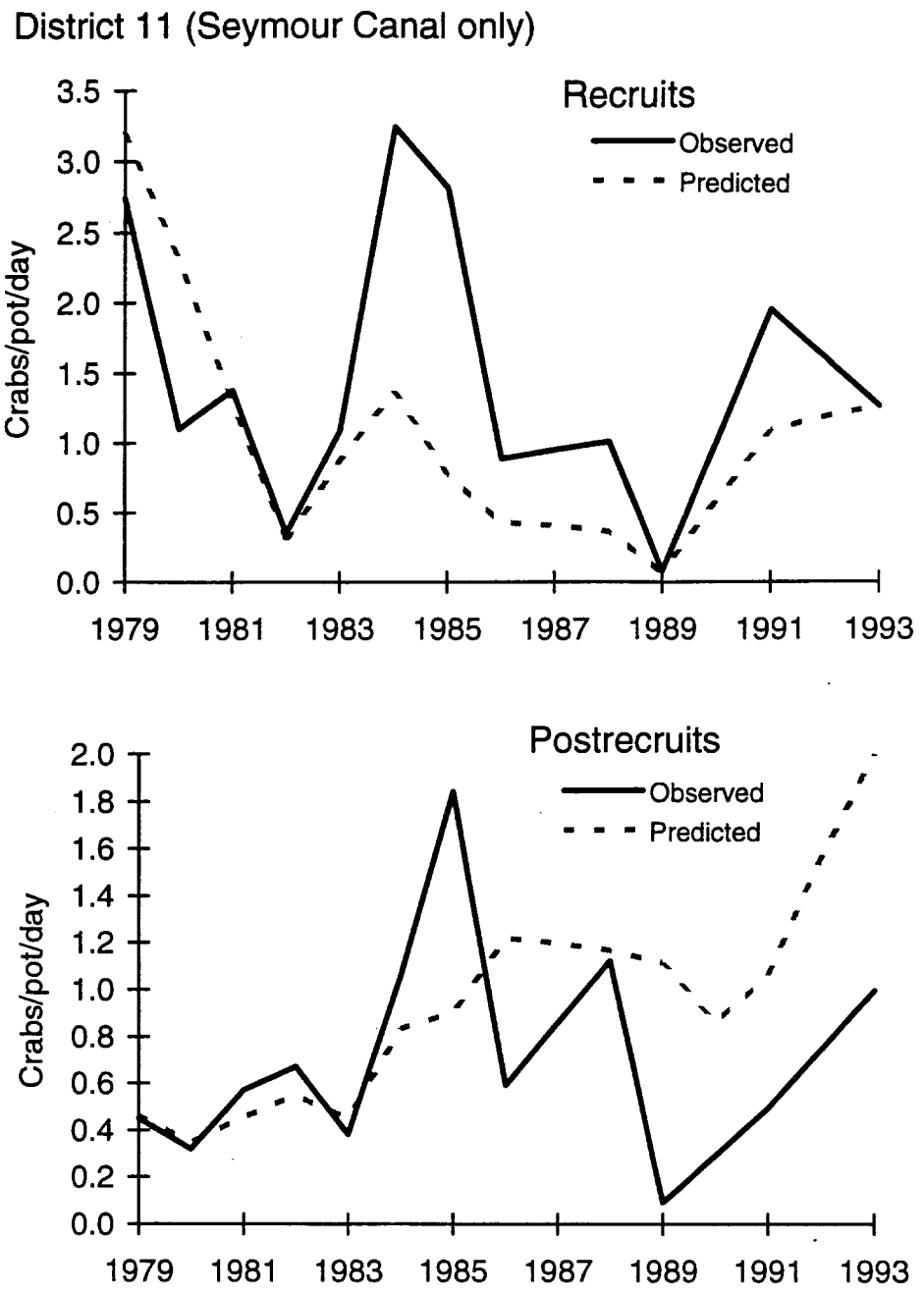

Figure 4. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 11 (Seymour Canal only), 1979 to 1993.

