Draft

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN 2004

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EXECUTIVE SUMMARY

A length-based analysis was applied to eastern Bering Sea trawl survey, catch sampling, and commercial catch data to estimate stock abundance of Bristol Bay red king crabs (*Paralithodes camtschaticus*) during 1972-2004. Four scenarios with different levels of natural mortality and weighting factors were compared. The base scenario with 3 levels of male natural mortality and 4 levels of female natural mortality over time fit the data very well, and its results were used to construct stock–recruitment relationships and determine the preseason guideline harvest level (GHL). Due to a sharp decline of survey abundance during the early 1980s, the constant natural mortality scenario fit the data poorly.

Due to above average year classes 1990, 1994 and 1997, abundances of mature males, legal males, and mature females all increased from last year and are at the highest levels since 1982. Abundance of mature males increased from 15.1 million in 2003 to 16.0 million in 2004, and legal male abundance increased from 10.1 to 10.4 million. Mature female abundance increased from 28.1 million to 35.3 million crabs, and effective spawning biomass increased from 57.6 to 61.9 million pounds. The effective spawning biomass is above the target rebuilding level of 55 million pounds; thus, a 15% harvest rate is applied. By multiplying the 15% harvest rate times mature male abundance times an average weight of 6.44 pounds per legal crab, an overall GHL of 15.424 million pounds is set. A total of 7.5% of the GHL or 1.157 million pounds is reserved for the community

development quota (CDQ) fishery resulting in a GHL of 14.267 million pounds for the open access fishery. The open access fishery will open October 15, 2001.

INTRODUCTION

Stock Structure

Red king crabs (RKC), *Paralithodes camtschaticus*, are found in several areas of the Aleutian Islands and eastern Bering Sea: off the Aleutian Islands, the Pribilof Islands and St. Lawrence Island and in Bristol Bay and Norton Sound. The State of Alaska divides the Aleutian Islands and eastern Bering Sea into three management registration areas to manage RKC fisheries: Aleutian Island, Bristol Bay, and Bering Sea (ADF&G 2002). The Aleutian Islands area covers two stocks, Adak and Dutch Harbor, and the Bering Sea area contains two other stocks, the Pribilof Islands and Norton Sound. The largest stock is found in the Bristol Bay area, which includes all waters north of the latitude of Cape Sarichef (54^{o}36' N lat.), east of 168^{o} W long., and south of the latitude of Cape Newneham (58^{o}39' N lat.) (ADF&G 2002). Besides these five stocks, RKC stocks elsewhere in the Aleutian Islands and eastern Bering Sea are too small to support a fishery. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States (ADF&G 2003). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974 (ADF&G 2003). The Russian fleet fished for RKC from 1959 through 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch caught by trawl and pots. The Russian fleet used only tanglenets. U.S. trawlers started to fish for Bristol Bay RKC in 1947 and effort and catches declined in the 1950s (ADF&G 2003). The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 59,000 t, worth an estimated $115.3 million ex-vessel value (ADF&G 2003). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades (Table 1). The Bristol Bay RKC fishery currently takes place during a short period in the fall (usually lasting less than a week), and the catch quota is based on the stock assessment conducted in the previous summer (Zheng and Kruse 2002a). Historical guideline harvest levels and actual catch are compared in Table 2. The implementation errors are quite high for some years, and total actual catch from 1980 to 2003 is about 8% less than the GHLs (Table 2).

Fisheries Management

King and Tanner crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through a federal king and Tanner crab fishery management plan (FMP). Under the FMP, management measurements are divided into three categories: (1) fixed in the FMP, (2) frameworked in the FMP, and (3) discretion of the State of Alaska. The State of Alaska is responsible for developing harvest strategies to determine GHLs under the framework in the FMP.

Harvest strategies for the Bristol Bay RKC fishery have changed over time. 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 2002). In attempting to meet these objectives, the 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 2002). 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 (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: 10% when effective spawning biomass (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. In 2003, the Board adopted the current harvest strategy by adding a mature harvest rate of 12.5% when the stock is between 34.75 and 55 million pounds of ESB. The current harvest strategy is illustrated in Figure 1.

The purpose of this report is to document the stock assessments for Bristol Bay RKC. This report includes (1) all data used to conduct the stock assessments, (2) details of the analytic approach, (3) an evaluation of the assessment results, and (4) an evaluation of the implications of the assessments to fishery management.

DATA

Catch Data

Landings of Bristol Bay RKC by length and year and catch per unit effort data were obtained from annual reports of the International North Pacific Fisheries Commission from 1960 to 1973 (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the Alaska Department of Fish and Game from 1974 to 2003 (ADF&G 2003). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (ADF&G 2003). Sample sizes for catch by length and shell condition are summarized in Table 3. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1. Retained catch and estimated bycatch from the directed fishery include both the general open access fishery and the CDQ fishery. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for seasons defined as June 1 to May 31, e.g., year 2002 in Table 1 corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 2.

Catch Size Composition

Retained catch by length and shell condition and bycatch by length, shell condition, and sex are summarized in Tables 4-6. From 1960 to 1966, only retained catch length compositions from the Japanese fishery were available. Retained catches from the Russian and U.S. fisheries were assumed to have the same length compositions as the Japanese fishery during this period. From 1967 to 1969, the length compositions from the Russian fishery were assumed to be the same as those from the Japanese and U.S. fisheries. After 1969, foreign catch declined sharply and only length compositions from the U.S. fishery were used to distribute catch by length. Retained catch data are illustrated in Figure 3.

Catch per Unit Effort

Catch per unit effort (CPUE) is defined as number of retained crabs per tan (a unit fishing effort for tanglenets) for the Japanese and Russian fisheries and number of retained crabs per potlift for the U.S. fishery (Table 7). Although soak time is an important factor influencing CPUE, it is difficult to standardize it. Furthermore, complete historical soak time data from the U.S. fishery are not available. Based on the approach of Balsiger (1974), all fishing efforts from Japan, Russia, and U.S. were standardized as the Japanese tanglenet from 1960 to 1971, and the CPUE was standardized as crabs per tan. The U.S. CPUE data do not match very well with survey legal abundance after 1967 (Figure 4).

Survey Data

NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each equipped with an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution. The survey on Bristol Bay area occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2003 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach without post-stratification (Table 8; Figure 5). If multiple tows were made for a single station in a given year, the average of the abundances from all tows was used as the estimate of abundance for that station. NMFS used a post-stratification approach until the late 1980s and has assumed Bristol Bay as a single stratum since then. If more than one tow is conducted in a station because of high RKC abundance (i.e., the station is a "hot spot"), NMFS regards the station as a separate stratum. Due to poor documentation, it is difficult to duplicate NMFS post-stratifications. A "hot spot" was not surveyed with multiple tows during the early years. Two such "hot spots" affected the survey abundance estimates greatly: station H13 in 1984 (mostly juvenile crabs 75-90 mm CL) and station F06 in 1991 (mostly newshell legal males). The tow at station F06 was discarded in the NMFS abundance estimates (Stevens et al. 1991). In this study, the average abundances from all tows in the 9 stations (the station itself and the 8 adjacent stations) were used as the estimates of abundance for station H13 in 1984 and station F06 in 1991.

The approach here results in estimates close to those made by NMFS with some exceptions (Figure 6). Two surveys were conducted for Bristol Bay red king crabs in 1999 and 2000: the standard survey that was performed in late May (about two weeks earlier than historic surveys) and a resurvey of 31 stations (1999) and 23 stations (2000) with high female density that was performed in late July. The resurveys were necessary because most females had not yet molted or mated prior to the standard surveys. Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations can be attributed to survey measurement errors or, possibly, to seasonal changes in distribution between survey and resurvey. The size distribution of females was significantly larger in the resurveys than during the standard surveys because most mature females had not molted prior to the standard surveys. NMFS included all survey tows in its estimates. I used data from both surveys to assess male abundance but only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundance during these two years.

For 1968-1970 and 1972-1974, abundance estimates were obtained from NMFS directly because the original survey data by tow are not currently available. There were spring and fall surveys in 1968 and 1969. The average of estimated abundances from spring and fall surveys was used for those two years. Different catchabilities were assumed for survey data before 1973 because of an apparent change in survey catchability. A footrope chain was added to the trawl gear starting in 1973, and the crab abundances in all length classes in 1973 and beyond were much greater than those estimated prior to 1973 (Reeves et al. 1977).

ANALYTIC APPROACH

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, the Alaska Department of Fish and Game developed a length-based analysis (LBA) in 1993 that incorporates multiple years of data and multiple data sources in the estimation procedure. Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). Alternative LBAs (not included in this report) were developed in 2004 to include small size groups and extend to the data before 1972. A stock-recruitment (S-R) relationship, estimated from the results of the LBA, was used to develop the current harvest strategy.

Population Model

A male population model is the original LBA model that was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002a). Pulse fishing was assumed for the model. The model was fitted to the abundance data after 1971 because shell condition data were limited to that period. Crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment and additions to or losses from each length class due to growth:

$$N_{l+1,t+1} = \sum_{l'=1}^{l'=l+1} \{P_{l',l+1} [(N_{l',t} + O_{l',t})\, e^{-M_t} - C_{l',t}\, e^{(y_t -1)M_t}]\, m_{l',t}\} + R_{l+1,t+1}, \qquad (1)$$

$$O_{l+1,t+1} = [(N_{l+1,t} + O_{l+1,t})\, e^{-M_t} - C_{l+1,t}\, e^{(y_t -1)M_t}]\,(1 - m_{l+1,t}),$$

where

- $N_{l,t}$ is newshell crab abundance in length class *l* and year *t*,
- $O_{l,t}$ is oldshell crab abundances in length class *l* and year *t*,
- M_t is the instantaneous mortality in year *t*, which includes natural mortality and indirect fishing mortality;
- $m_{l,t}$ is the molting probability for length class *l* in year *t*,
- $R_{l,t}$ is recruitment into length class *l* in year *t*,
- y_t is the lag in years between assessment survey and the fishery in year *t*,
- $P_{l',l}$ is the proportion of molting crabs growing from length class *l′* to *l* after one molt, and
- $C_{l,t}$ is the catch of length class *l* in year *t*.

The minimum carapace length is set at 95 mm for males and crab abundance is modeled with a length-class interval of 5 mm. The last length class includes all crabs ≥160-mm CL. There are 14 length classes/groups (1-14). $P_{l',l}$, $m_{l,t}$, and $R_{l,t}$ are computed as follows.

Mean growth increment per molt is assumed to be a linear function of pre-molt length:

$$G_l = a + b\,\iota, \qquad (2)$$

where *a* and *b* are constants. Growth increment per molt is assumed to follow a gamma distribution:

$$g(x \mid \alpha_l, \beta) = x^{\alpha_l -1}\; e^{-x/\beta} / [\beta^{\alpha_l}\;\; \Gamma(\alpha_l)]. \qquad (3)$$

The expected proportion of molting individuals growing from length class l_1 to length class l_2 after one molt is equal to the sum of probabilities within length range $[\iota_1,\ \iota_2)$ of the receiving length class l_2 at the beginning of the next year:

$$P_{l_1,l_2} = \int_{l_1-\iota}^{l_2-\iota} g(x \mid \alpha_\iota, \beta) dx, \tag{4}$$

where ι is the mid-length of length class l_1. For the last length class L, $P_{L,L}$ = 1.

The molting probability for a given length class l and time t is modeled by an inverse logistic function:

$$m_{l,t} = 1 - \frac{1}{1+\alpha_t e^{-\beta_t \iota}}, \tag{5}$$

where

α_t, β_t are parameters, and

ι is the mid-length of length class l.

Three logistic functions were used to describe the molting probability during different periods (Zheng et al. 1995a): high molting probabilities with α_1 and β_1 during 1972-1979, low molting probabilities with α_2 and β_2 during 1980-1984, 1992-1994, 1997, 1999, and 2001, and intermediate molting probabilities with α_3 and β_3 during 1985-1991, 1995-1996, 1998, 2000, and 2002-2004. Grouping of years for molting probabilities is based on the fit of newshell and oldshell crab abundances.

Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, R_t, and size-dependent variables, U_l, representing the proportion of recruits belonging to each length class. R_t was assumed to consist of crabs at the recruiting age with different lengths and thus represents year class strength for year t. $R_{l,t}$ is computed as

$$R_{l,t} = R_t U_l, \tag{6}$$

where U_l is described by a gamma distribution similar to equations (3) and (4) with a set of parameters α_r and β_r.

The female crab model is the same as the male crab model except that catch equals zero and molting probability equals 1.0 to reflect annual molting (Powell 1967). The minimum carapace length is set at 90 mm for females, and the last length class includes all crab ≥140-mm CL, corresponding to length groups 1-11 with 5 mm length intervals.

Model Scenarios

A variety of scenarios were run for the model; the results for each scenario were compared. Four scenarios were examined in this report:

A1-1: 4 levels of *M* for females and 3 levels of *M* for males over time,

A1-2: 2 levels of *M* over time,

A1-3: a constant *M*, and

A1-4: 4 levels of *M* for females and 3 levels of *M* for males over time with 50% weight for the terminal year 2004.

The results from scenario A1-1 have been used for management during the last 10 years and is referred as the base scenario in the report. Scenarios A1-3 and A1-4 were suggested by NMFS scientists Jack Turnock and Lou Rugolo.

Parameters Estimated Independently

Length-weight relationships and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 95 mm for females and 102 mm for males.

Length-weight Relationship

Length-weight relationships for males and females were obtained from B. Stevens of the NMFS Alaska Fisheries Science Center, Kodiak:

Immature Females: $W = 0.010271\ L^{2.388}$,

Ovigerous Females: $W = 0.02286\ L^{2.234}$,

Males: $W = 0.000361\ L^{3.16}$,

where

W is weight in grams, and

L is CL in mm.

Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, the 1960s and the 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and the 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be a function of body size only in the models. Based on two points of the mean growth increment of pre-molt length 54-118 mm in the modal analysis of the 1990s data as the growth increment for pre-molt length 67.5 mm and the mean increment of tagging data during the 1990s as the growth increment for pre-molt length 162.5 mm, growth increment per molt was estimated as a linear function of pre-molt length for male crabs (Figure 7). The line is about parallel to and slightly lower than that estimated from the tagging data during the 1950s and 1960s (Figure 7). Since the models primarily used the survey data after 1971, the growth increment per molt function estimated from the 1990s data was used in the LBA. The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females, and the data presented in Gray (1963) were used to estimate those for mature females (Figure 7). To make a smooth transition of growth increment per molt from immature to mature females, the weighted average of growth increment of 70% from matures and 30% from immatures was used for pre-molt length 92.5 mm and that of 90% from matures and 10% from immatures was used for pre-molt length 97.5 mm. These percentages are roughly close to the composition of maturity. Once mature, the growth increment per molt for male crabs increases slightly and annual molting probability decreases, whereas the growth increment for female crabs decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

Trawl Survey Catchability

Trawl survey selectivities/catchability were fixed at 1. As a comparison, lower catchabilites were estimated by Weinberg (2004) based on a trawl experiment (Figure 8).

Parameters Estimated Conditionally

The following model parameters were estimated separately for male and female crabs: recruits for each year (year class strength R_t for t = 1973 to 1994-2004), total abundance in the first year (1972), parameters β and β_r, and instantaneous natural mortality M_t. Molting probability parameters α_1, α_2, α_3, β_1, β_2, and β_3 were also estimated for male crabs. M_t was assumed to be a function of time and independent of body size in the assessments with terminal years 1994-2004. There were 3 levels of M_t for females and 2 levels for males in the assessments with terminal years 1994-1997 and 4 levels of M_t for females and 3 levels for males in the assessments with terminal years 1998-2004 (for females: M_1 for 1972-80, M_2 for 1981-84, M_3 for 1985-93 and 1998-2000, and M_4 for 1994-97 and 2001-04; for males: M_1 for 1972-79 and 1985-93, M_2 for 1980-84, and M_3 for 1994-97 and 2001-2004). These levels were determined interactively by searching for the best fit of area-swept estimates of abundances to the population model. To increase the efficiency of the parameter-estimation algorithm, I assumed that the relative frequencies of length and shell classes from the first survey year (1972) approximate the true relative frequencies within sexes. Thus, only total abundances of males and females for the first year were estimated; 3n unknown parameters, where n is the number of length-classes, for the abundances in the first year were reduced to 2 under this assumption.

Parameter Estimation

Measurement errors were assumed to be log-normally distributed, and parameters of the model were estimated using a nonlinear least squares approach, which minimized the residual sum of squares (RSS), or measurement errors:

$$RSS = \sum_{l,t} \{[\ln(N_{l,t} + \kappa) - \ln(\tilde{N}_{l,t} + \kappa)]^2 + [\ln(O_{l,t} + \kappa) - \ln(\tilde{O}_{l,t} + \kappa)]^2\}, \quad (7)$$

where

$\tilde{N}_{l,t}$, $\tilde{O}_{l,t}$ are area-swept estimates of abundances of newshell and oldshell crabs in length class *l* and year *t* from trawl survey data, and

κ is a constant set equal to 0.1 millions of crabs (<0.7% and 0.3% of the largest observed male and female abundances by length).

Constant κ was used to prevent taking the logarithm of zero and to reduce the effect of length classes with zero or very low abundances on parameter estimation. A smaller κ gives a heavier weight for low abundances, and vice versa. This constant functions similar to the constant used in the robust likelihood function by Fournier et al. (1990).

The annual abundance data can be weighted by the inverse of variance if good estimates of the annual variance are available. Because of aggregation of crabs, a huge catch may occur occasionally if the trawl hits a "hot spot". If a "hot spot" was not surveyed with multiple tows, the NMFS usually lumped the "hot spot" tow together with all other tows as a single stratum for Bristol Bay to estimate the variance, resulting in a high estimate of the coefficient of variation. Thus, using the inverse of variance as an annual weight may somewhat reduce the influence of a single tow on a "hot spot". However, if multiple tows were conducted on a "hot spot", the NMFS would regard the "hot spot" as a single stratum, thus reducing the estimate of the coefficient of variation. Because red king crabs do not uniformly distribute within Bristol Bay, variance estimates depend on how the survey data are stratified. The current NMFS approach regards Bristol Bay as a single stratum. Because there were usually tows without any crabs in some marginal areas, high population abundances most likely result in high estimates of the coefficient of variation with the current approach (Figure 9). Unless the estimates of variance can be improved, the inverse of variance may not be a good weighting factor. Thus, annual survey data were weighted equally in the current LBA. There was one exception. In 2001, the survey estimate of mature male abundance was much lower than expected based on previous surveys and the survey estimate of female abundance in 2001. To reduce the influence of the 2001 survey estimate of male abundance on the terminal population estimates, a 50% weight on it was used in the 2001 assessment. The surveys during 2002-2004 also indicate that the estimated survey male abundance in 2001 was much too low. This weight was changed back to 100% for later assessments due to its small influence on the estimates of terminal year abundances after 2001.

S-R MODELS

The results from the LBA were used to estimate the parameters of S-R models. I followed Zheng et al. (1995a) and Zheng and Kruse (2003) to estimate effective spawning biomass for Bristol Bay RKC. Male reproductive potential is defined as the mature male abundance by carapace length multiplied by the maximum number of females with which a male of a particular length can mate (Zheng et al. 1995a; Table 9). The maximum mating ratios (Table 9) used in this study are conservative and less than those observed in the laboratory studies (Powell and Nickerson 1965; Powell et al. 1974; Paul and Paul 1980, 1997). If mature female abundance was less than male reproductive potential, then mature female abundance was used as female spawning abundance. Otherwise, female spawning abundance was set equal to the male reproductive potential. The female spawning abundance was converted to biomass, defined as the effective spawning biomass SP_t. The S–R relationships of Bristol Bay RKC were modeled using a general Ricker curve:

$$R_t = SP_{t-k}^{r1}\, e^{r2 - r3\, SP_{t-k} + v_t}, \tag{8}$$

and an autocorrelated Ricker curve:

$$R_t = SP_{t-k}\; e^{r2 - r3\, SP_{t-k} + \upsilon_t}, \tag{9}$$

where

$\upsilon_t = \delta_t + a1\ \upsilon_{t-1}$,

v_t, δ_t are environmental noises assumed to follow a normal distribution $N(0,\sigma^2)$,

$r1$, $r2$, $r3$, and $a1$ are constants.

Equation (8) was linearized as

$$\ln(R_t) = r2 + r1\ \ln(SP_{t-k}) - r3\ SP_{t-k} + v_t, \tag{10}$$

and equation (9) as

$$\ln(R_t / SP_{t-k}) = r2 - r3\ SP_{t-k} + \upsilon_t. \tag{11}$$

An ordinary linear regression was applied to equation (10) to estimate model parameters *r*1*, r*2 and *r*3, and an autocorrelation regression (procedure AUTOREG, SAS Institute Inc. 1988) with a maximum likelihood method was used to estimate parameters *r*2*, r*3 and *a*1 for equation (11). A time lag of 8 years from mating to recruitment was used (Loher et al. 2001; Zheng and Kruse 2003).

To include the maximum range of available S–R data in the study of S–R relationships, I estimated the effective spawning biomass from 1968 to 1971 using survey abundance and the estimated survey catchability in 1972. The catchability for the survey gear in 1972 was estimated by comparing survey and model estimates. I assumed that the catchability for the survey gears in 1968-1971 was the same as in 1972 because the survey gears and methods were identical during these years (Reeves et al. 1977). Thus, the relative abundances from 1968 to 1971 were divided by the estimated catchability in 1972 to obtain the absolute abundances. The absolute abundances from 1968 to 2004 were used to construct S-R relationships.