District 12

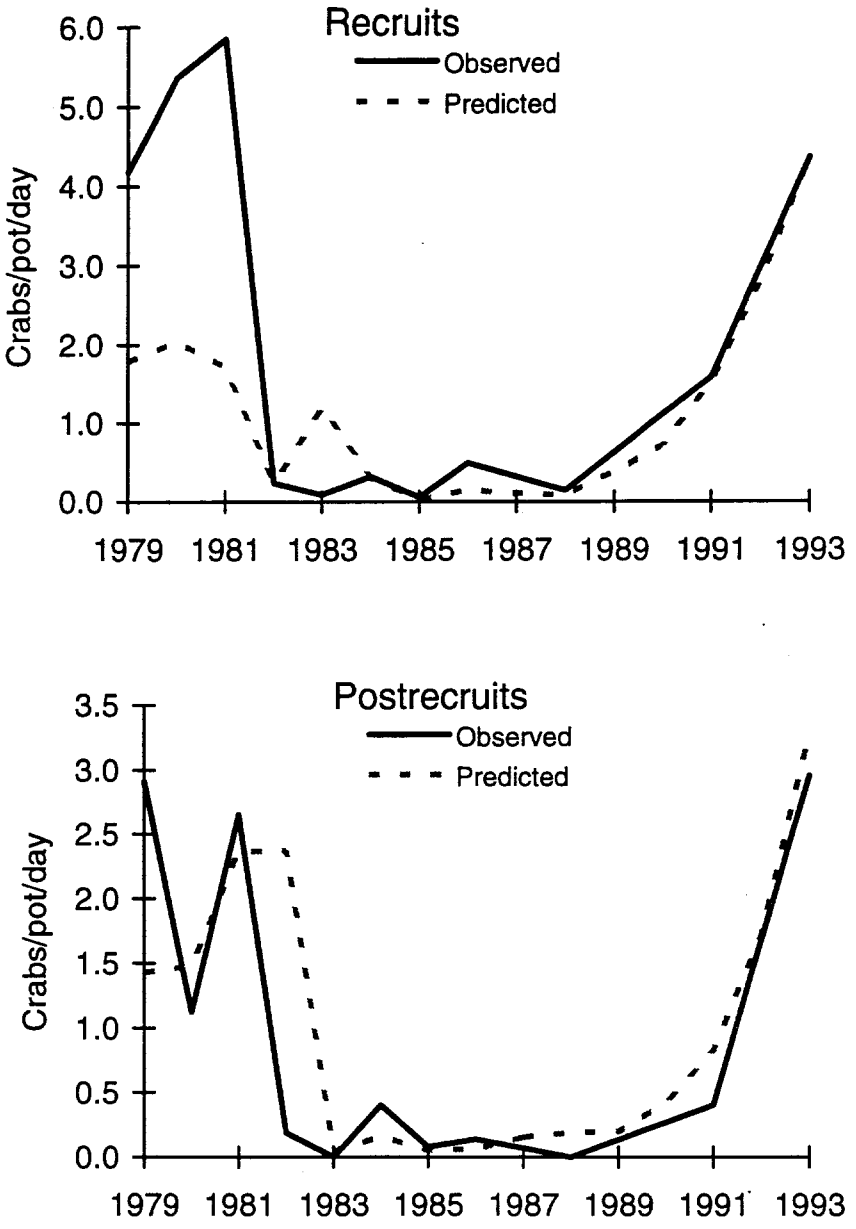

Figure 5. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 12, 1979 to 1993.

District 13

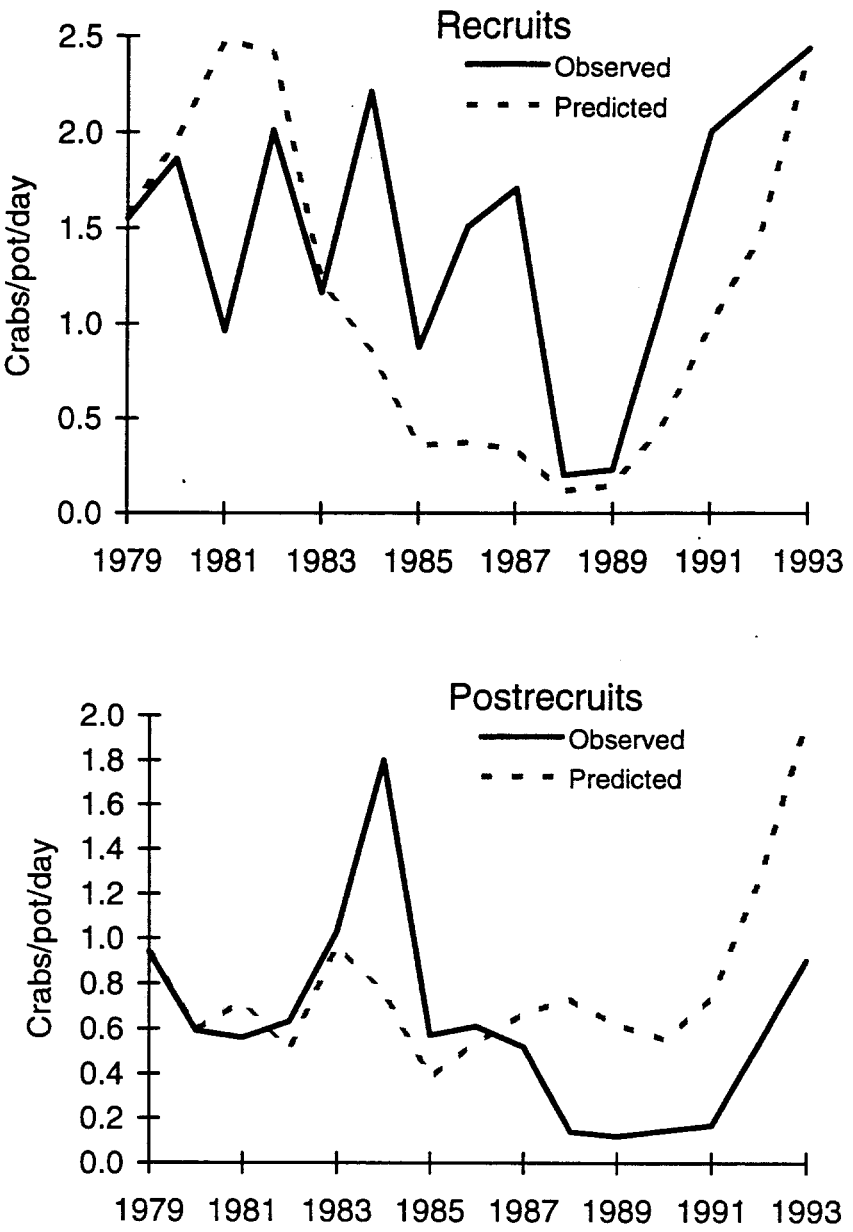

Figure 6. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 13, 1979 to 1993.