Because of the regime shift in climate and physical oceanography that occurred in 1976–77 (Hare and Mantua 2000), it may not be realistic to expect the strong recruitment from hatching years before 1976 to occur in the near future. Also 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, a normal Ricker S–R curve was also fit to the S–R data from hatching years after 1975 to estimate an alternative S–R relationship under the current environmental conditions.

RESULTS

Model Evaluation

Model parameter estimates for four scenarios are summarized in Tables 10 and 11, and estimated mature male and female abundances are compared in Figure 10. Common features of the four scenarios were strong recruitment in the 1970s and relatively weak recruitment during the last 20 years. However, recruitment was much lower in the early 1980s for scenario A1-3 (constant *M*) than for the other three scenarios. Abundances estimated with scenarios A1-1 and A1-4 are pretty much identical except in the terminal year, in which the lower weight on the 2004 data (scenario A1-4) resulted in slightly higher mature and legal male abundance estimates. These two scenarios fit closely to the survey abundance with RSS of male crabs 145.04 and 141.15 and female crabs 43.90 and 43.69. The model of constant natural mortality (scenario A1-3) did not fit the data well (RSS = 264.61 for males and 261.01 for females); the survey abundance was underestimated before 1983 and overestimated during the mid and late 1980s. Scenario A1-2 fit the male abundance nearly as well as scenario A1-1 except that the estimated abundance was slightly lower during the 1970s, higher during the mid 1980s, and lower in the last three years than the fit of scenario A1-1 (Figure 10). Scenario A1-1 fit the female abundance (RSS = 43.90) much better than scenario A1-2 (RSS = 69.08).

It is not surprising that the constant *M* scenario did not fit the data as well as the variable *M* scenarios. Zheng et al. (1995a, 1995b) used the *F* statistic test (Schnute 1981) to test the null hypothesis that the constant *M* scenario is the same as the variable *M* scenario and concluded that the variable *M* scenario fit the survey data statistically much better than the constant *M* scenario. The survey abundance declined sharply during the early 1980s (Table 8 and Figure 5), which explains why the constant *M* scenario performed so poorly.

The RSS is not comparable between scenarios A1-1 and A1-4 because of different weighting factors. The survey abundance in 2004 is consistent with the survey abundances during the last few years except that the survey estimate of oldshell male abundance was lower than expected. Therefore, it is difficult to justify a different weight for the 2004 data from the previous 32 years of data. Scenario A1-4 serves as a comparison only.

Population Abundance

LBA estimates of Bristol Bay RKC abundance and 95% bootstrap confidence limits for 2004 under the base scenario (A1-1) are shown in Table 12. Mature crab abundance increased to a peak in the late 1970s, decreased dramatically in the early 1980s, remained at low levels during the 1980s and early 1990s, and increased somewhat since the mid 1990s due to the above average year classes (termed the 1990, 1994 and 1997 year classes in this report based on estimated hatching year; Figure 10). As most male crabs from the above average year class 1994 entered the legal-sized population this year, abundance of large-size groups continued to increase from last year. Prerecruit male abundance increased from 7.7 million to 11.3 million crabs, mature male abundance increased from 15.1 million to 16.0 million crabs, and legal males increased from 10.1 million to 10.4 million from 2003 to 2004 (Table 12). Due to the above average year class 1997, mature female abundance also continued to increase from last year (35.3 million crabs in 2004 from 28.1 million crabs in 2003). Effective spawning biomass in 2004 (61.9 million pounds) was higher than that in 2003 (57.6 million pounds).

The model scenario A1-1 closely fit the survey abundance by length, shell condition, and sex (Figure 11). It appeared that model estimates of oldshell male crabs in 1974, 1980, 1985, 1988, 2001, and 2004 were much higher than those of the survey. The abundance of newshell males was much higher than the oldshell males in the 1970s.

Molting Probabilities

Three levels of molting probabilities were estimated for different periods. Molting probabilities were very high during 1972-1979, low during 1980-1984 and 1992-1994, and intermediate during 1985-1991, 1995-1996, and 2002-2004 (Figure 12). Estimated molting probabilities during these periods were consistent with that estimated from the 1966-1969 tagging data (Balsiger 1974) but lower than those estimated from the tagging data during 1954-1961 (Balsiger 1974) (Figure 12).

Natural Mortality

Estimated natural mortality was much higher for females than males. For the base scenario, estimated natural mortality was very high in the early 1980s and very low in the mid 1990s and the recent years (Tables 10 and 11). The high natural mortality is consistent with survey data (Table 8 and Figure 5), which show a sharp decline of crab abundances in the early 1980s. Factors causing the high natural mortality are not clear. Physical environmental conditions, predation, disease, and handling mortality or a combination of all these factors may have contributed to high natural mortality (Otto 1986; Blau 1986). Senescence may also play a role for high natural mortality (Stevens 1990); however, high mortality seems to occur for almost all sizes of crabs in the early 1980s.

Exploitation

The RKC fishery in Bristol Bay harvests only legal crabs. Mature male and legal male harvest rates were computed by dividing total catch by the mature male abundance and legal crab abundance estimated in the base scenario, respectively. The legal male harvest rates ranged from 0.18 to 0.55 in the 1970s and the early 1980s and fluctuated around 0.19 since the current harvest strategy was adopted in 1996 (Figure 13). The mature male harvest rates were close to 0.2 in the early and middle 1970s and peaked at 0.35 in 1980 (Figure 13). These high harvest rates and legal crab abundances produced the record catches in the late 1970s and early 1980s, which were followed by the quick collapse of the population. Harvest not only removes legal male crabs but also reduces abundances of sublegal male and female crabs through handling mortality. Although the bycatch mortality biomass was very low relative to the retained catch biomass based on the assumed handling mortality rates (Figure 2), the bycatch handling mortality rate could be higher than those assumed during extremely cold years (Carls and O'Clair 1990). In summary, it appears that high natural mortality coupled with high harvest rates may have contributed to the collapse of the Bristol Bay RKC population in the early 1980s (Zheng et al. 1995a). The current conservative harvest strategy (low harvest rates) and low natural mortality since the mid 1990s may be helping the gradual recovery of the stock.

One assumption needed to estimate natural mortality from the survey data is that trawl catchability is equal to 1 during 1973-2004. The recent experiment shows that survey catchability may be less than 1 (Figure 8). Harvest rates would be lower than estimated in Figure 12 if the real catchability is lower than my assumption.

Retrospective Analysis

Past assessments were summarized for a retrospective analysis. The assessment under the base scenario in 2004 serves as the baseline estimates. The long-term trends of abundance estimates made by LBA assessments in terminal years 1994-2004 were similar (Figures 14 and 15). Abundance increased sharply from the early 1970s to the late 1970s and then dropped dramatically during the early 1980s. Abundance fluctuated around a low level during the last two decades.

The baseline total abundance estimates and the estimates made for terminal years 1994-2004 differed. The biggest difference for total abundance occurred in 1996 with a -19% relative error (Table 13). In addition to the survey measurement errors, this difference may also be due to assumptions about natural mortality (i.e., process errors). Natural mortality from 1985 to 1997 was assumed constant for the stock assessments conducted before 1998 (Zheng et al. 1997). Consistently lower model estimates than area-swept estimates of large-sized crab abundance from 1995 to 1997 (Figure 14) prompted reevaluation of the assumption of natural mortality. In the 1998 and 1999 assessments, a new level of natural mortality was estimated after 1993, which was much lower than estimated natural mortalities from 1972 to 1993 (Figure 16; Zheng et al. 1998; Zheng and Kruse 1999). The fishery was closed in 1994 and 1995, and RKC bycatch in the groundfish fisheries was further reduced because of the depressed crab stock. Both factors may have lowered indirect fishing mortality, part of the natural mortality in the model. Overestimates of 1994-1997 natural mortality during the assessments in terminal years 1995-1997 partially caused underestimates of large-sized crab abundance in those terminal years.

Relative errors for Bristol Bay RKC stock estimates are smaller than those for many groundfish stock estimates. Relative errors range from –19% to 12% for total crab abundance, whereas relative errors of biomass could range from –57% to 27% for some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002a; Ianelli et al. 2003). In a retrospective catch-at-age analysis for Pacific halibut (*Hippoglossus stenolepis*) from 1944 to 1990, Parma (1993) indicated that historical estimates could be several times higher than the most recent estimates. As a contrast to the results by Parma (1993) that historical assessments tended to greatly overestimate Pacific halibut abundance during the 1960s and 1970s, historical assessments substantially underestimated pollock abundance in the eastern Bering Sea (Ianelli et al. 2003). In both stocks, historical errors in abundance estimates were highly autocorrelated over time. Such large errors were most likely caused by mis-specification of survey or fishery catchabilities (Parma 1993).

Even though the estimated historical errors of total crab abundance estimates are relatively small, their impacts on annual GHL can be substantial (Table 13). Mature female abundance assessed in 1995 was close to the threshold level, and the fishery was closed due to conservation concerns. Under the current model assessment of abundance in 1995, the fishery would have been opened. The estimated mature male harvest rates are close to the targeted rates in 1996, 1997, and 1999, but are much higher in 1998. Because the step harvest rates are based on effective spawning biomass (Figure 1), the higher estimated effective spawning biomass in 1998 resulted in a target rate of 15%. The current model assessment would have triggered a target rate of 10%. Model assessment errors could greatly affect annual GHLs if effective spawning biomass is near transition points between 0% and 10% and 10% and 15% harvest rates, as in 1995 and 1998. However, over a period of years, total GHL may not be affected much by assessment errors: total estimated GHL from 1994 to 2004 is very close to that derived from the current model assessment.

Overall, abundance estimates by the length-based model and area-swept method had the same trends over time (Zheng et al. 1995a, 1995b; Zheng and Kruse 2002a). The model provides smoother, more consistent abundance estimates than the area-swept method, and it is considered to be an improvement over a single-year point estimate of abundance derived from the area-swept method. The reduction of annual assessment error estimates with the model decreases estimated errors in setting annual GHLs.

The LBA for Bristol Bay RKC is flexible, and I intend to continue to improve the model by incorporating new knowledge and data as they become available. One potential improvement is to improve growth parameter estimates. The 1990, 1994 and 1997 year classes show distinctive modes over time and provides good information for future modal analysis for estimating growth parameters. Another potential improvement is to incorporate length-dependent catchability for trawl survey data. Data on males < 95-mm and females < 90-mm CL could also be incorporated to reduce measurement error estimates of recruitment, particularly as new strong year classes become recruited to the survey gear and model. The new model is being developed to incorporate these elements and expand to the data before 1972. The standardized CPUE data will be used in the new model to tune the length-based model in the early years (before 1972) due to lack of survey data.
The new model will also estimate pot and trawl bycatches to improve natural mortality estimates.

S–R Relationships

I estimated S-R relationships for Bristol Bay RKC from the results of the LBA base scenario (Figure 17). Generally, strong recruitment occurred with intermediate levels of effective spawning biomass, and very weak recruitment was associated with extremely low levels of effective spawning biomass. These features suggest a density-dependent S–R relationship. On the other hand, strong year classes occurred in the late 1960s and early 1970s, and weak year classes occurred in the 1980s and 1990s. Therefore recruitment is highly autocorrelated, so environmental factors may play an important role in recruitment success. I used the general Ricker curve to describe the density-dependent relationship and the autocorrelated Ricker curve to depict the autocorrelation effects. Because the autocorrelated curve regards the strong recruitment during the late 1960s and early 1970s as a result of autocorrelation, the recruitment associated with intermediate effective spawning biomass is much lower for the autocorrelated curve than for the general curve (Figure 17). Likewise, because the autocorrelated curve is less density-dependent, it has much higher recruitment than the general curve when effective spawning biomass is very high. Overall, the general Ricker curve (R^2=0.53, *df*=26) fit the data better than the autocorrelated curve (R^2=0.45, *df*=26), in contrast to the earlier results when S–R data were fitted up to the 1987 brood year (Zheng et al., 1995a, 1995b). The autocorrelation parameter fit the residuals well only before the 1982 year class and then fit the residuals poorly.

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. Egg clutch data are subject to subjective rating errors as well as sampling errors, but their trends over time may be useful. Proportions of empty clutches for newshell mature females >89 mm CL were high during some years before 1990 and have been very low since 1990 (Figure 18). The highest proportion of empty clutches was in 1986 with 0.20, and they were found with primarily soft shell females (shell condition 1). Clutch fullness fluctuated annually around their average levels during two periods: before 1991 and after 1990 (Figure 18). The average clutch fullness was almost identical for these two periods (Figure 18).

The recruitment strength and the Aleutian Low Pressure index were examined by Zheng and Kruse (2000) and are compared in Figure 19. The average seasonal index of

December-March with a 3-point running average was used. The recruitment trends of Bristol Bay RKC may partly relate to decadal shifts in physical oceanography: all strong year classes occurred before 1977 when the Aleutian Low was weak. The largest year class during the last 20 years, the 1990 year class, was also coincidental with the weak Aleutian Low index during 1989-1991.

Many Alaskan RKC stocks, like Bristol Bay, tend to have periods of weak recruitment that coincide with decades of strong winter Aleutian Lows, the opposite of trends for many fish stocks (Hollowed and Wooster 1992; Beamish and Bouillon 1993). The mechanisms are uncertain, but food availability is hypothesized to be important to RKC (Zheng and Kruse 2000) because their larvae suffer reduced survival and feeding capability if they do not feed within the first 2-6 days after hatching (Paul and Paul 1980). Diatoms such as *Thalassiosira* are important food for first-feeding RKC larvae (Paul et al. 1989) and they predominate the spring bloom in years of light winds when the water column is stable (Ziemann et al. 1991; Bienfang and Ziemann 1995). One hypothesis is that years of strong wind mixing associated with intensified Aleutian Lows may depress RKC larval survival and subsequent recruitment (Zheng and Kruse 2000).

FISHERY MANAGEMENT IMPLICATIONS

Directed Crab Fishery.

The Alaska Board of Fisheries harvest strategy for Bristol Bay RKC sets a GHL by harvest rate coupled to a fishery threshold (Figure 1). When the stock is not above the threshold of 8.4 million mature females (> 89 mm CL) and 14.5 million pounds of ESB, the fishery is closed. When the stock is above threshold, GHL is determined by the ESB and abundance of mature and legal-sized males. A mature male harvest rate of 10% or 12.5% is applied to promote stock rebuilding when ESB is below the target rebuilding level of 55 million pounds. Once the stock is at or above 55 million pounds of ESB, a 15% harvest rate is applied to mature male abundance. To prevent a disproportionate harvest of large male crabs, the GHL is capped so that no more than 50% of the legal male crabs may be harvested in any one year.

In 2004 the estimates of mature female abundance and ESB were 35.3 million and 61.9 million pounds, respectively, both above the thresholds needed to conduct a directed commercial fishery. Because ESB is above the target rebuilding level of 55 million pounds, a 15% harvest rate is applied. Applying this harvest rate times mature male abundance of 15.967 million results in a harvest of 2.395 million crabs. Because 2.395 million is only 23.1% of the legals, the 50% cap is not required. By multiplying 2.395 million crabs times an average weight of 6.44 pounds per legal crab, a preseason GHL of 15.424 million pounds was established for the 2004 fishery. A total of 7.5% of the GHL or 1.157 million pounds is reserved for the community development quota (CDQ) fishery, resulting in a GHL of 14.267 million pounds for the open access fishery. The actual CDQ harvest level will be based on a percentage of the total catch from the open-access commercial fishery.

Implications on the Bering Sea Groundfish Trawl Fisheries

Prohibited species catch (PSC) limits for RKC caught during groundfish trawl fisheries are set annually as a function of estimated ESB of Bristol Bay RKC (Figure 1). When ESB exceeds 14.5 million pounds but is less than 55 million pounds, the PSC is 97,000 crabs. When ESB exceeds 55 million pounds, the PSC is 197,000 crabs. Given the estimate of 61.9 million pounds of ESB for 2004, the RKC PSC limit for the Bering Sea will be set at 197,000 crabs for groundfish trawl fisheries in 2005.

A portion of the year-round closure to non-pelagic trawling in the RKC Savings Area (162^{o} to 164^{o} W, 56^{o} to 57^{o} N) is open to the rock sole fishery in years when there is a RKC fishery in Bristol Bay (Witherell and Roberts 1996). Thus, the portion of the RKC Savings Area bounded by 56^{o} to 56^{o} 10' N latitude will remain open to the rock sole fishery in 2005. A separate bycatch limit is established for this area not to exceed 35% of the RKC PSC limits apportioned to the rock sole fishery by the NPFMC.

PROJECTIONS AND FUTURE OUTLOOK

Future population projections primarily depend on future recruitment predictions. Crab recruitment is extremely difficult to predict. Therefore, unless the projections are required for regulatory purposes, no projections are made in the stock assessment report.

Due to above average year classes 1990, 1994 and 1997, abundances of mature males, legal males, and mature females all increased from last year and are at the highest levels since 1982. Another potential above average year class may be possible with lengths centered around 67.5 mm (Figure 20), although it is still too early to determine year class strength for this cohort due to unreliable survey estimates of juvenile crabs. The trawl survey next year will help determine the strength of this cohort. Due to these above average year classes, mature and legal crabs should maintain relatively high levels compared to those during the last 20 years if natural mortality does not increase greatly, as in the early 1980s for this stock and in 1999 for St. Matthew Island blue king crabs (Zheng and Kruse 2002b). Current crab abundance is still very low relative to those in the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s may be difficult.

ACKNOWLEDGMENTS

I thank Doug Woodby, Doug Pengilly and Shareef Siddeek for reviewing the earlier draft of this manuscript and Jack Turnock and Lou Rugolo for suggesting the scenario of a smaller weight for the survey data in 2004. This report is funded in part by a cooperative agreement from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Table 1. Bristol Bay red king crab annual catch and bycatch mortality biomass (million lbs) from June 1 to May 31. A handling mortality rate of 20% for pot and 80% for trawl was assumed to estimated bycatch mortality biomass.

	Retained Catch				Pot Bycatch		Trawl
Year	U.S.	Cost-recovery	Foreign	Total	Males	Females	Bycatch
1960	0.600		26.898	27.498			
1961	0.427		44.592	45.019			
1962	0.068		54.275	54.343			
1963	0.653		54.963	55.616			
1964	0.823		58.170	58.993			
1965	1.429		41.294	42.723			
1966	0.997		42.356	43.353			
1967	3.102		33.636	36.738			
1968	8.686		27.469	36.155			
1969	10.403		14.383	24.786			
1970	8.559		12.984	21.543			
1971	12.946		6.134	19.080			
1972	21.745		4.720	26.465			
1973	26.914		0.228	27.142			
1974	42.266		0.476	42.742			
1975	51.326		0.000	51.326			
1976	63.920		0.000	63.920			1.426
1977	69.968		0.000	69.968			2.685
1978	87.618		0.000	87.618			2.757
1979	107.828		0.000	107.828			2.783
1980	129.948		0.000	129.948			2.135
1981	33.591		0.000	33.591			0.448
1982	3.001		0.000	3.001			1.201
1983	0.000		0.000	0.000			0.885
1984	4.182		0.000	4.182			2.316
1985	4.175		0.000	4.175			0.829
1986	11.394		0.000	11.394			0.432
1987	12.289		0.000	12.289			0.311
1988	7.388		0.000	7.388			1.174
1989	10.265		0.000	10.265			0.374
1990	20.362	0.081	0.000	20.443	1.139	1.154	0.501
1991	17.178	0.206	0.000	17.384	0.881	0.142	0.576
1992	8.043	0.074	0.000	8.117	1.191	0.780	0.571
1993	14.629	0.053	0.000	14.682	1.649	1.133	0.836
1994	0.000	0.093	0.000	0.093	0.000	0.000	0.180
1995	0.000	0.080	0.000	0.080	0.000	0.000	0.213
1996	8.406	0.108	0.000	8.514	0.356	0.002	0.238
1997	8.756	0.155	0.000	8.911	0.528	0.034	0.168
1998	14.757	0.188	0.000	14.946	2.074	1.547	0.355
1999	11.670	0.186	0.000	11.856	0.679	0.015	0.408
2000	8.154	0.086	0.000	8.241	0.779	0.078	0.230
2001	8.403	0.120	0.000	8.523	0.902	0.309	0.330
2002	9.570	0.096	0.000	9.666	0.956	0.013	0.245
2003	15.697	0.034	0.000	15.731	1.945	0.709	

Table 2. Comparison of GHL and actual catch (million lbs) of Bristol Bay red king crabs.

Year	GHL Range	GHL Mid-point	Actual Catch	Rel.Error	%Rel.Error
1980	70-120	95.00	129.95	34.95	36.79
1981	70-100	85.00	33.59	-51.41	-60.48
1982	10-20	15.00	3.00	-12.00	-79.99
1983	0	0.00	0.00	NA	NA
1984	2.5-6	4.25	4.18	-0.07	-1.59
1985	3-5	4.00	4.18	0.18	4.38
1986	6-13	9.50	11.39	1.89	19.94
1987	8.5-17.7	13.10	12.29	-0.81	-6.19
1988		7.50	7.39	-0.11	-1.50
1989		16.50	10.26	-6.24	-37.79
1990		17.10	20.36	3.26	19.08
1991		18.00	17.18	-0.82	-4.57
1992		10.30	8.04	-2.26	-21.91
1993		16.80	14.63	-2.17	-12.93
1994		0.00	0.00	0.00	
1995		0.00	0.00	0.00	
1996		5.00	8.41	3.41	68.11
1997		7.00	8.76	1.76	25.09
1998		16.40	14.76	-1.64	-10.02
1999		10.66	11.67	1.01	9.48
2000		8.35	8.15	-0.20	-2.34
2001		7.15	8.40	1.25	17.52
2002		9.27	9.57	0.30	3.24
2003		15.71	15.70	-0.01	-0.08
Total		391.59	362.01	-29.58	-7.59

Table 3. Annual sample sizes for catch by length and shell condition for retained catch and bycatch of Bristol Bay red king crabs.

Year	Trawl Survey		Retained	Pot Bycatch		Trawl Bycatch	
	Males	Females	Catch	Males	Females	Males	Females
1960			3960				
1961			3116				
1962			9120				
1963			9600				
1964			13080				
1965			10559				
1966			11772				
1967			21834				
1968	3684	2165	18044				
1969	6144	4992	22812				
1970	1546	1216	3394				
1971			10340				
1972	1106	767	15046				
1973	1783	1888	11848				
1974	2505	1800	27067				
1975	2943	2139	29570				
1976	4724	2956	26450			2327	676
1977	3636	4178	32596			14014	689
1978	4132	3948	27529			8983	1456
1979	5807	4663	27900			7228	2821
1980	2412	1387	34747			47463	39689
1981	3478	4097	18029			42172	49634
1982	2063	2051	11466			84240	47229
1983	1524	944	0			204464	104910
1984	2679	1942	4404			357981	147134
1985	792	415	4582			169767	30693
1986	1962	367	5773			62023	20800
1987	1168	1018	4230			60606	32734
1988	1834	546	9833			102037	57564
1989	1257	550	32858			47905	17355
1990	858	603	7218	873	699	5876	2665
1991	1378	491	36820	1801	375	2964	962
1992	513	360	23552	3248	2389	1157	2678
1993	1009	534	32777	5803	5942		
1994	443	266	0	0	0	4953	3341
1995	2154	1718	0	0	0	1729	6006
1996	835	816	8896	230	11	24583	9373
1997	1282	707	15747	4102	906	9035	5759
1998	1097	1150	16131	11079	9130	25051	9594
1999	820	540	17666	1048	36	16653	5187
2000	1278	1225	14091	8970	1486	36972	10673
2001	611	743	12854	9102	4567	56070	32745
2002	1032	896	15932	9943	302	27705	25425
2003	1669	1311	16212	17998	10327		

Table 4. Estimated annual retained catch by length (1000 crabs) based on catch sampling and fish ticket reporting for Bristol Bay red king crabs from June 1 to May 31.

Year	Carapace Length (mm)									
	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5+
1960	0.0	0.0	10.7	32.0	53.3	134.4	298.7	462.9	603.7	680.5	1755.7
1961	16.9	50.6	97.0	168.6	219.2	240.3	286.7	459.5	691.3	919.0	3385.0
1962	0.0	69.7	145.7	202.7	297.7	430.7	557.3	671.3	798.0	937.3	3869.7
1963	31.9	106.4	202.1	308.5	436.2	659.6	808.5	851.1	851.1	861.7	3478.8
1964	17.6	52.9	101.4	211.6	357.1	573.2	806.8	925.9	996.4	992.0	3782.9
1965	0.0	0.0	37.0	103.0	221.8	459.5	720.9	937.4	1090.6	1032.5	2062.3
1966	0.0	0.0	129.7	358.9	485.5	618.2	769.0	787.1	775.0	741.9	2240.7
1967	0.0	0.0	13.0	173.1	366.6	580.1	827.6	926.5	934.8	834.1	2091.7
1968	0.0	0.0	23.6	151.1	297.5	415.5	590.2	613.8	651.6	533.5	1463.7
1969	0.0	1.3	102.2	252.9	375.6	431.0	511.8	457.9	399.2	279.5	567.9
1970	0.0	18.5	149.9	350.2	568.3	637.9	511.7	423.7	275.4	190.6	381.9
1971	0.0	0.0	0.0	18.1	333.8	720.1	788.2	617.7	460.3	300.1	371.2
1972	0.0	0.0	0.0	38.6	585.7	973.8	1001.4	851.7	611.5	378.7	445.4
1973	0.0	0.0	0.4	34.4	488.3	872.5	821.3	722.8	584.2	358.8	419.5
1974	0.0	0.0	0.0	90.7	945.4	1716.3	1735.5	1408.3	912.7	542.2	543.7
1975	0.0	0.0	0.0	62.1	648.0	1504.8	1958.4	1855.8	1280.0	750.0	686.1
1976	0.0	0.0	0.0	17.2	307.7	1503.1	2456.1	2331.2	1733.8	1135.8	1118.5
1977	0.0	0.0	0.0	19.8	225.7	1621.2	2864.9	2612.2	1883.6	1219.9	1285.8
1978	0.0	0.0	0.0	17.1	308.0	2125.4	3816.5	3540.1	2466.6	1423.7	1048.2
1979	0.0	0.0	0.0	21.1	200.6	1256.2	2771.5	3357.7	3368.0	2616.1	3217.4
1980	0.0	0.0	0.0	16.3	288.0	1915.9	3691.1	4064.2	3734.6	2926.1	4209.2
1981	0.0	0.0	0.0	3.3	119.2	617.9	925.2	908.2	841.0	681.4	1211.8
1982	0.0	0.0	0.0	0.0	29.4	139.4	151.6	90.2	45.3	27.5	57.7
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.2	1.8	51.9	246.9	248.9	140.0	67.2	25.5	11.5
1985	0.0	0.0	0.4	3.5	62.9	228.4	246.6	151.1	68.5	24.4	10.3
1986	0.0	0.0	0.0	3.4	111.4	548.6	690.6	437.6	205.3	73.9	28.8
1987	0.0	0.0	0.0	2.8	60.3	402.2	646.2	535.3	301.5	120.0	54.1
1988	0.0	0.0	0.0	0.0	25.0	160.0	327.1	305.4	231.9	127.7	58.9
1989	0.0	0.0	0.0	0.8	31.5	204.0	372.1	368.9	321.5	201.6	184.4
1990	0.0	0.0	0.9	0.0	45.6	276.7	562.1	532.6	539.1	446.6	716.8
1991	0.0	0.1	0.3	1.3	37.2	223.1	434.3	470.8	457.5	376.8	629.3
1992	0.0	0.3	0.2	0.6	11.4	76.4	157.6	200.2	209.1	195.8	345.4
1993	0.0	0.0	0.0	3.2	31.0	211.3	402.3	391.0	359.0	299.4	551.7
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.0	0.7	0.7	16.4	98.7	178.2	205.1	224.3	211.6	330.9
1997	0.0	0.0	0.5	0.4	18.5	120.3	199.0	214.6	227.6	212.7	345.4
1998	0.7	0.8	0.4	1.8	49.9	263.0	353.5	330.0	317.3	308.8	589.3
1999	0.0	0.1	0.0	0.1	27.9	250.3	490.7	436.8	309.5	183.1	207.2
2000	0.3	0.0	0.2	0.4	13.9	117.1	244.7	265.6	229.3	156.9	229.7
2001	0.3	0.3	0.3	1.6	23.2	107.6	216.2	255.5	251.3	193.8	236.6
2002	0.4	0.1	0.0	0.3	22.4	160.3	279.7	284.3	249.8	198.1	289.2
2003	0.5	0.2	0.6	2.2	61.0	367.6	582.4	469.8	375.8	249.4	400.9

Table 5a. Estimated annual male bycatch by length (1000 crabs) based on observer data from the directed pot fishery for Bristol Bay red king crabs from June 1 to May 31.

Year	Carapace Length (mm)															
	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5+	Total
1990	1.9	0.0	1.9	13.8	7.9	21.7	11.9	65.0	86.6	131.8	210.7	261.8	320.9	419.4	147.6	15.8	1719
1991	4.8	14.7	28.6	31.1	35.2	57.3	47.4	91.6	90.7	100.6	93.2	163.5	230.6	313.1	136.5	14.7	1454
1992	0.0	2.1	2.8	25.6	51.2	126.6	200.4	263.5	272.8	283.6	272.1	288.4	256.4	186.1	67.6	6.5	2305
1993	5.1	12.1	15.3	13.4	16.7	32.8	83.9	153.5	209.1	290.3	358.6	415.0	408.0	458.3	200.8	14.8	2688
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1996	0.0	0.0	0.0	7.8	31.2	49.4	44.1	18.2	28.6	41.6	36.4	59.7	88.4	119.5	62.4	7.8	595
1997	0.0	0.2	0.5	0.6	1.4	17.9	50.3	99.2	115.4	118.7	93.8	91.2	116.0	129.6	68.3	6.9	910
1998	0.6	1.6	2.5	14.0	22.2	31.7	33.0	55.5	124.1	307.8	444.9	654.3	649.5	574.6	226.6	30.8	3174
1999	0.0	0.0	0.0	7.9	7.9	2.7	7.0	7.9	13.2	26.4	58.1	116.2	195.3	299.1	173.3	7.0	922
2000	0.4	7.1	26.7	67.3	85.4	80.2	82.9	80.9	74.1	77.7	99.2	147.5	208.5	216.5	124.7	13.5	1393
2001	2.6	9.3	15.1	18.7	25.2	49.0	92.2	140.6	163.8	194.2	201.2	229.1	214.1	183.1	78.1	7.3	1624
2002	1.8	9.3	9.2	13.9	9.9	15.9	20.3	51.2	96.2	174.4	235.6	260.4	250.7	241.6	122.6	14.2	1527
2003	28.7	42.2	51.8	112.4	195.7	236.1	255.3	237.5	227.6	212.4	232.2	339.7	468.7	605.6	276.9	22.7	3546

Table 5b. Estimated annual female bycatch by length (1000 crabs) based on observer data from the directed pot fishery for Bristol Bay red king crabs from June 1 to May 31.

Year	Carapace Length (mm)															
	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5+	Total
1990	0.0	3.7	7.7	7.7	15.2	19.2	38.2	179.5	271.4	462.3	450.8	569.4	363.0	191.0	64.9	26.7	2671
1991	2.6	11.6	29.7	46.4	64.5	77.3	59.3	34.8	33.5	27.1	33.5	38.7	16.8	5.1	2.6	1.3	485
1992	1.9	3.1	7.0	42.4	192.4	423.2	467.5	408.0	230.7	196.5	139.0	97.8	97.8	62.4	28.2	11.1	2409
1993	4.2	6.8	12.4	16.6	36.6	91.8	284.5	449.5	406.4	320.0	254.7	240.1	235.0	208.3	122.1	125.5	2815
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1996	0.0	0.0	0.0	0.9	6.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10
1997	0.0	0.0	0.1	0.1	0.7	2.0	2.7	3.5	5.2	10.4	12.5	10.8	8.8	8.1	4.6	5.6	75
1998	0.8	1.6	3.9	10.1	24.9	70.1	222.1	706.4	898.9	595.0	322.6	333.2	225.2	200.3	131.3	150.4	3897
1999	0.0	0.0	0.0	0.8	0.8	0.8	1.7	0.0	0.0	3.4	4.2	2.5	3.4	3.4	2.5	6.7	30
2000	0.0	5.3	31.5	67.9	63.6	40.1	23.5	9.8	6.4	9.6	13.7	15.7	7.0	4.3	1.4	4.1	304
2001	2.1	3.9	11.9	25.9	46.2	68.1	76.3	68.1	45.2	41.3	68.7	109.4	111.7	51.0	22.9	33.5	786
2002	1.2	5.7	6.9	7.4	5.5	3.1	1.2	1.1	2.6	2.0	1.7	1.2	1.5	1.7	1.5	3.2	48
2003	28.3	37.5	51.1	144.2	223.8	232.0	149.0	95.5	132.6	180.9	202.9	125.9	99.7	101.1	92.2	108.3	2005

Table 6a. Estimated annual male bycatch by length (1000 crabs) based on observer data from the trawl fisheries for Bristol Bay red king crabs from June 1 to May 31 (data in 1993 are not available).

Year	Carapace Length (mm)																			
	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5+	Total
1976	0.0	0.0	0.0	0.0	0.0	5.0	3.3	1.7	8.3	3.3	10.0	15.0	16.7	25.0	38.3	33.3	28.3	35.0	25.0	50.0	298
1977	2.8	0.7	0.7	0.7	2.0	2.8	6.2	7.6	25.0	38.2	47.2	78.5	85.4	98.5	81.9	83.3	79.1	49.9	25.7	34.7	751
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.8	1.6	9.6	17.7	33.0	56.4	80.5	74.9	51.5	63.6	43.4	121.5	556
1979	13.1	1.0	1.8	1.0	1.8	5.6	2.8	1.8	1.0	4.6	3.8	8.4	16.8	40.9	42.8	52.1	66.1	63.3	59.6	136.8	525
1980	60.6	23.6	11.0	15.4	16.2	18.6	31.3	30.0	43.4	42.8	48.2	45.0	42.0	43.0	35.7	26.4	23.6	16.2	15.0	30.2	618
1981	7.0	0.7	1.2	1.8	3.0	4.7	7.5	9.3	10.3	13.5	11.6	12.8	7.7	8.9	6.4	5.7	3.0	1.7	1.4	2.3	120
1982	55.1	21.0	19.4	25.6	28.0	34.8	32.1	31.7	31.5	37.3	33.5	37.6	31.8	25.6	17.1	12.0	6.6	4.1	3.0	7.8	496
1983	11.4	10.5	16.6	17.0	15.3	15.7	18.6	21.9	23.3	23.2	22.5	21.5	20.2	20.4	18.3	13.9	10.1	6.4	4.7	8.9	320
1984	42.8	18.2	17.2	23.2	31.5	40.0	46.6	47.5	50.3	55.6	59.7	69.6	69.4	65.8	55.3	41.5	30.8	19.9	12.7	17.1	815
1985	1.4	0.4	0.9	1.6	2.7	4.5	7.0	10.9	9.8	12.3	14.8	17.5	23.2	23.7	24.3	23.2	17.5	12.5	8.2	15.9	232
1986	2.2	0.4	1.3	1.7	2.5	3.2	3.8	4.2	3.9	5.0	6.3	8.5	11.8	12.3	12.8	11.2	9.6	6.3	5.2	6.4	119
1987	0.2	0.3	0.7	0.9	1.4	2.1	2.9	3.6	4.1	4.3	5.9	6.3	6.8	7.7	8.0	7.6	7.2	4.4	2.9	3.2	81
1988	9.8	0.4	0.6	1.0	1.9	4.1	6.7	9.2	10.8	12.0	12.5	14.3	16.8	20.3	26.0	30.0	33.0	27.3	18.5	16.9	272
1989	0.1	0.1	0.1	0.1	0.3	0.4	0.9	1.1	1.7	2.5	3.3	5.2	5.5	6.7	8.6	9.3	8.8	8.4	7.0	10.0	80
1990	4.1	1.0	1.5	0.5	1.8	1.3	5.1	2.8	5.7	6.2	4.1	5.4	5.4	7.5	11.8	12.9	13.1	11.1	5.9	11.8	119
1991	8.8	5.3	4.1	1.2	4.1	2.4	3.0	3.0	7.1	4.1	7.7	5.9	5.9	4.1	5.9	13.6	6.5	9.4	9.4	27.1	139
1992	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	3.8	4.7	5.7	11.4	10.5	11.4	10.5	7.6	6.7	1.9	8.6	85
1993																					
1994	0.3	0.3	0.3	0.4	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.7	1.0	2.1	2.0	2.6	3.8	13.9	28
1995	2.1	0.2	0.9	0.7	0.4	0.9	1.7	1.7	1.0	1.7	1.6	0.7	1.2	1.0	1.0	1.7	2.6	2.1	0.4	1.2	25
1996	0.0	0.0	0.1	0.1	0.7	1.5	2.4	3.2	3.4	3.5	3.5	3.6	3.0	4.0	2.5	3.2	2.9	3.5	3.4	10.8	55
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.9	1.6	2.2	2.4	2.5	3.1	2.8	2.5	2.7	2.2	6.6	30
1998	0.2	0.0	0.1	0.0	0.0	0.1	0.2	0.2	0.5	0.7	1.5	2.0	4.2	6.3	7.1	8.5	8.1	7.8	6.3	13.8	68
1999	0.6	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.5	0.9	1.6	4.3	7.4	9.2	12.3	12.1	10.5	7.1	5.8	11.0	84
2000	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.9	1.4	1.7	1.7	2.0	2.2	2.4	2.6	3.8	4.6	4.9	4.3	12.2	45
2001	0.0	0.0	0.1	0.0	0.2	0.6	0.6	0.8	1.4	1.7	2.1	2.1	2.4	2.9	3.6	4.0	5.4	5.2	5.7	17.9	57
2002	0.0	0.0	0.2	0.5	0.7	0.8	0.9	0.5	0.5	0.5	0.9	1.7	2.1	2.5	3.8	4.1	4.2	3.8	3.7	8.2	40

Table 6b. Estimated annual female bycatch by length (1000 crabs) based on observer data from the trawl fisheries for Bristol Bay red king crabs from June 1 to May 31 (data in 1993 are not available).

Year	Carapace Length (mm)															
	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5+	Total
1976	0.0	0.0	0.0	0.0	0.0	0.0	5.0	3.3	8.3	10.0	11.7	21.7	5.0	10.0	1.7	10.0	87
1977	0.0	0.7	0.7	0.0	0.0	0.7	2.0	4.2	5.5	6.9	4.9	4.2	3.5	2.0	0.7	0.7	37
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	3.2	4.8	16.9	20.9	39.4	90
1979	9.6	1.0	0.0	0.0	4.6	2.8	11.2	34.5	26.1	28.9	40.0	15.8	12.1	13.0	1.0	10.2	211
1980	49.4	18.3	11.0	21.6	32.1	46.7	56.7	53.9	55.8	59.9	41.3	30.2	15.3	9.2	4.5	4.6	510
1981	16.3	6.5	6.5	11.7	14.4	16.2	14.0	11.4	8.4	10.2	8.3	7.1	6.4	4.2	2.5	2.3	147
1982	49.6	18.5	18.6	22.4	29.8	32.4	26.1	19.3	14.9	13.9	12.3	11.3	8.2	6.3	2.7	3.8	290
1983	13.8	11.5	17.3	17.9	17.6	20.1	19.3	15.6	10.9	7.6	4.9	4.3	3.2	2.1	1.5	2.0	170
1984	46.7	18.2	18.1	24.6	34.8	40.2	46.6	41.9	33.5	17.6	9.9	7.0	4.9	3.6	2.2	3.4	353
1985	0.9	0.4	0.7	1.3	2.6	4.7	5.4	5.3	4.5	3.5	3.3	3.0	3.0	1.6	0.7	1.8	43
1986	2.3	0.8	1.3	2.1	3.9	4.7	6.2	5.3	4.9	3.2	2.2	1.1	0.9	0.5	0.4	0.9	41
1987	0.4	0.2	1.5	3.1	3.4	5.1	6.8	6.0	5.4	3.7	2.8	2.1	1.1	0.6	0.3	1.3	44
1988	10.3	1.5	2.6	4.8	9.4	15.8	22.4	19.2	20.0	18.7	13.6	7.7	4.9	2.7	1.1	3.4	158
1989	0.1	0.0	0.1	0.3	0.9	1.4	1.6	3.5	3.6	3.8	3.3	2.8	2.4	1.8	1.0	2.5	29
1990	0.3	0.8	1.8	1.5	1.5	1.8	4.4	4.9	8.5	6.9	6.9	5.7	3.1	1.5	0.3	2.8	53
1991	1.8	0.6	1.2	0.6	0.0	1.2	0.6	1.2	4.7	2.4	3.0	4.7	3.0	4.7	0.6	14.8	45
1992	0.0	0.0	0.0	1.0	13.3	20.0	15.2	15.2	14.3	15.2	20.0	21.9	15.2	14.3	12.4	18.1	196
1993																	
1994	1.5	0.1	0.4	1.3	1.4	1.9	1.3	2.9	1.9	0.7	0.6	0.5	0.7	0.9	0.9	3.1	20
1995	2.3	0.2	0.7	1.0	1.7	0.9	2.4	4.3	5.9	7.7	13.7	11.8	8.0	7.3	5.7	7.8	82
1996	0.0	0.0	0.1	0.3	1.0	1.8	1.9	1.8	2.2	2.2	2.0	1.7	1.6	1.3	0.8	2.7	21
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.1	1.4	2.2	1.7	1.5	2.0	1.4	1.5	5.6	19
1998	0.0	0.0	0.0	0.0	0.1	0.2	1.0	3.0	3.6	2.5	2.2	1.5	1.8	1.9	2.3	5.7	26
1999	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.2	0.8	1.6	2.3	3.0	4.5	3.5	2.3	7.3	26
2000	0.1	0.0	0.0	0.1	0.0	0.2	0.5	0.7	0.4	0.7	1.6	2.3	1.8	1.3	0.9	2.5	13
2001	0.1	0.0	0.1	0.1	0.4	0.6	1.0	1.4	1.5	1.8	3.0	5.2	4.6	3.0	2.5	7.9	33
2002	0.0	0.1	0.1	0.4	0.8	0.8	0.6	1.1	2.0	2.2	2.2	3.3	4.1	4.3	4.3	10.2	36

Table 7. Annual catch (millions of crabs) and catch per unit effort of the Bristol Bay red king crab fishery.