District 14

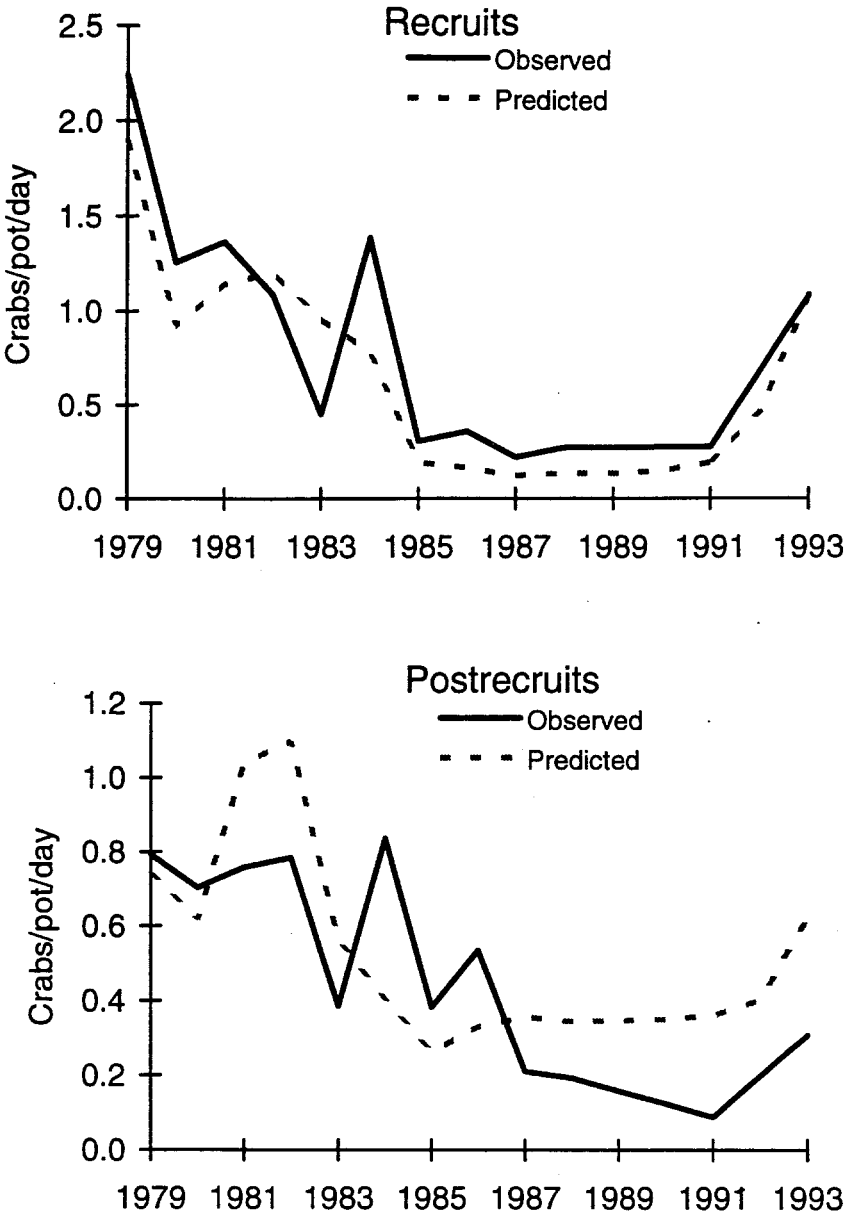

Figure 7. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 14, 1979 to 1993.

District 15

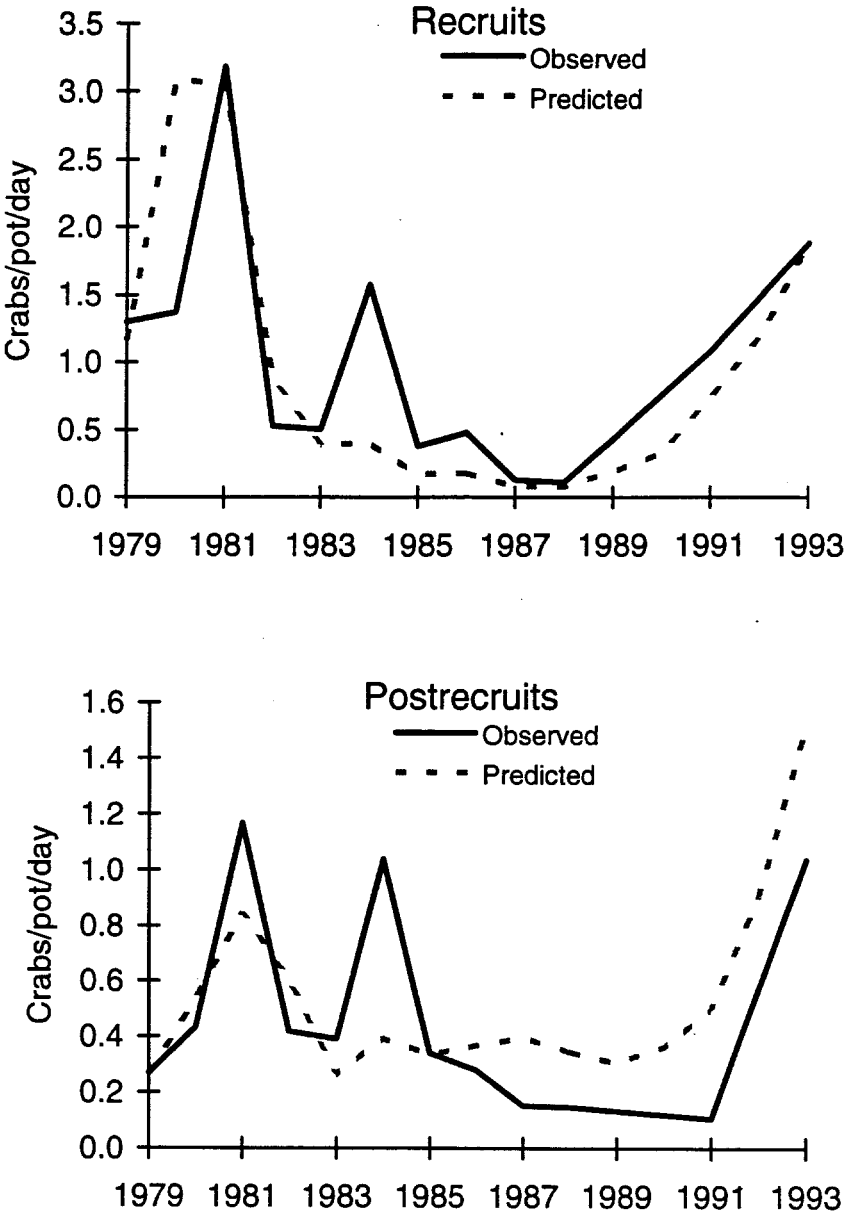

Figure 8. Observed and predicted catch rates of recruit and postrecruit male red king crabs in District 15, 1979 to 1993.