	Japanese Tanglenet		Russian Tanglenet		U.S. Pot/trawl		Standardized
Year	Catch	Crabs/tan	Catch	Crabs/tan	Catch	Crabs/potlift	Crabs/tan
1960	1.949	15.2	1.995	10.4	0.088		15.8
1961	3.031	11.8	3.441	8.9	0.062		12.9
1962	4.951	11.3	3.019	7.2	0.010		11.3
1963	5.476	8.5	3.019	5.6	0.101		8.6
1964	5.895	9.2	2.800	4.6	0.123		8.5
1965	4.216	9.3	2.226	3.6	0.223		7.7
1966	4.206	9.4	2.560	4.1	0.140	52	8.1
1967	3.764	8.3	1.592	2.4	0.397	37	6.3
1968	3.853	7.5	0.549	2.3	1.278	27	7.8
1969	2.073	7.2	0.369	1.5	1.749	18	5.6
1970	2.080	7.3	0.320	1.4	1.683	17	5.6
1971	0.886	6.7	0.265	1.3	2.405	20	5.8
1972	0.874	6.7			3.994	19	
1973	0.228				4.826	25	
1974	0.476				7.710	36	
1975					8.745	43	
1976					10.603	33	
1977					11.733	26	
1978					14.746	36	
1979					16.809	53	
1980					20.845	37	
1981					5.308	10	
1982					0.541	4	
1983					0.000		
1984					0.794	7	
1985					0.796	9	
1986					2.100	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.120	12	
1991					2.631	12	
1992					1.197	6	
1993					2.249	9	
1994					0.000		
1995					0.000		
1996					1.267	16	
1997					1.339	15	
1998					2.216	15	
1999					1.906	12	
2000					1.258	12	
2001					1.287	19	
2002					1.484	20	
2003					2.510	18	

Table 8a. Area-swept survey estimates of male newshell crabs (millions of crabs) by length for Bristol Bay red king crabs.

Year	Carapace Length (mm)																					
	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5+
1968	0.234	0.691	1.498	1.612	0.947	1.011	1.309	1.898	2.650	3.449	3.432	2.565	2.024	1.939	1.736	1.639	1.505	1.197	1.268	1.392	1.127	0.827	1.384
1969	0.713	0.884	1.757	2.614	2.070	1.565	2.387	3.074	4.235	4.934	6.008	4.958	4.794	4.247	2.757	2.524	2.213	1.827	1.789	1.296	0.931	0.531	0.690
1970	0.071	0.098	0.101	0.211	0.502	1.282	1.418	1.251	0.982	1.260	1.100	1.052	1.684	1.450	1.532	1.890	1.803	1.711	1.312	1.176	0.552	0.271	0.227
1972	0.000	0.000	0.028	0.140	0.498	0.873	1.950	2.293	2.932	3.158	2.401	1.882	1.631	1.860	1.311	1.689	1.591	1.396	1.392	0.540	0.873	0.230	0.484
1973	0.697	1.073	0.861	1.977	4.164	4.670	4.839	3.672	5.491	4.960	6.206	8.050	6.607	5.010	5.426	4.283	3.923	2.919	2.127	1.998	1.046	0.784	0.808
1974	1.112	3.311	4.055	3.569	4.841	7.395	7.098	6.798	5.793	4.056	5.585	4.961	6.096	5.080	6.792	6.595	6.377	5.602	4.815	3.230	1.684	2.993	0.749
1975	1.090	4.520	6.508	7.784	14.116	8.647	9.650	9.656	7.420	7.347	5.614	6.019	6.909	6.363	6.317	6.700	6.021	4.906	5.079	4.085	2.390	1.701	2.409
1976	0.000	0.021	0.282	0.760	4.080	8.908	15.613	18.620	14.306	14.928	10.810	9.218	8.711	9.022	9.701	7.768	8.024	7.205	5.096	4.591	3.196	1.980	1.967
1977	4.757	2.903	1.230	2.535	2.208	2.581	4.178	6.913	12.888	15.097	15.083	13.631	14.761	13.660	13.031	9.761	10.555	10.371	7.905	5.229	3.821	2.808	3.568
1978	2.189	1.042	0.622	1.287	3.590	4.165	6.877	4.941	4.847	4.725	7.817	7.493	8.613	9.143	8.552	9.039	10.316	10.614	9.576	9.529	6.344	5.317	4.512
1979	3.433	6.105	4.266	2.319	2.117	2.812	3.595	3.418	3.995	3.268	3.331	3.270	3.538	4.555	6.253	6.932	6.863	5.819	5.558	5.111	4.281	2.556	4.035
1980	1.715	0.647	0.228	1.372	2.713	5.689	6.266	6.585	6.700	5.622	5.689	5.063	4.267	4.855	4.189	5.993	6.044	6.575	7.520	6.167	5.469	4.348	5.554
1981	0.494	2.111	5.336	4.295	2.750	2.347	3.792	5.633	4.660	4.670	4.566	4.152	4.336	2.866	2.415	1.508	1.456	1.128	0.931	0.576	0.497	0.224	0.747
1982	0.341	2.403	9.787	18.860	19.247	16.186	6.664	5.468	7.149	8.071	6.686	4.439	3.769	4.247	3.014	2.251	1.639	1.040	0.803	0.536	0.128	0.097	0.198
1983	1.538	1.689	1.247	2.427	2.639	3.699	4.987	5.881	5.845	4.242	3.188	2.676	2.573	1.717	1.620	1.004	0.767	0.589	0.139	0.064	0.033	0.000	0.000
1984	0.017	0.057	0.489	1.844	5.165	6.775	7.359	5.085	4.438	3.742	3.943	3.380	2.972	2.300	1.736	1.095	1.169	0.646	0.580	0.241	0.135	0.003	0.036
1985	0.000	0.038	0.030	0.104	0.513	0.977	1.578	2.357	2.328	1.687	1.609	2.370	2.401	2.038	2.002	1.724	1.649	0.947	0.911	0.072	0.129	0.166	0.000
1986	0.000	0.035	0.115	0.494	0.785	1.055	0.932	1.105	0.789	1.850	1.924	2.271	1.599	1.759	1.788	1.500	1.734	1.708	1.015	0.921	0.340	0.054	0.006
1987	0.068	0.189	0.108	0.119	0.575	2.625	4.105	3.688	2.528	2.345	2.348	2.448	1.978	2.518	1.888	2.399	1.913	1.630	1.419	1.153	1.093	0.278	0.219
1988	0.000	0.000	0.000	0.054	0.045	0.280	0.456	0.501	0.897	1.806	1.798	1.532	1.595	1.180	1.316	0.764	1.325	0.989	1.483	1.054	0.697	0.431	0.343
1989	0.993	0.290	0.118	0.065	0.011	0.000	0.103	0.622	1.380	0.731	1.505	0.881	1.705	1.367	1.304	1.792	2.116	1.466	1.350	1.052	0.992	0.555	0.855
1990	0.328	0.132	0.230	0.064	0.515	0.747	1.724	1.562	0.475	0.341	0.283	0.610	1.001	0.906	0.935	0.969	1.009	0.781	1.073	0.755	0.505	0.498	0.892
1991	0.000	0.000	0.029	0.057	0.485	1.186	0.857	1.363	1.081	0.624	1.197	1.007	0.576	0.147	0.523	0.843	0.891	1.087	1.355	1.090	0.727	0.760	1.280
1992	0.056	0.056	0.028	0.029	0.000	0.057	0.328	0.758	0.991	1.511	1.465	1.012	0.994	0.833	1.072	0.700	0.436	0.339	0.484	0.389	0.430	0.357	0.880
1993	0.000	0.030	0.000	0.080	0.432	0.509	0.357	0.331	0.547	0.442	0.753	0.713	1.242	0.990	1.645	0.860	0.670	0.396	0.335	0.297	0.355	0.232	0.320
1994	1.405	1.288	0.351	0.034	0.000	0.064	0.439	0.367	0.261	0.228	0.228	0.357	0.679	0.648	0.587	0.806	1.078	0.427	0.519	0.555	0.418	0.227	0.322
1995	0.000	0.061	0.214	0.921	2.223	1.820	0.733	0.367	0.522	0.706	0.771	0.878	0.974	0.695	0.761	0.845	0.806	1.228	0.757	0.608	0.511	0.216	0.392
1996	0.210	0.574	1.661	1.330	0.621	1.375	2.503	2.873	2.801	1.282	0.937	0.525	0.702	0.639	0.492	0.428	0.152	0.290	0.342	0.318	0.448	0.530	0.606
1997	0.032	0.053	0.056	0.000	0.262	0.160	0.375	0.922	4.092	6.900	7.839	6.599	3.688	2.032	0.979	0.882	0.699	0.842	0.989	1.152	0.767	0.738	1.959
1998	0.131	0.129	0.517	1.521	1.267	0.748	0.913	0.874	0.744	0.994	1.096	1.533	3.311	3.211	2.969	2.613	1.381	0.495	0.563	0.325	0.222	0.096	0.269
1999	0.064	0.250	1.440	1.875	1.123	0.571	0.555	0.551	0.395	0.472	0.455	0.359	0.456	0.630	1.044	1.738	1.882	2.319	2.252	1.438	0.980	0.471	0.538
2000	0.035	0.000	0.113	0.096	0.358	0.909	1.910	1.732	1.245	1.313	1.030	1.363	0.745	0.645	0.978	0.593	0.961	0.594	0.860	0.643	0.404	0.167	0.437
2001	0.030	0.124	0.210	0.300	0.218	0.471	0.667	0.687	1.831	1.592	2.346	1.560	0.919	0.995	0.603	0.452	0.551	0.349	0.252	0.477	0.452	0.451	0.529
2002	0.119	0.542	1.503	3.882	4.724	3.243	1.982	0.878	0.574	0.434	0.526	1.094	1.511	1.513	1.693	0.741	0.624	0.711	0.453	0.382	0.626	0.441	0.353
2003	0.034	0.157	0.811	1.412	0.640	1.305	2.142	3.684	2.944	2.830	1.539	0.803	1.171	0.952	1.924	1.585	2.425	1.961	2.019	1.245	0.809	0.665	1.803
2004	0.584	1.547	3.045	4.385	3.428	3.199	2.319	2.230	1.908	2.766	3.900	3.495	3.416	2.574	1.947	1.204	1.210	1.233	1.764	1.514	2.056	1.146	2.459

Table 8b. Area-swept survey estimates of male oldshell crabs (millions of crabs) by length for Bristol Bay red king crabs.

Year	Carapace Length (mm)																					
	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5+
1968	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1969	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1970	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1972	0.000	0.000	0.000	0.000	0.000	0.000	0.056	0.000	0.031	0.000	0.000	0.000	0.025	0.028	0.134	0.263	0.053	0.134	0.155	0.236	0.163	0.079	0.059
1973	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.097	0.179	0.111	0.258	0.206	0.274	0.263	0.282	0.123	0.040
1974	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.046	0.036	0.011	0.114	0.145	0.161	0.183	0.233	0.446	0.505	0.218
1975	0.000	0.000	0.000	0.000	0.026	0.000	0.061	0.000	0.031	0.000	0.185	0.201	0.407	0.242	0.345	0.421	0.376	0.502	1.021	0.512	0.588	0.435	0.180
1976	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.005	0.000	0.000	0.003	0.159	0.133	0.229	0.929	0.688	1.363	1.345	0.980	1.290	1.499	0.779	0.504
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.169	0.061	0.228	0.279	0.349	0.809	0.821	0.717	0.936	1.041	0.621	1.153	0.479	0.870
1978	0.000	0.000	0.000	0.043	0.167	0.146	0.556	0.330	1.154	0.782	0.608	0.595	0.524	0.549	0.913	1.299	2.042	1.368	1.042	0.650	0.355	0.377	0.376
1979	0.071	0.163	0.269	0.031	0.186	0.123	0.139	0.139	0.234	0.066	0.128	0.141	0.219	0.303	0.510	0.475	0.893	0.971	0.962	1.196	1.029	0.484	0.983
1980	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.046	0.000	0.000	0.034	0.081	0.056	0.137	0.183	0.392	0.483	0.305	0.484	0.207	0.555
1981	0.034	0.000	0.000	0.017	0.013	0.066	0.000	0.109	0.124	0.179	0.335	0.351	0.726	0.664	0.878	1.049	1.145	0.889	0.968	0.876	1.074	0.709	1.379
1982	0.000	0.000	0.000	0.000	0.000	0.000	0.133	0.223	0.191	0.288	0.156	0.278	0.330	0.409	0.319	0.848	0.237	0.523	0.219	0.402	0.000	0.000	0.253
1983	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.109	0.030	0.251	0.347	0.355	0.461	0.663	0.682	0.411	0.206	0.219	0.124	0.123	0.091	0.000	0.000
1984	0.000	0.000	0.000	0.000	0.032	0.034	0.018	0.047	0.037	0.159	0.082	0.093	0.274	0.212	0.126	0.248	0.284	0.176	0.194	0.010	0.118	0.000	0.069
1985	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.036	0.000	0.070	0.221	0.000	0.138	0.033	0.000	0.061	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.066	0.000	0.101	0.035	0.201	0.323	0.460	0.683	0.315	0.230	0.201	0.000	0.066	0.105
1987	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.075	0.000	0.050	0.063	0.140	0.170	0.288	0.530	0.877	0.701	0.895	0.379	0.189	0.029	0.125
1988	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.088	0.000	0.000	0.000	0.000	0.000	0.065	0.116	0.202	0.307	0.354	0.646	0.513	0.290	0.020	0.044
1989	0.032	0.032	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.001	0.064	0.212	0.076	0.031	0.336	0.430	0.976	1.402	1.124	1.112	0.647	0.332
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000	0.030	0.032	0.115	0.192	0.153	0.459	0.478	0.687	0.887	0.806	0.617	0.996	0.401	0.617
1991	0.000	0.000	0.000	0.000	0.000	0.031	0.031	0.063	0.094	0.122	0.209	0.090	0.292	0.181	0.226	0.326	0.293	0.875	0.806	0.766	0.509	0.388	0.683
1992	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.064	0.123	0.116	0.129	0.186	0.096	0.097	0.345	0.397	0.365	0.216	0.301	0.497	0.150	0.628
1993	0.000	0.000	0.000	0.000	0.000	0.029	0.056	0.030	0.085	0.143	0.181	0.479	0.437	0.852	0.872	1.111	0.980	0.942	0.804	0.933	0.778	0.661	1.267
1994	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.122	0.057	0.028	0.135	0.092	0.064	0.217	0.259	0.501	0.775	0.569	0.447	0.436	0.261	0.260	0.738
1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.029	0.095	0.060	0.059	0.185	0.158	0.338	0.562	0.460	0.712	0.488	0.302	0.152	0.488
1996	0.000	0.000	0.030	0.030	0.030	0.030	0.000	0.129	0.030	0.031	0.130	0.033	0.155	0.033	0.222	0.229	0.467	0.736	0.442	0.591	0.375	0.344	0.600
1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.057	0.060	0.154	0.185	0.206	0.281	0.216	0.246	0.560	0.478	0.545	0.987
1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.161	0.190	0.221	0.443	0.983	0.768	0.796	0.891	0.586	1.136	0.789	0.505	1.571
1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.064	0.105	0.050	0.162	0.186	0.106	0.385	0.584	0.541	0.406	0.489	0.420	0.506	0.741
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.079	0.065	0.161	0.514	1.007	1.537	1.450	1.157	1.143	0.731	0.257	0.795
2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.066	0.032	0.033	0.000	0.163	0.164	0.190	0.371	0.251	0.258	0.508	0.421	0.415	0.924
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.085	0.117	0.246	0.567	0.653	1.006	0.648	0.727	1.206	0.514	0.966	1.053	0.975	1.305	1.892
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000	0.033	0.066	0.033	0.160	0.132	0.132	0.297	0.301	0.525	0.755	0.610	0.625	0.551	0.496	1.215
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.047	0.013	0.033	0.032	0.000	0.033	0.007	0.040	0.361	0.362	0.373	0.485	0.358	0.981

Table 8c. Area-swept survey estimates of female crabs (millions of crabs) by length for Bristol Bay red king crabs.

Year	Carapace Length (mm)																	
	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5+
1968	0.332	1.339	0.975	0.979	2.030	1.789	1.413	2.447	4.373	4.156	4.094	3.806	3.500	2.983	3.293	2.682	2.469	1.149	3.094
1969	1.062	0.961	1.693	3.028	1.516	1.169	1.634	2.952	4.530	4.362	2.911	2.184	2.219	1.965	2.206	1.653	1.344	0.965	1.927
1970	0.085	0.101	0.035	0.204	0.355	1.288	1.391	1.412	2.071	1.980	2.411	1.366	0.868	0.989	0.739	0.758	0.499	0.469	0.774
1972	0.000	0.000	0.000	0.087	0.415	1.451	2.241	3.484	3.404	3.624	2.318	1.622	0.894	0.737	0.322	0.264	0.206	0.081	0.227
1973	0.993	0.486	1.698	1.842	2.622	3.002	4.532	5.945	10.067	12.519	14.971	10.565	7.761	5.601	5.294	3.379	2.350	1.871	1.791
1974	1.064	3.276	3.627	2.986	6.102	6.674	5.884	7.750	11.208	13.628	14.619	9.089	8.656	4.103	4.702	2.291	1.734	1.275	0.738
1975	1.772	4.556	4.634	10.954	13.018	12.940	12.134	14.583	10.803	9.832	10.093	7.956	7.016	3.944	3.726	2.805	1.133	0.749	0.733
1976	0.000	0.345	0.058	0.993	2.915	9.612	17.071	20.650	17.358	13.589	8.493	5.971	6.804	5.062	4.118	2.068	1.320	0.369	0.970
1977	6.879	3.605	3.259	2.888	4.208	3.355	7.756	12.866	25.368	29.362	26.334	16.724	16.264	15.849	13.273	6.424	4.114	1.513	1.772
1978	2.454	0.944	0.832	1.876	3.488	5.805	6.154	7.017	12.818	26.631	34.097	22.320	12.175	7.038	5.631	3.483	2.328	0.625	1.333
1979	5.775	11.350	6.124	2.903	2.171	2.477	4.122	5.506	6.422	10.610	16.293	20.373	19.788	10.863	5.964	4.529	2.013	0.918	1.047
1980	1.217	0.610	0.142	0.897	4.527	6.887	5.725	13.114	18.207	9.992	10.844	10.558	8.186	5.984	2.599	1.925	1.099	0.657	0.399
1981	0.569	1.510	5.072	5.664	3.358	2.831	3.747	5.769	6.607	6.423	6.667	7.737	9.324	9.293	5.640	2.803	1.732	0.466	0.352
1982	0.345	1.891	5.993	12.756	22.657	14.326	8.976	10.020	11.399	9.432	5.533	4.543	6.136	6.688	4.818	2.763	1.484	0.571	0.203
1983	2.023	1.773	1.713	1.291	2.841	3.527	4.699	4.817	2.955	2.522	1.135	0.796	0.316	0.665	0.427	0.463	0.153	0.101	0.000
1984	0.000	0.069	0.550	2.298	5.426	7.565	6.500	4.665	4.083	3.377	1.941	0.672	0.445	0.088	0.139	0.022	0.049	0.029	0.000
1985	0.000	0.000	0.034	0.034	0.621	1.514	2.087	2.575	2.215	2.049	1.556	0.639	0.270	0.000	0.000	0.058	0.000	0.000	0.000
1986	0.000	0.033	0.117	0.546	0.983	1.544	1.172	1.186	1.455	1.569	1.649	1.164	0.488	0.333	0.035	0.017	0.000	0.033	0.000
1987	0.016	0.060	0.097	0.102	0.947	4.050	7.038	5.955	3.689	3.525	4.538	3.239	2.312	1.426	0.620	0.137	0.032	0.000	0.000
1988	0.000	0.000	0.000	0.026	0.325	0.270	0.236	0.652	2.968	3.990	4.191	2.969	2.445	1.708	0.761	0.230	0.316	0.000	0.000
1989	0.702	0.256	0.096	0.064	0.000	0.075	0.325	1.227	3.027	2.712	2.877	2.340	1.605	1.319	0.784	0.239	0.202	0.000	0.001
1990	0.331	0.331	0.294	0.196	0.262	1.175	2.579	2.644	0.356	1.296	2.885	3.578	3.375	2.950	1.895	0.955	0.270	0.176	0.173
1991	0.029	0.064	0.030	0.229	0.628	1.060	1.738	1.173	1.925	1.934	1.736	2.051	1.827	1.567	2.447	1.301	0.617	0.377	0.161
1992	0.000	0.028	0.056	0.000	0.158	0.217	0.589	1.094	1.224	1.889	1.355	1.050	0.951	1.328	1.194	0.786	0.619	0.479	0.351
1993	0.079	0.142	0.062	0.257	0.316	0.694	0.302	0.520	0.990	1.683	2.466	2.290	0.971	1.043	1.022	0.931	1.514	0.583	0.748
1994	1.823	0.429	0.214	0.000	0.034	0.092	0.061	0.352	0.194	0.259	0.447	0.907	0.867	0.759	0.588	0.829	0.983	0.616	0.673
1995	0.000	0.000	0.241	0.956	1.571	1.026	0.487	0.459	0.612	0.537	0.840	0.774	1.104	0.900	0.764	0.792	0.486	0.673	0.505
1996	0.030	0.453	1.449	1.270	1.053	2.044	3.779	3.767	2.112	1.091	1.056	1.195	0.961	0.771	1.367	1.160	0.747	0.415	1.130
1997	0.027	0.053	0.083	0.030	0.268	0.117	0.145	1.061	5.752	7.033	4.486	1.560	1.009	0.694	1.062	1.068	0.786	0.624	1.496
1998	0.033	0.129	0.544	1.062	1.437	0.729	0.634	0.813	0.843	2.222	7.741	8.543	4.360	2.280	1.913	1.709	1.756	1.741	2.498
1999	0.032	0.030	0.352	1.197	0.826	0.622	0.568	0.218	0.271	0.469	0.819	2.561	4.025	2.911	1.714	1.680	0.941	0.593	1.259
2000	0.000	0.000	0.065	0.097	0.375	1.207	1.949	1.854	1.532	1.361	1.198	1.981	2.920	3.776	3.366	2.319	1.160	0.968	2.378
2001	0.032	0.000	0.245	0.246	0.738	0.854	0.597	1.138	2.656	3.503	2.594	1.769	1.807	1.308	3.119	2.558	1.193	0.470	0.938
2002	0.183	0.566	1.601	3.717	5.733	3.617	1.816	1.639	1.295	1.657	3.864	2.963	2.186	1.195	1.523	1.506	1.631	0.515	0.997
2003	0.000	0.156	0.566	1.563	0.542	1.304	2.934	3.937	4.380	2.272	2.716	3.298	4.992	4.906	3.357	2.041	2.460	2.001	3.315
2004	0.404	1.482	3.615	3.298	3.864	2.318	1.425	2.184	3.119	4.741	4.974	3.358	2.473	2.432	2.779	2.209	1.977	1.538	2.786

Table 9. Average weight and assumed maximum number of female mates for male red king crabs in Bristol Bay by length-class.

Male Carapace Length (mm)	Average Male Weight (kg)	Number of Female Mates
0-119		0.0
120-124	1.43	1.0
125-129	1.63	1.2
130-134	1.84	1.4
135-139	2.06	1.6
140-144	2.31	1.8
145-149	2.58	2.1
150-154	2.86	2.4
155-159	3.17	2.7
160+	3.50	3.0

Table 10. Summary of parameter estimates for a length-based population model of male red king crabs in Bristol Bay with four model scenarios. The abundance in 1972, N_{72}, recruits, R_t, and mature males are in millions of crabs.

	Scenario			
Parameter	A1-1	A1-2	A1-3	A1-4
N_{72}	37.430	35.760	40.358	37.345
$ß$	0.653	0.651	0.787	0.660
$ß_r$	1.252	1.172	1.120	1.255
α_1	345288.69	376486.69	332286.34	356668.22
α_2	35281.22	38864.70	12632.92	34667.24
α_3	353885.31	363124.81	309133.34	327676.17
$ß_1$	0.082	0.083	0.082	0.082
$ß_2$	0.081	0.081	0.073	0.081
$ß_3$	0.090	0.090	0.089	0.090
M_1	0.225	0.192	0.273	0.224
M_2	1.050	1.061	NA	1.049
M_3	0.122	NA	NA	0.116
R_{73}	31.186	27.566	36.914	31.053
R_{74}	23.006	21.118	24.693	22.932
R_{75}	33.469	30.589	36.790	33.331
R_{76}	45.692	41.184	50.734	45.565
R_{77}	57.617	51.887	46.921	57.378
R_{78}	25.185	23.679	11.056	25.108
R_{79}	13.885	13.658	4.623	13.862
R_{80}	25.140	25.463	4.756	25.095
R_{81}	17.928	18.367	4.071	17.899
R_{82}	22.069	22.481	4.936	22.072
R_{83}	12.180	12.364	4.347	12.202
R_{84}	18.272	18.142	7.489	18.414
R_{85}	9.730	8.406	9.757	9.780
R_{86}	7.096	6.366	8.635	7.076
R_{87}	6.800	6.078	8.064	6.760
R_{88}	7.072	6.322	8.952	7.019
R_{89}	5.787	5.233	7.595	5.708
R_{90}	1.620	1.563	1.708	1.608
R_{91}	4.359	4.310	5.748	4.300
R_{92}	5.993	6.351	9.720	5.918
R_{93}	2.572	2.847	3.625	2.542
R_{94}	1.187	1.322	1.502	1.175
R_{95}	2.929	3.483	4.729	2.883
R_{96}	3.191	3.600	4.549	3.152
R_{97}	13.326	14.360	21.136	13.171
R_{98}	3.283	3.157	3.633	3.272
R_{99}	1.459	1.451	1.551	1.455
R_{00}	3.767	3.872	4.459	3.753
R_{01}	8.017	9.125	11.095	8.170
R_{02}	2.368	2.498	2.512	2.515
R_{03}	5.817	6.052	6.272	6.048
R_{04}	15.132	15.174	15.200	14.975
RSS	145.037	147.480	264.610	141.145
df	853	854	855	853
Mature males	15.967	14.348	12.172	16.533

Table 11. Summary of parameter estimates for a length-based population model of female red king crabs in Bristol Bay with four model scenarios. The abundance in 1972, N_{72}, recruits, R_t, and mature females are in millions of crabs.

Parameter	Scenario A1-1	A1-2	A1-3	A1-4
N_{72}	59.465	40.054	58.027	59.434
$ß$	1.018	1.108	1.183	0.890
$ß_r$	0.456	0.465	0.618	0.464
M_1	0.496	0.318	0.510	0.498
M_2	1.765	1.934	NA	1.768
M_3	0.361	NA	NA	0.364
M_4	0.064	NA	NA	0.059
R_{73}	35.233	18.274	31.297	35.220
R_{74}	28.883	17.636	24.232	28.826
R_{75}	22.344	15.740	17.719	22.346
R_{76}	34.160	24.456	28.138	34.155
R_{77}	74.977	49.893	37.978	74.829
R_{78}	49.568	38.722	1.000	49.524
R_{79}	21.499	19.347	21.482	21.558
R_{80}	36.208	32.597	1.000	36.253
R_{81}	14.205	14.377	1.000	14.241
R_{82}	18.166	20.719	1.000	18.211
R_{83}	4.566	4.873	2.474	4.562
R_{84}	7.928	8.314	3.707	7.910
R_{85}	5.615	5.302	4.061	5.614
R_{86}	4.038	3.717	4.661	4.042
R_{87}	10.317	9.503	19.535	10.345
R_{88}	6.279	6.349	11.895	6.288
R_{89}	5.945	6.218	12.116	5.970
R_{90}	0.938	0.964	1.131	0.944
R_{91}	3.853	4.515	6.998	3.856
R_{92}	3.356	4.870	9.416	3.335
R_{93}	2.229	3.084	4.504	2.225
R_{94}	0.404	0.469	0.512	0.404
R_{95}	1.592	2.128	2.384	1.587
R_{96}	4.375	5.807	6.034	4.347
R_{97}	16.284	25.184	53.803	16.244
R_{98}	1.774	1.769	2.074	1.794
R_{99}	0.654	0.645	0.687	0.663
R_{00}	4.719	4.975	5.345	4.694
R_{01}	7.658	11.361	15.986	7.894
R_{02}	2.632	3.101	3.701	2.713
R_{03}	7.473	8.559	9.901	7.694
R_{04}	9.052	9.691	10.679	8.959
RSS	43.900	69.082	261.005	43.687
df	314	316	317	314
Mature females	35.345	27.276	23.793	36.030

Table 12. Annual abundance estimates (millions of crabs), effective spawning biomass (ESB, millions of pounds), and 95% confidence intervals for 2004 for red king crabs in Bristol Bay estimated by length-based analysis from 1972-2004 for the base scenario (A1-1). Size measurements are mm CL.

	Males					Females		
Year	Recruits	Small	Prerec.	Mature	Legal	Recruits	Mature	ESB
mm→	(to model)	(95-109)	(110-134)	(>119)	(>134)	(to model)	(>89)	(M lbs)
1972	NA	13.120	14.608	17.962	9.706	NA	59.465	53.833
1973	31.186	21.480	25.116	22.155	10.489	35.233	71.189	61.959
1974	23.006	16.309	33.797	33.826	14.968	28.883	71.981	93.023
1975	33.469	23.099	34.851	40.407	20.849	22.344	65.969	116.699
1976	45.692	31.582	44.437	48.454	25.234	34.160	74.172	128.012
1977	57.617	39.925	59.079	61.709	30.446	74.977	119.899	165.008
1978	25.185	18.526	59.814	76.460	40.132	49.568	122.040	203.999
1979	13.885	10.047	37.336	74.481	48.631	21.499	95.459	170.907
1980	25.140	17.257	25.851	59.805	44.502	36.208	94.185	167.942
1981	17.928	12.868	16.814	18.066	9.423	14.205	71.300	58.815
1982	22.069	15.427	15.017	9.691	2.911	18.166	30.342	22.963
1983	12.180	8.924	12.255	8.423	2.429	4.566	9.723	16.363
1984	18.272	12.687	11.573	7.363	2.271	7.928	9.583	14.387
1985	9.730	7.147	9.809	6.439	1.688	5.615	7.239	10.773
1986	7.096	5.134	11.887	11.216	4.290	4.038	9.036	14.338
1987	6.800	4.828	10.619	13.164	6.595	10.317	16.581	26.006
1988	7.072	4.995	9.855	13.933	8.029	6.279	17.749	29.561
1989	5.787	4.143	9.374	15.167	9.496	5.945	18.262	31.756
1990	1.620	1.304	7.145	14.960	10.123	0.938	13.616	26.238
1991	4.359	2.988	4.843	11.785	8.661	3.853	13.334	25.775
1992	5.993	4.176	5.955	9.906	6.761	3.356	12.616	24.651
1993	2.572	2.194	6.836	10.077	5.998	2.229	10.994	22.146
1994	1.187	1.042	5.311	8.586	4.893	0.404	8.047	17.552
1995	2.929	2.093	4.566	9.314	6.228	1.592	9.138	20.178
1996	3.191	2.400	5.113	10.222	7.088	4.375	12.931	26.710
1997	13.326	9.073	8.496	11.533	7.517	16.284	28.369	39.183
1998	3.283	3.332	13.109	15.306	7.817	1.774	28.210	51.427
1999	1.459	1.145	8.033	15.806	9.742	0.654	20.299	43.336
2000	3.767	2.654	5.733	12.872	8.859	4.719	18.860	39.589
2001	8.017	5.672	7.228	11.732	7.813	7.658	20.762	40.912
2002	2.368	2.294	9.289	13.552	7.943	2.632	22.027	45.900
2003	5.817	4.027	7.661	15.064	10.054	7.473	28.111	57.625
2004	15.132	10.381	11.339	15.967	10.358	9.052	35.345	61.868
95% Confidence Limits in 2004								
Lower	10.842	NA	9.035	12.332	7.630	7.176	29.276	NA
Upper	24.103	NA	14.000	18.943	12.814	14.930	45.044	NA

Table 13. Summary of 1994-2004 effective spawning biomass and mature male abundance estimates made in the terminal years and 2004, GHLs estimated from abundance assessments in the terminal years and 2004, actual GHLs set, and mature

male harvest rates based on the actual GHLs and targeted mature male harvest rates based on the abundance assessments made in 2004 under the base scenario.

	Effe. Spa. Biomass (millions of pounds)		Mature Males (millions of crabs)		GHL (millions of pounds)			Mature Male Harvest Rate	
Year	2004	Terminal	2004	Terminal	2004	Terminal	Actual	Actual	Target[1]
1994	17.553	18.064	8.586	9.124	0.00	0.00	0.00	0.00	0.00
1995	20.177	18.119	9.314	8.484	10.93	0.00	0.00	0.00	0.20
1996	26.711	20.263	10.222	7.795	6.50	4.96	5.00	0.08	0.10
1997	39.183	31.414	11.533	10.495	7.57	6.88	7.00	0.09	0.10
1998	51.427	56.323	15.306	17.314	9.64	16.36	16.40	0.17	0.10
1999	43.336	47.074	15.806	18.063	9.33	10.66	10.66	0.11	0.10
2000	39.588	39.936	12.872	13.663	7.86	8.35	8.35	0.10	0.10
2001	40.911	40.594	11.732	10.998	7.63	7.15	7.15	0.09	0.10
2002	45.900	37.706	13.552	14.262	8.81	9.27	9.27	0.11	0.10
2003	57.624	60.698	15.064	16.368	14.46	15.71	15.71	0.16	0.15
2004	61.868	61.868	15.967	15.967	15.42	15.42	15.42	0.15	0.15
Total	406.55	395.87	139.95	142.53	98.15	94.76	94.96		

[1]Target harvest rate was fixed at 0.2 before 1996, and from 1996 to 2004, target harvest rates were determined from Figure 1.

Figure Captions

Figure 11a. Comparison of area-swept and model estimated length frequencies of Bristol Bay newshell male red king crabs by year for two scenarios of instantaneous natural mortality (solid lines for A1-1 (3 *M*) and dotted lines for A1-3 (1 *M*)).

Figure 11b. Comparison of area-swept and model estimated length frequencies of Bristol Bay oldshell male red king crabs by year for two scenarios of instantaneous natural mortality (solid lines for A1-1 (3 *M*) and dotted lines for A1-3 (1 *M*)).

Figure 11c. Comparison of area-swept and model estimated length frequencies of Bristol Bay female red king crabs by year for two scenarios of instantaneous natural mortality (solid lines for A1-1 (4 *M*) and dotted lines for A1-3 (1 *M*)).

Figure 12. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for the other periods were estimated under the base scenario.

Figure 13. Retained catch, mature male crab harvest rate, and legal male crab harvest rate of red king crabs in Bristol Bay from 1972 to 2004 under the base scenario. The harvest rates in 2004 were obtained from the current harvest strategy.

Figure 14. Comparison of mature (top) and legal (bottom) male abundance estimates of Bristol Bay RKC from 1972 to 2004 made by LBA assessments with terminal years 1994-2004 under the base scenario and by area-swept methods. Legend shows the year in which the assessment was conducted. For each assessment year, abundances were estimated from 1972 to the terminal year.

Figure 15. Comparison of mature female abundance estimates (top) and effective spawning biomass estimates (bottom) of Bristol Bay RKC from 1972 to 2004 made by LBA assessments with terminal years 1994-2004 under the base scenario and by area-swept methods. Legend shows the year in which the assessment was conducted. For each assessment year, abundances were estimated from 1972 to the terminal year.

Figure 16. Estimates of natural mortalities of male (top) and female (bottom) Bristol Bay RKC from 1972 to 2004 made by LBA assessments with terminal years 1994-

2004 under the base scenario. Legend shows the year in which the assessment was conducted.

Figure 17. Relationships between effective spawning biomass and total recruits at age 7 (i.e., 8-year time lag) for Bristol Bay red king crabs under the base scenario. Numerical labels are brood year (year of mating), the solid line is a general Ricker curve, the dotted line is an autocorrelated Ricker curve without υ_t values (equation 9), and the dashed line is a Ricker curve fit to recruitment data after 1974 brood year. The vertical dotted line is the targeted rebuilding level of 55 million lbs of effective spawning biomass.

Figure 18. Average clutch fullness and proportions of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2004 from survey data. Oldshell females were excluded.

Figure 19. Recruits of Bristol Bay red king crabs and anomalies of the Aleutian Low index. A 7-year lag from hatching to recruitment was used.

Figure 20. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 1999-2004. For purposes of these graphs, abundance estimates are based on area-swept methods.

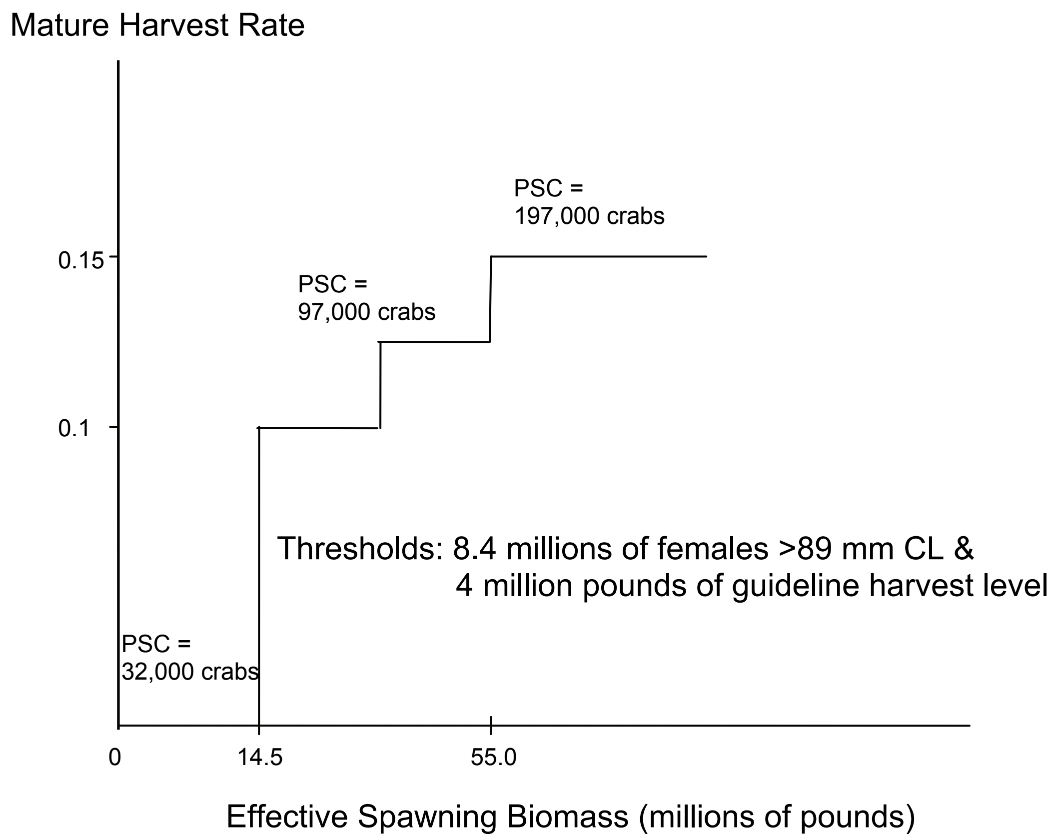


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay RKC in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of effective spawning biomass (ESB), whereas PSC limits apply to previous-year ESB.

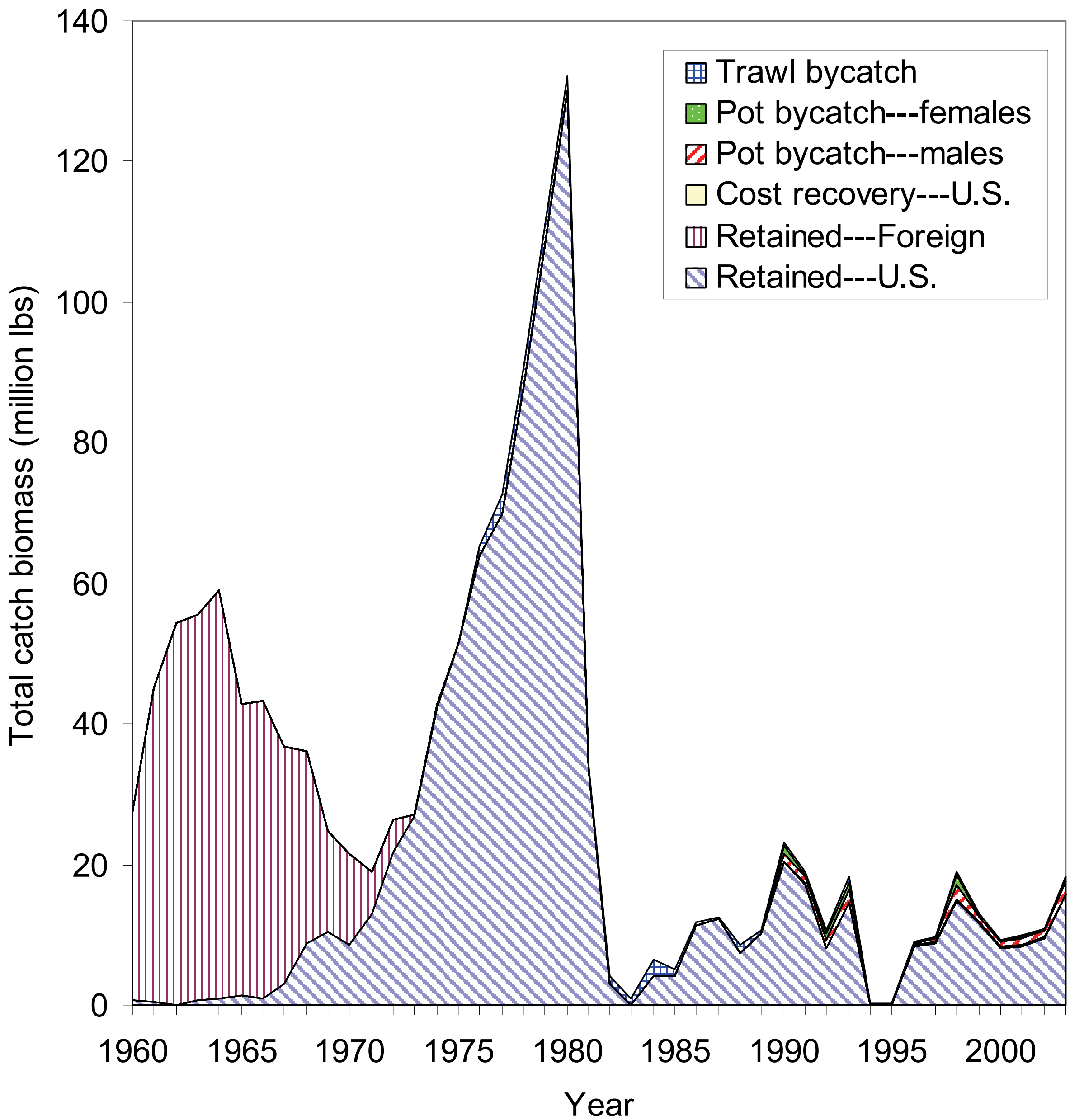


Figure 2. Retained catch biomass and bycatch mortality biomass (million lbs) for Bristol Bay red king crabs from 1960 to 2003. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