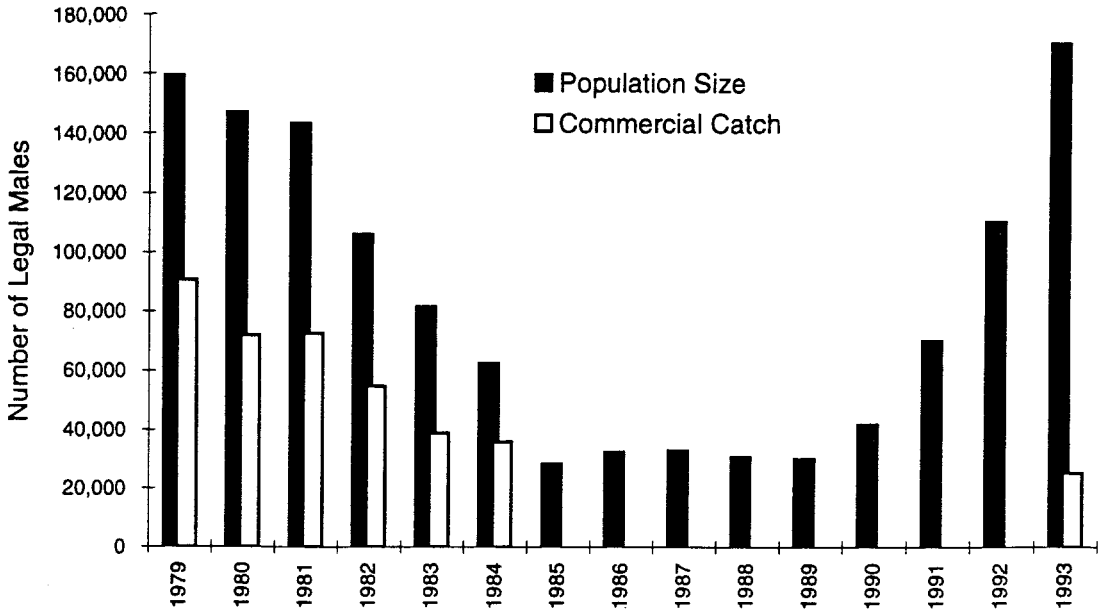

Figure 9. Commercial catches and estimated population sizes of legal male red king crab, 1979 to 1993.

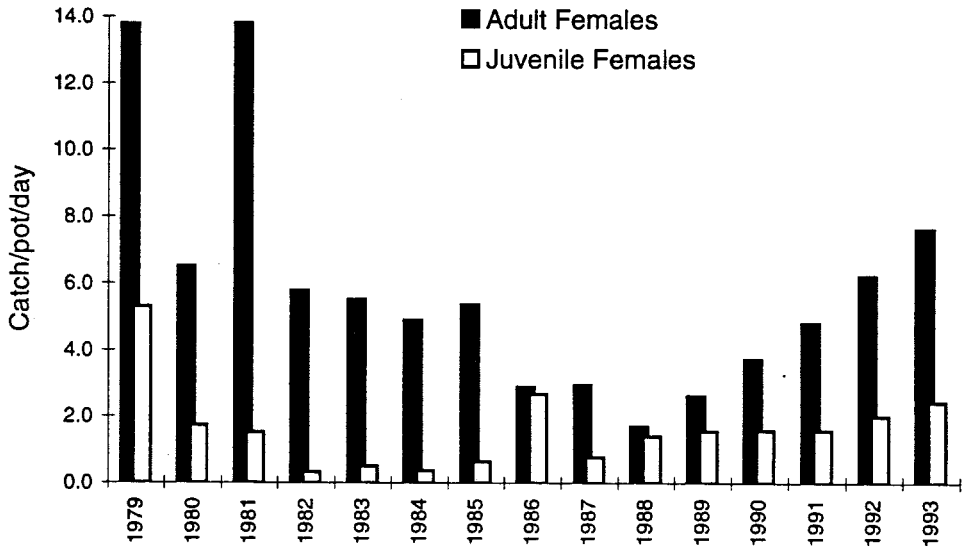

Figure 10. Survey catch rates of adult and juvenile female red king crab, 1979 to 1993. Data are from the assessments conducted in the 10 bays (areas) listed in Table 4. Annual catch rates are averages weightd by surface areas of the sampled portions of bays.