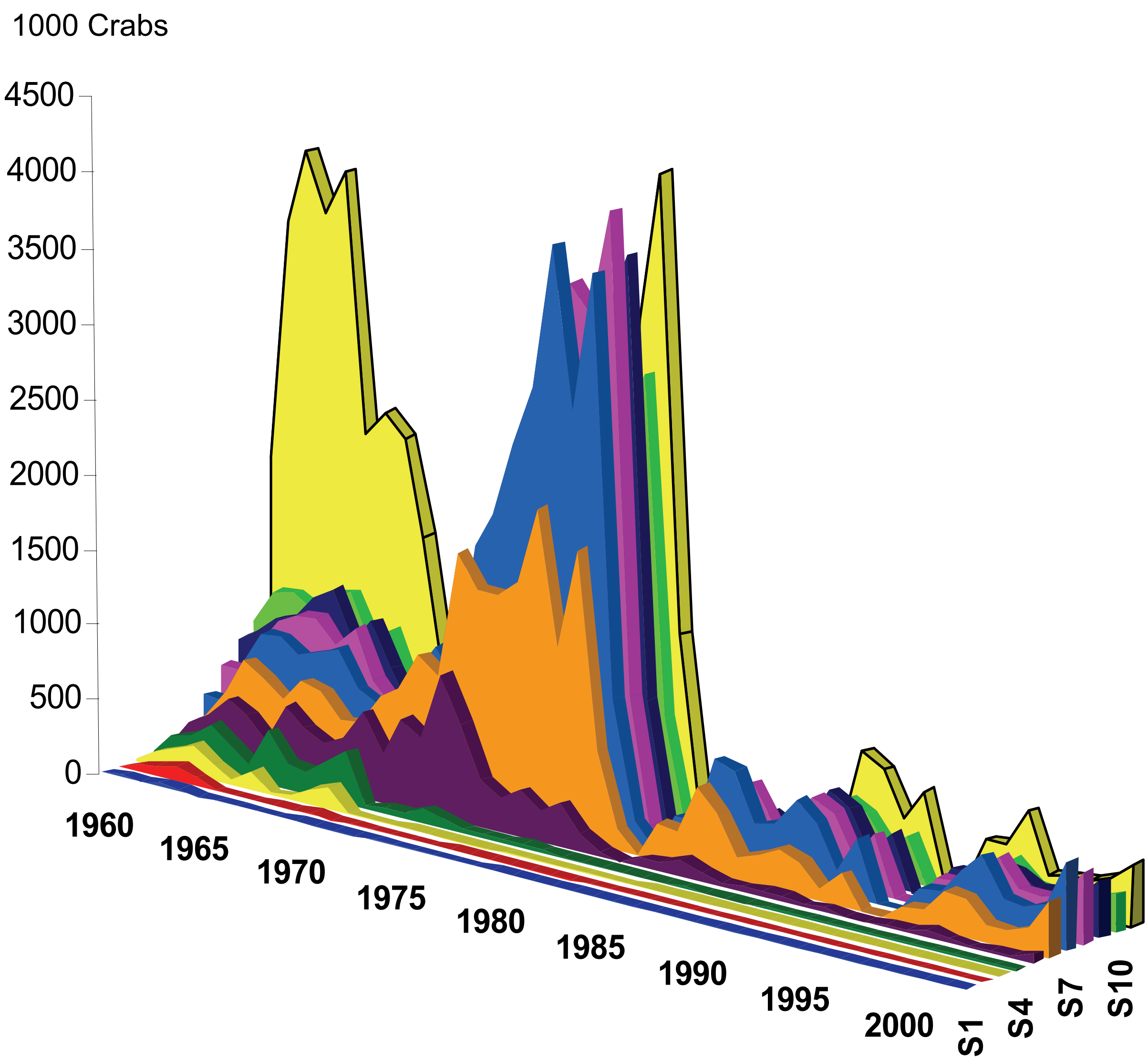


Figure 3. Retained catches by length for Bristol Bay red king crabs from 1960 to 2003. "S1"…"S11" represent size groups 112.5 mm to 162.5+ mm CL.

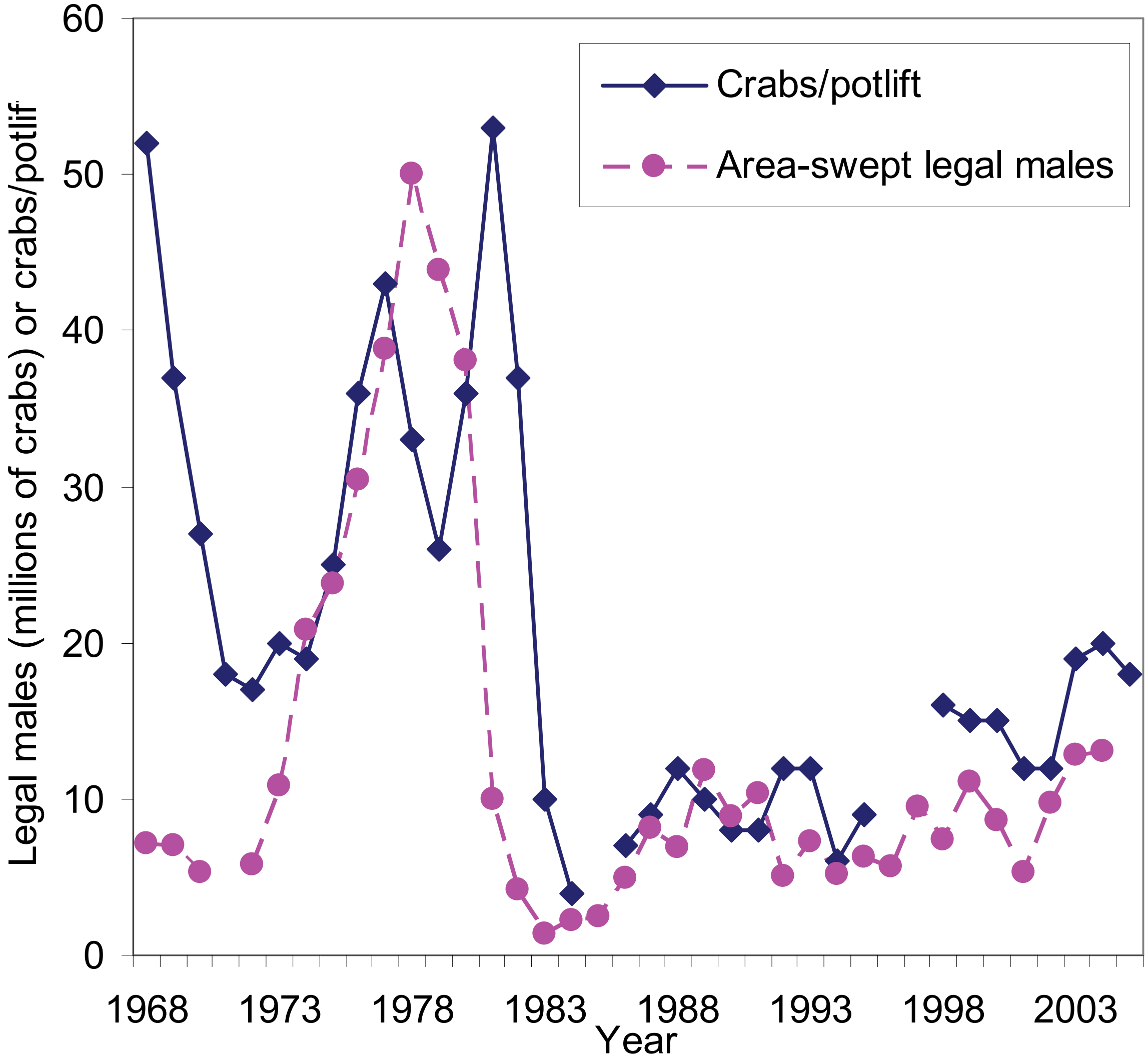


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crabs from 1968 to 2003.

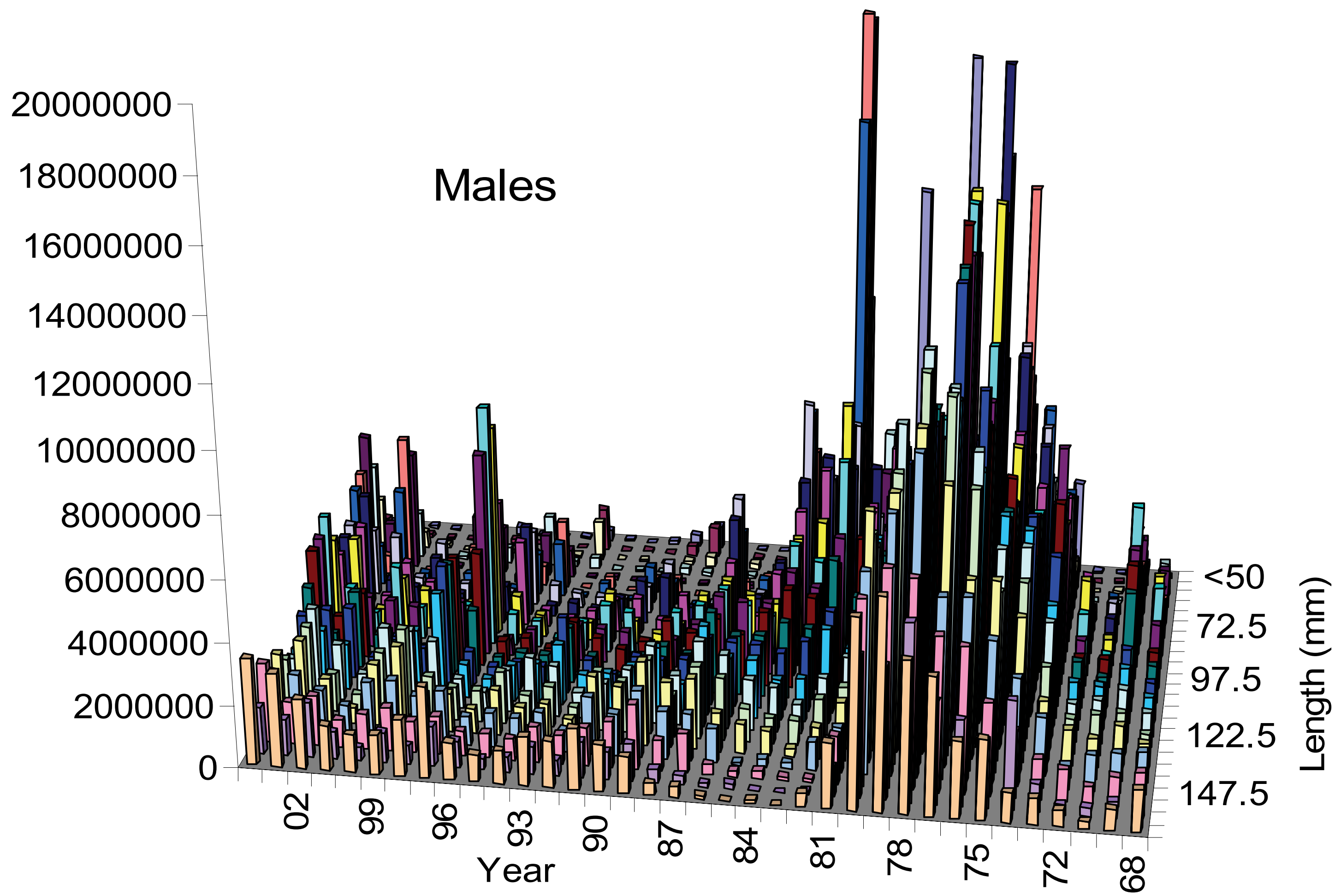


Figure 5a. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2004.

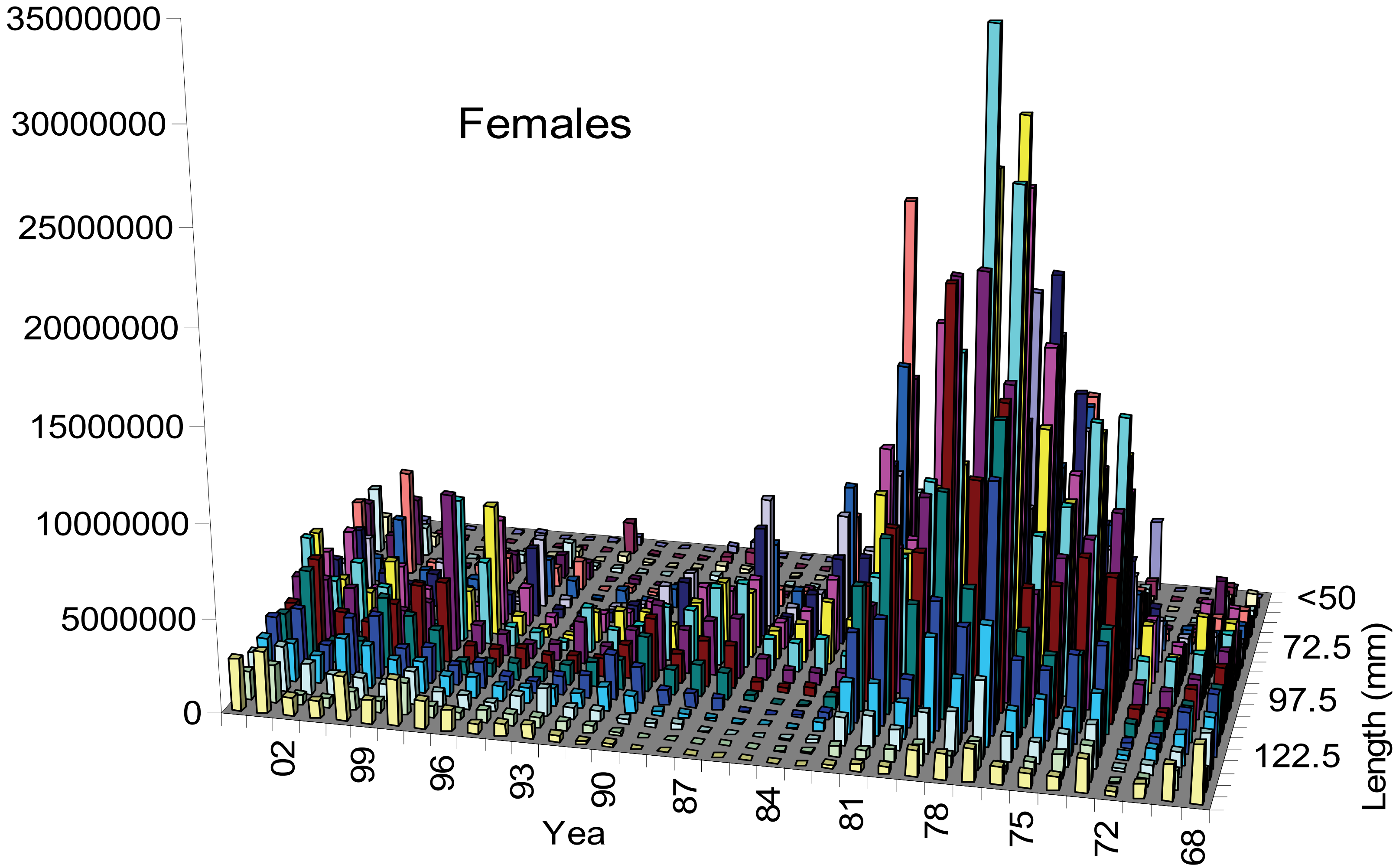


Figure 5b. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2004.

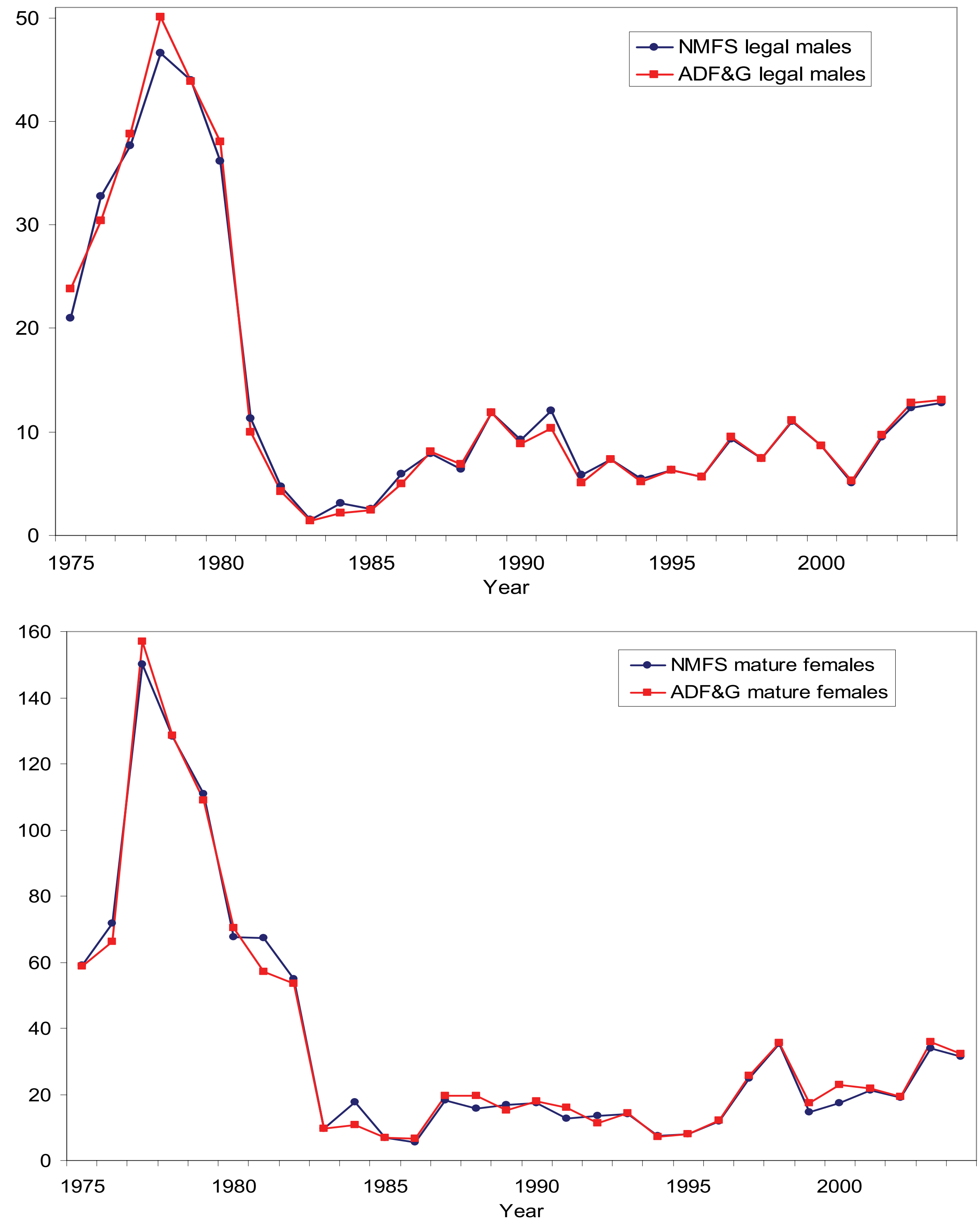


Figure 6. Comparison of survey abundance estimates (millions of crabs) by NMFS and ADF&G for Bristol Bay red king crabs from 1975 to 2004.

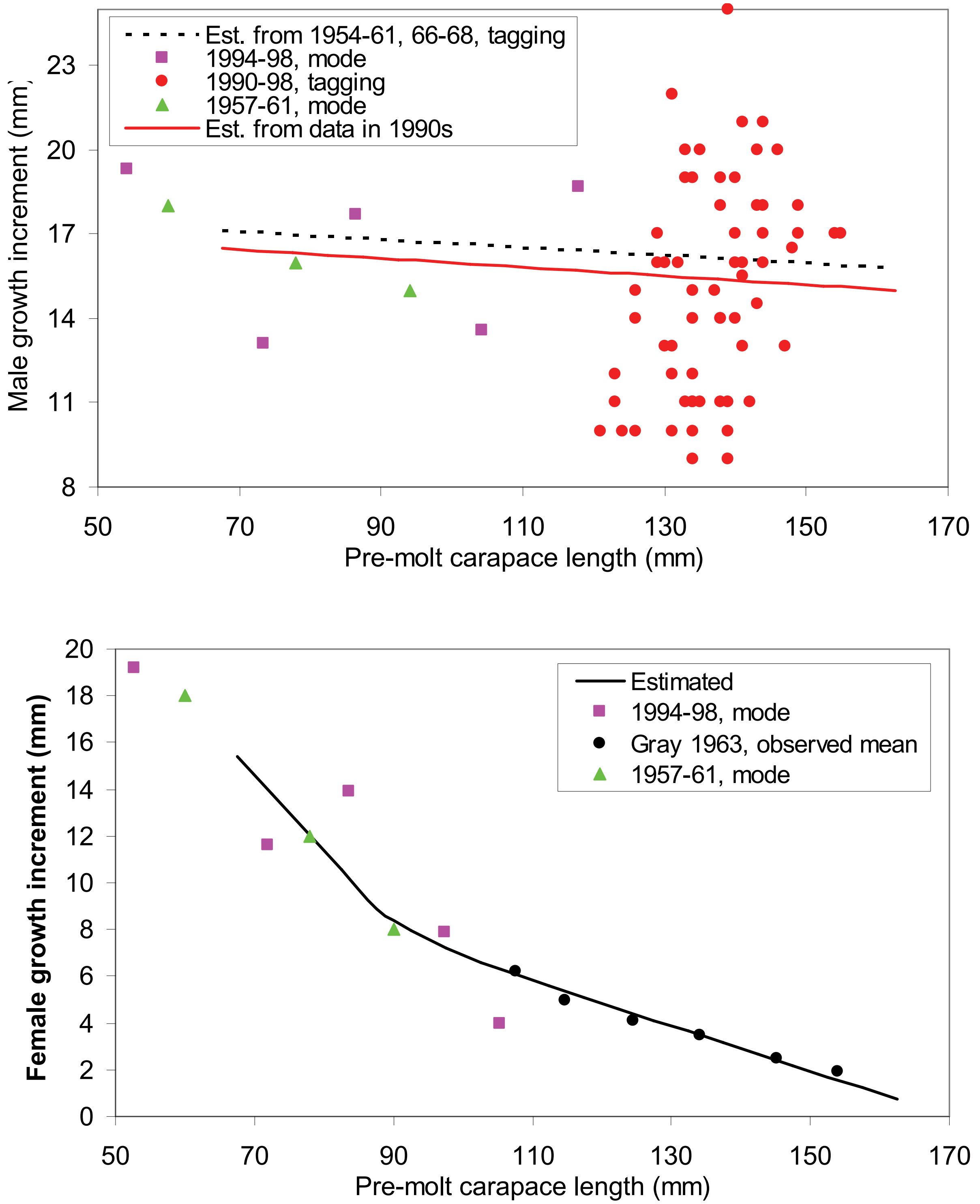


Figure 7. Mean growth increments per molt for Bristol Bay red king crabs. Note: "tagging"---based on tagging data; "mode"---based on modal analysis.

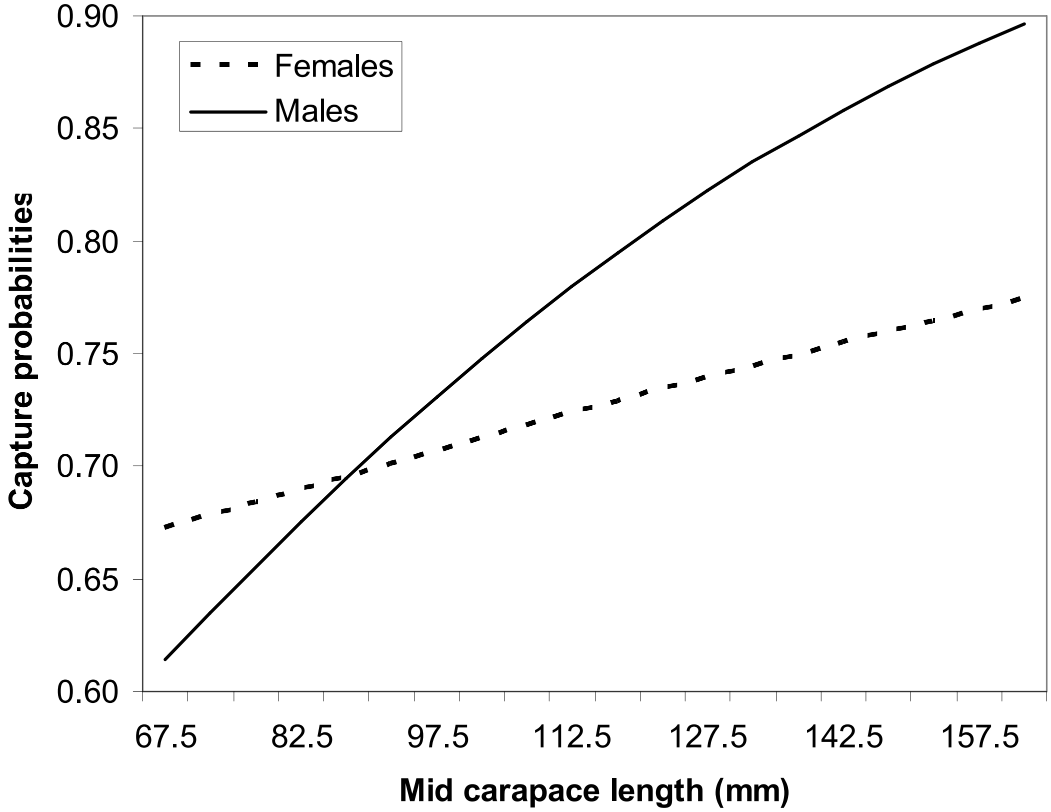


Figure 8. Estimated capture probabilities for Bristol Bay red king crab trawl survey by Weinberg et al. (2004).

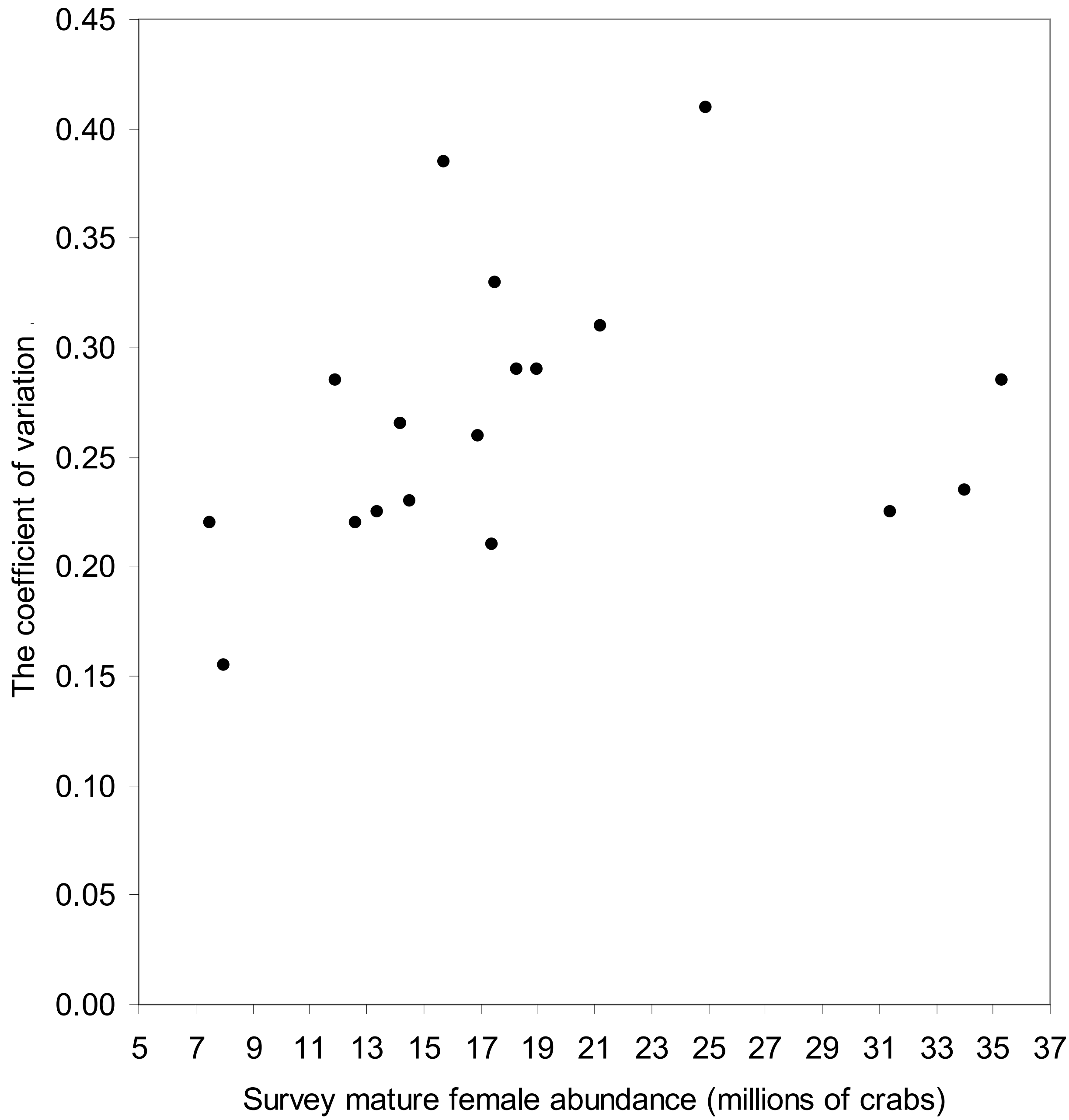


Figure 9. The relationship between estimated survey mature female abundance and the coefficient of variation estimated by NMFS from 1987 to 2004 for Bristol Bay red king crabs.

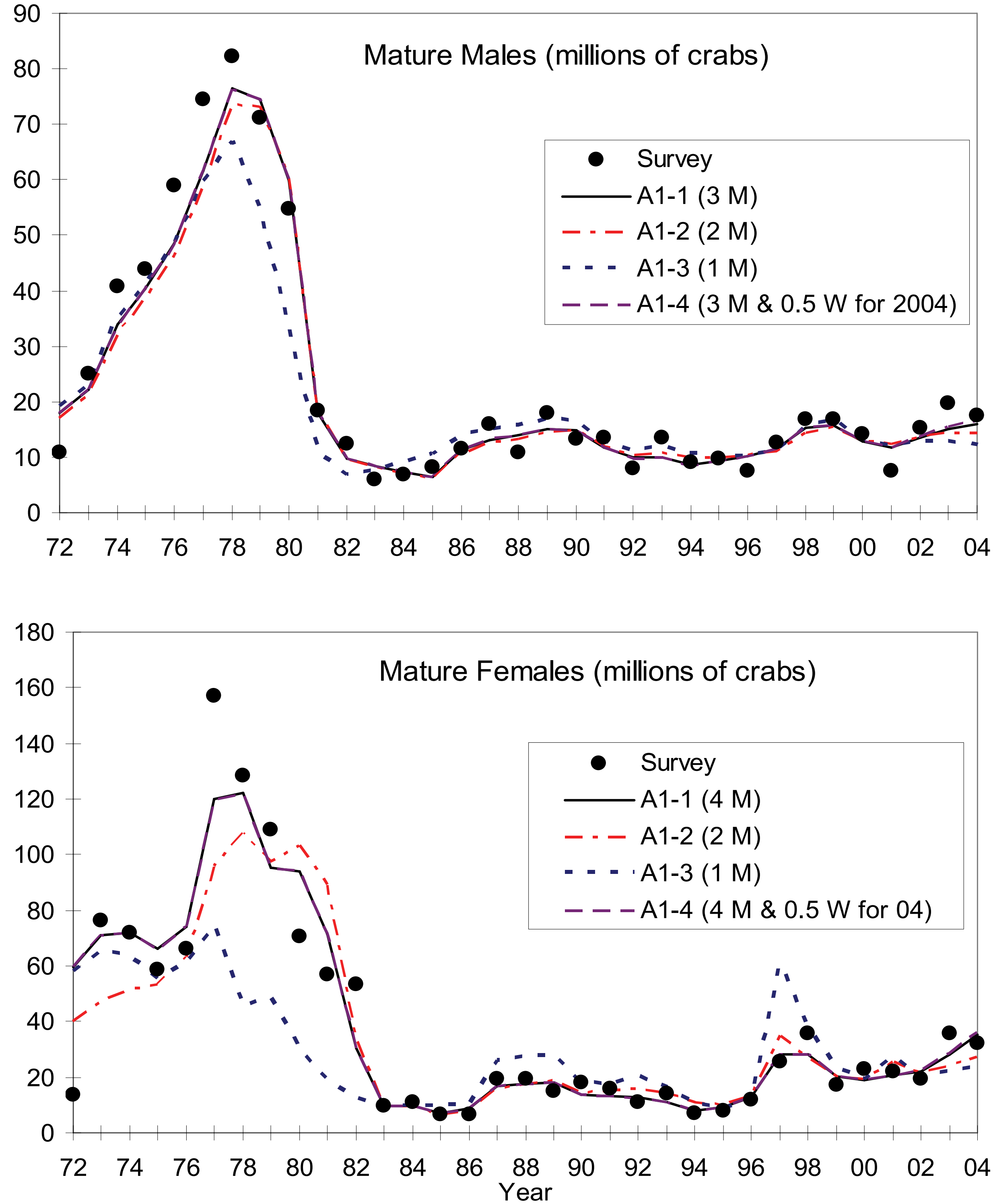
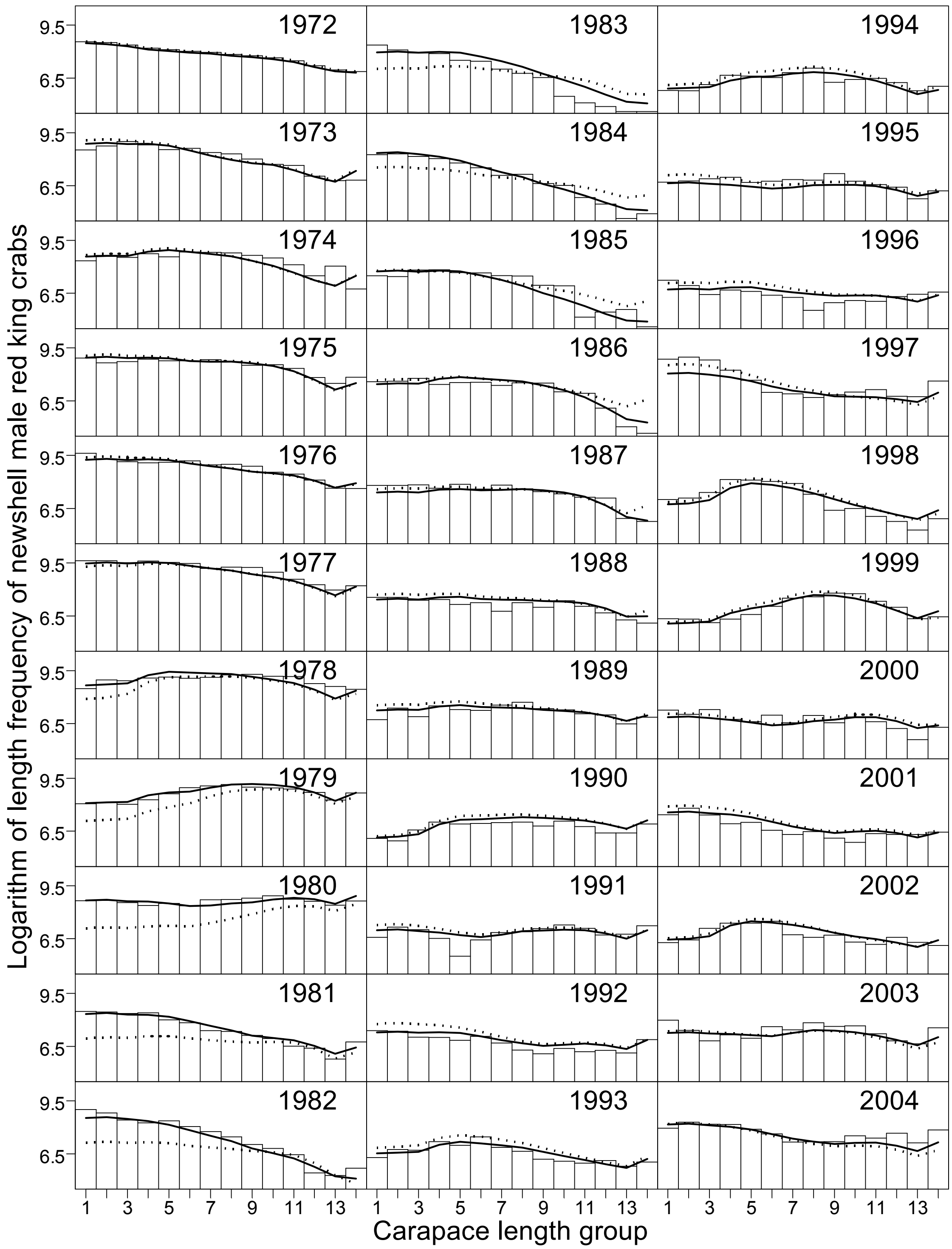


Figure 10. The length-based analysis fit (lines) to area-swept estimates (dots) of mature male (top panel) and mature female (bottom panel) Bristol Bay red king crab abundance (millions of crabs) for four model scenarios A1-1 – A1-4 with different levels of natural mortality.



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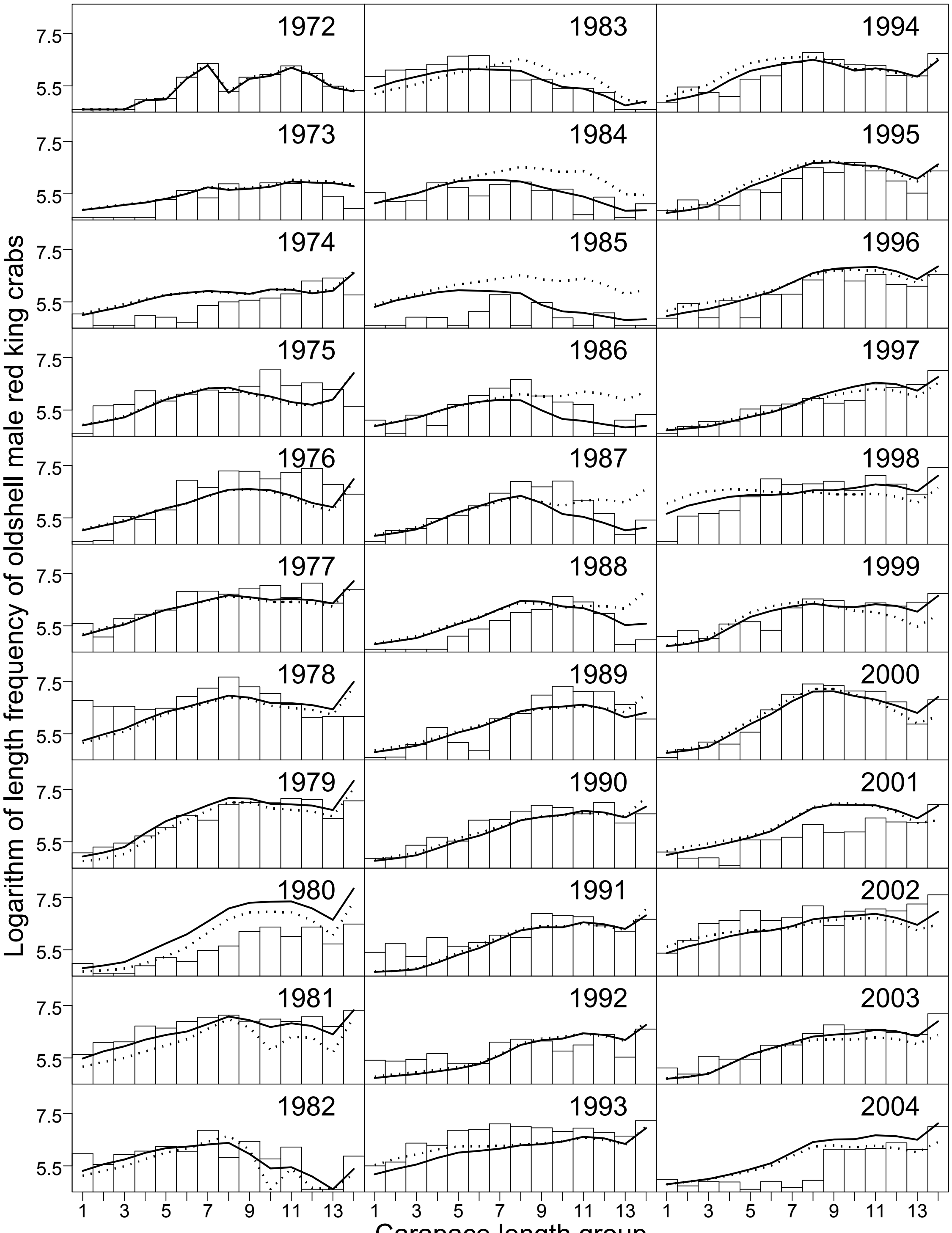

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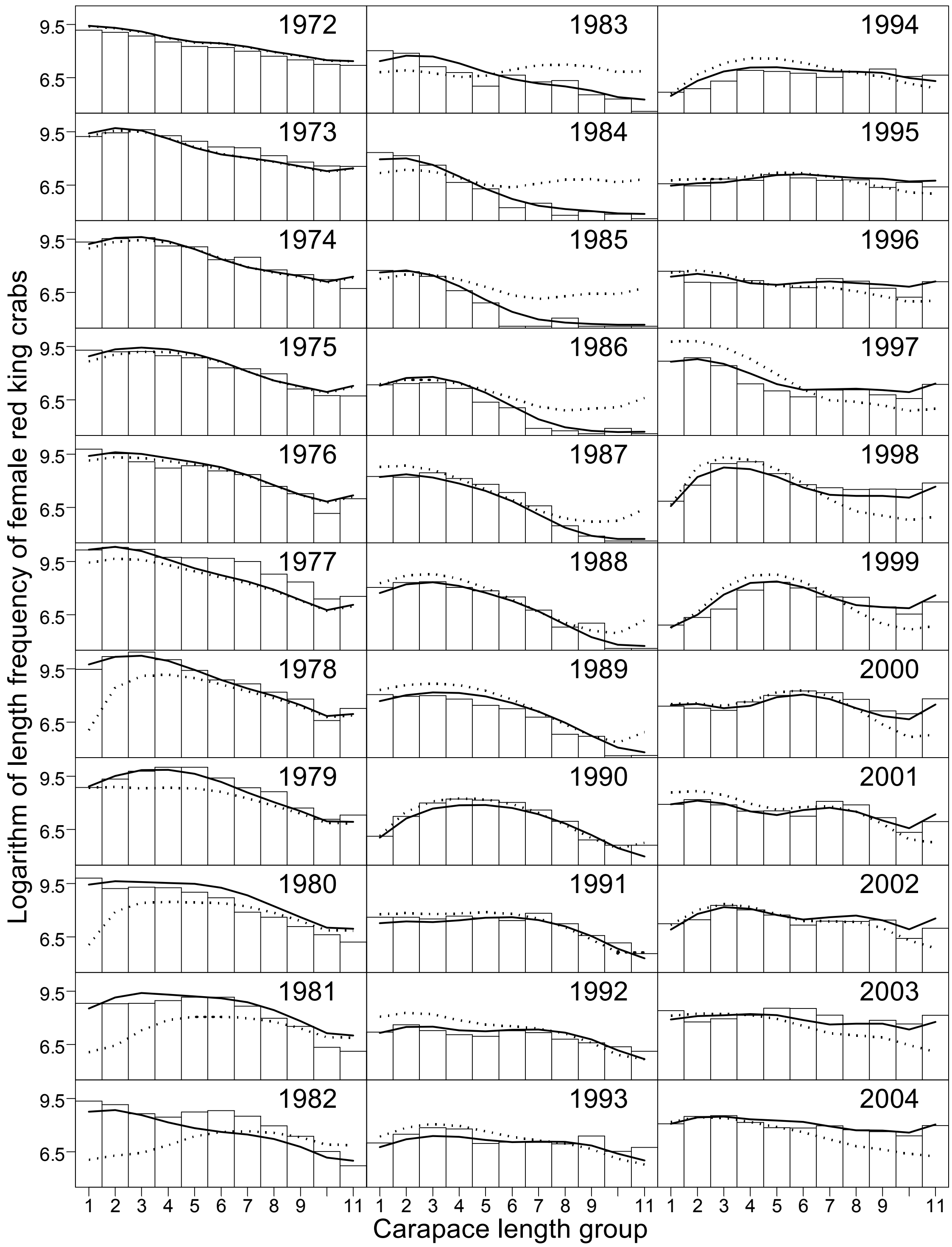