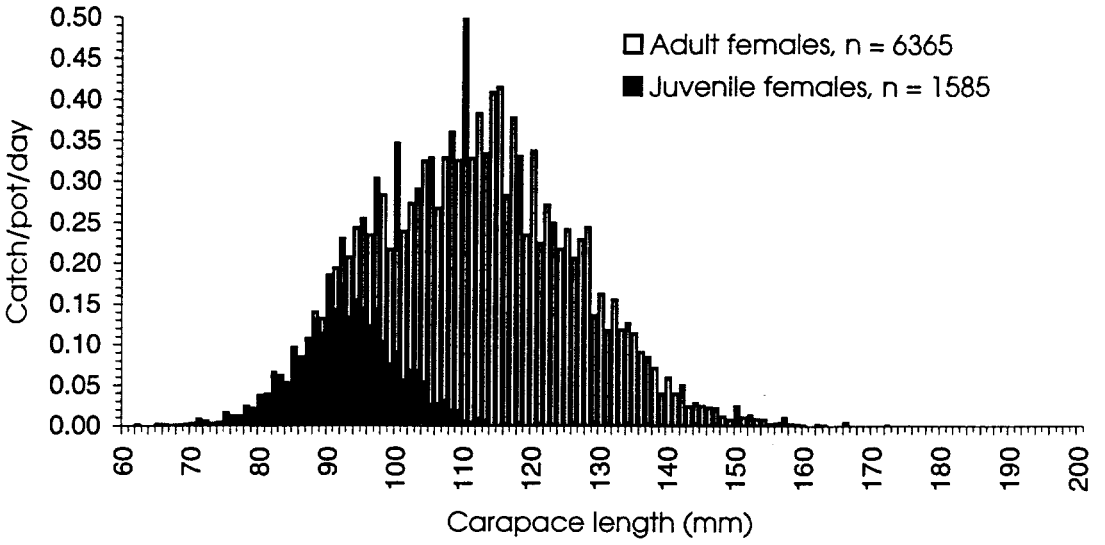

Figure 11. Relative abundance of female red king crab in Southeast Alaska , 1993. Data are expressed as catch rates for each mm size class for immature females and mature females.

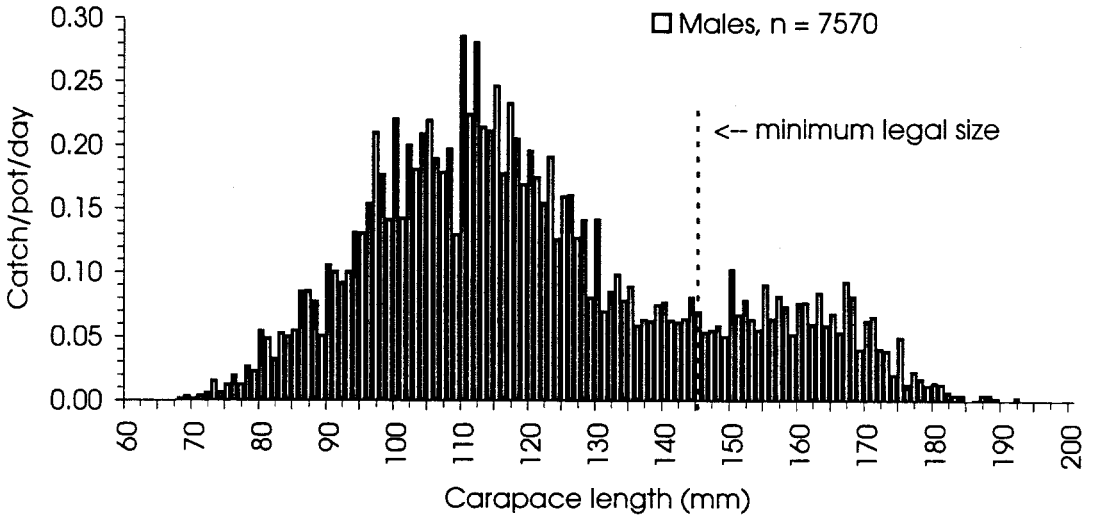

Figure 12. Relative abundance of male red king crabs in Southeast Alaska , 1993. Data are expressed as catch rates for each mm size class. Legal size is obtained at a mean length of 145 mm. Prerecruit 1 males range in size from 130 mm to 144 mm, on average.