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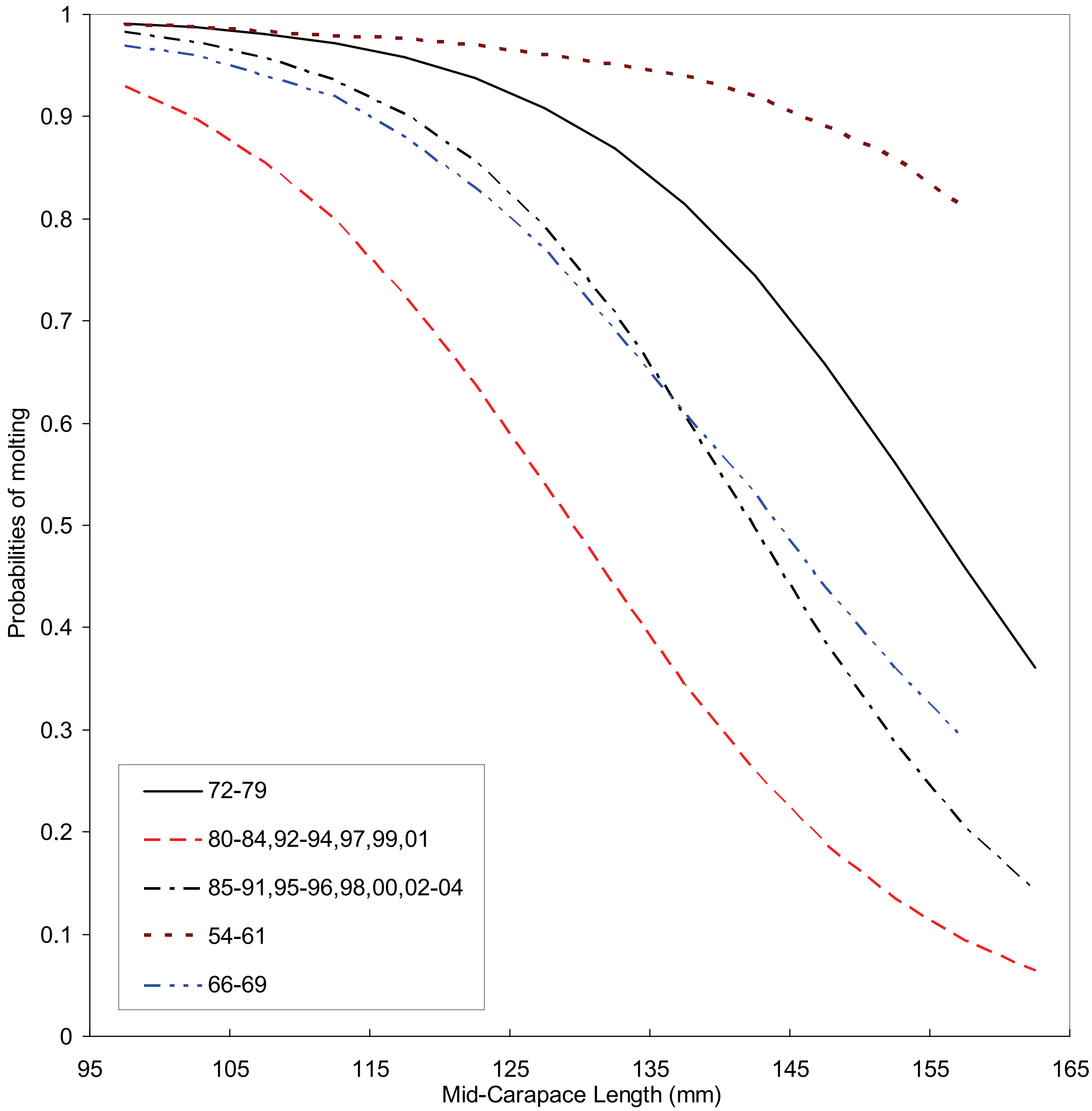

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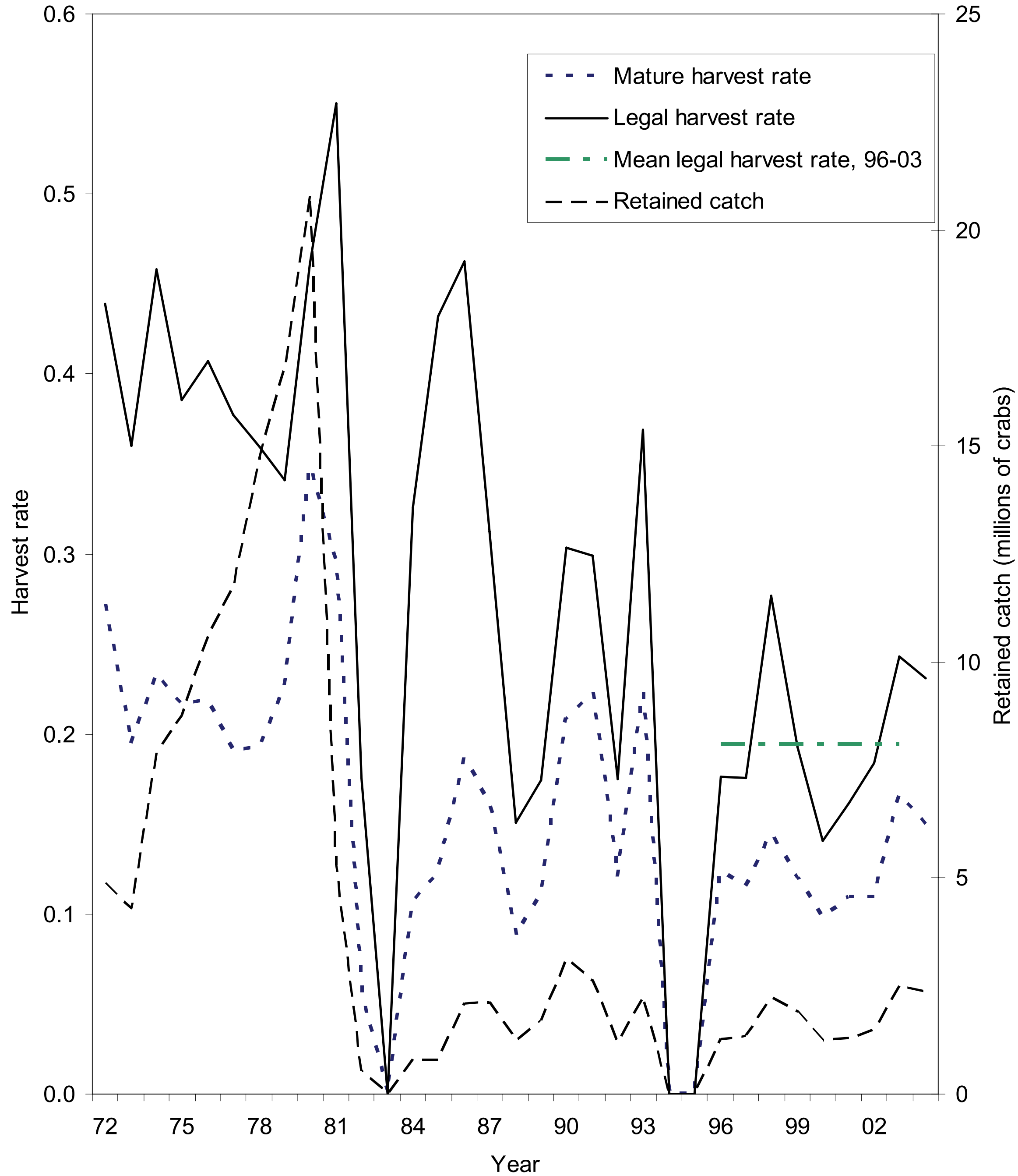

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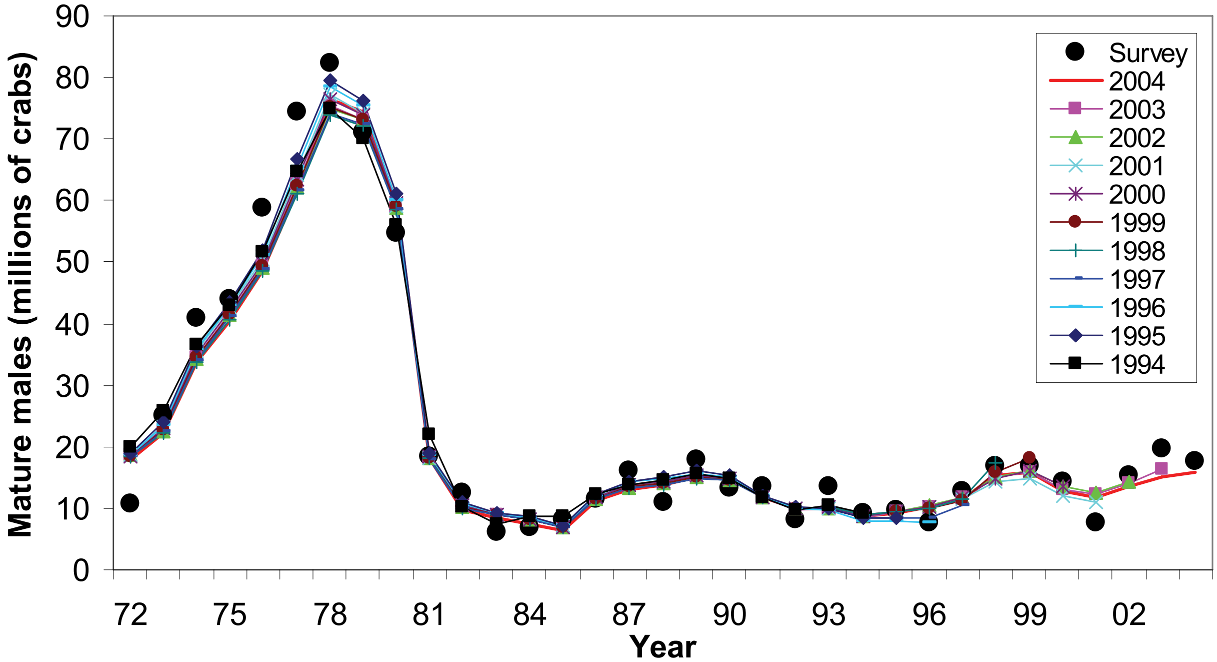

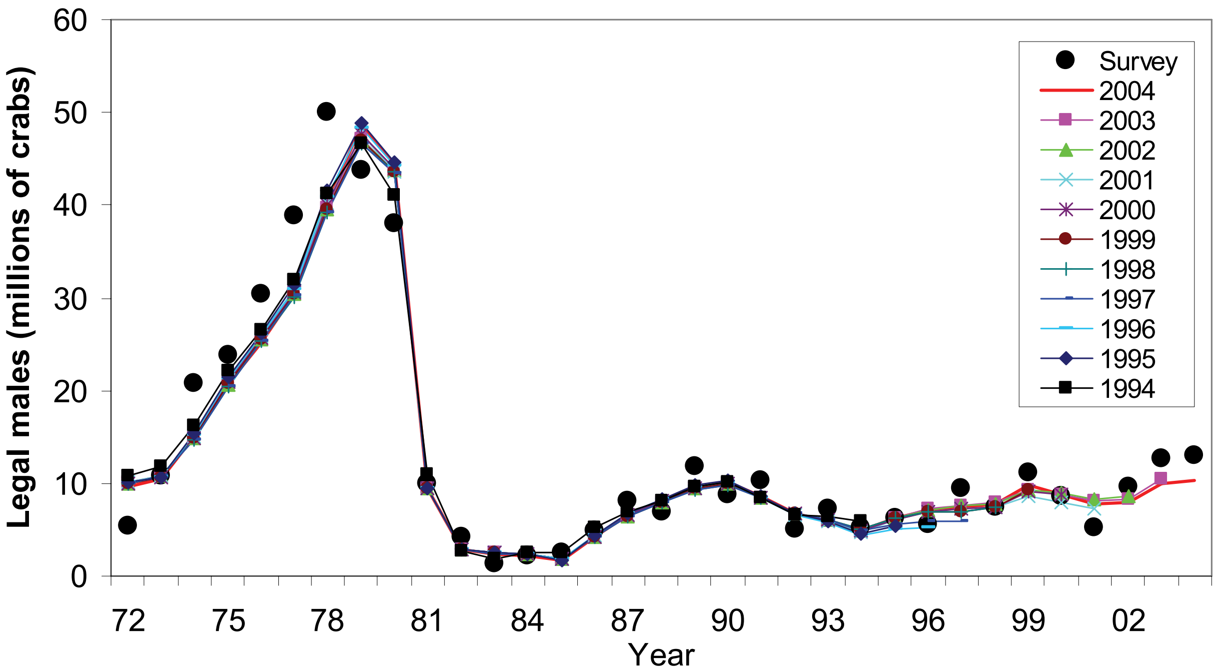

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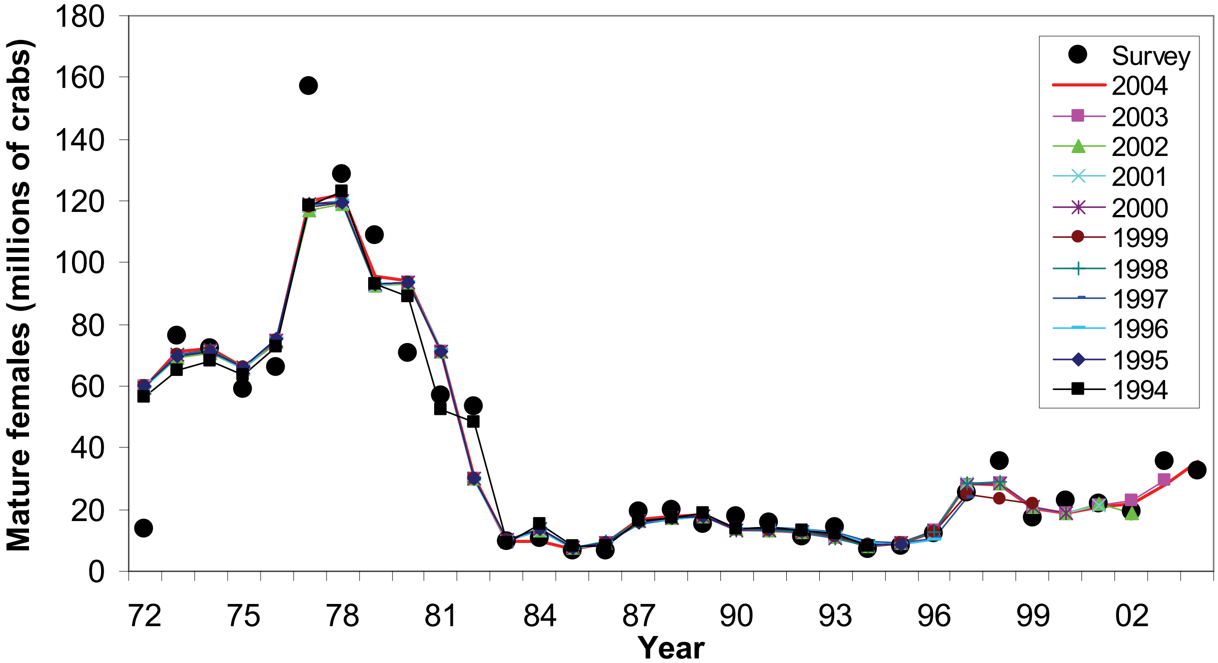

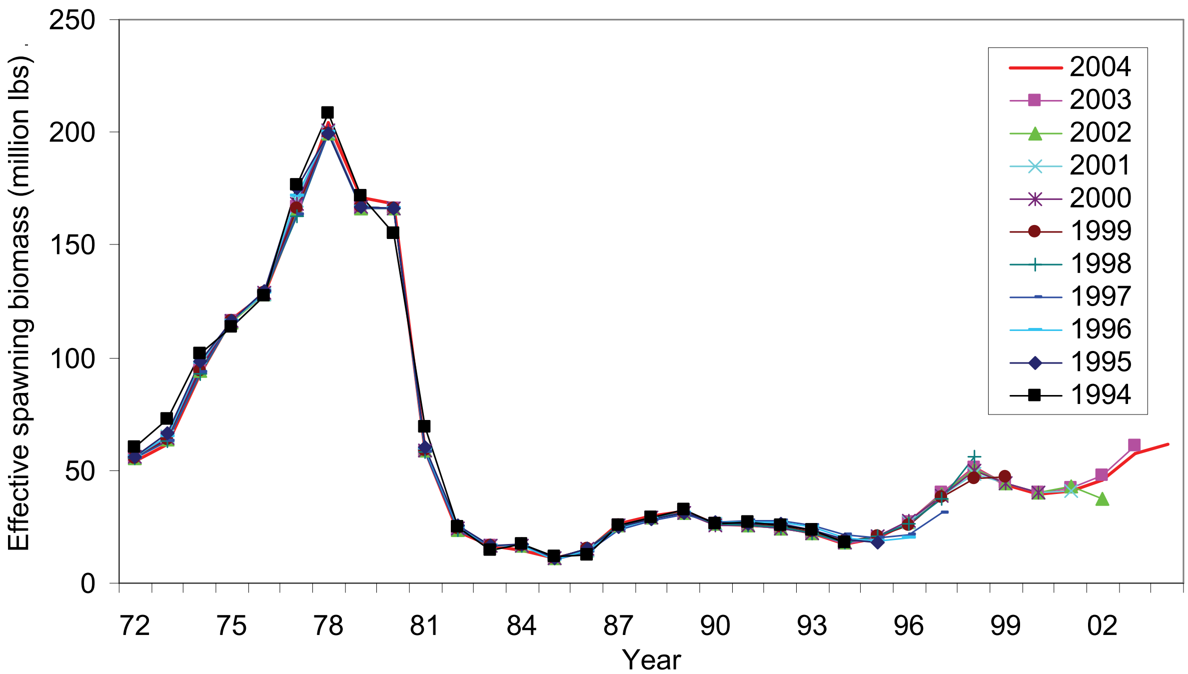

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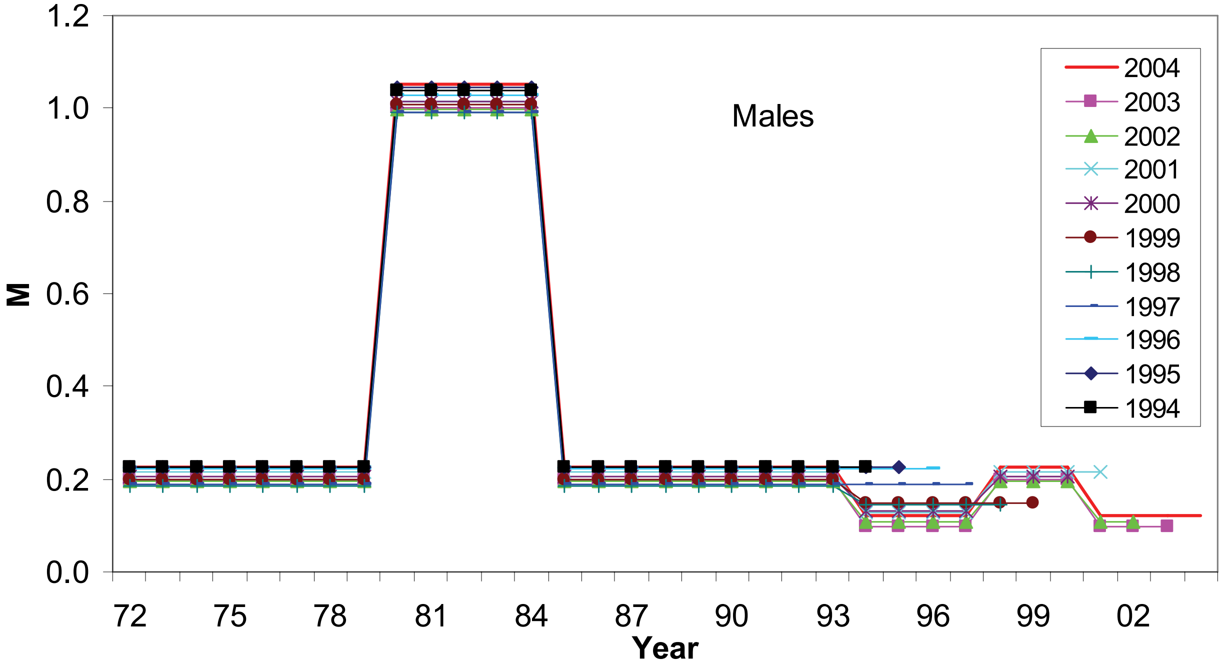

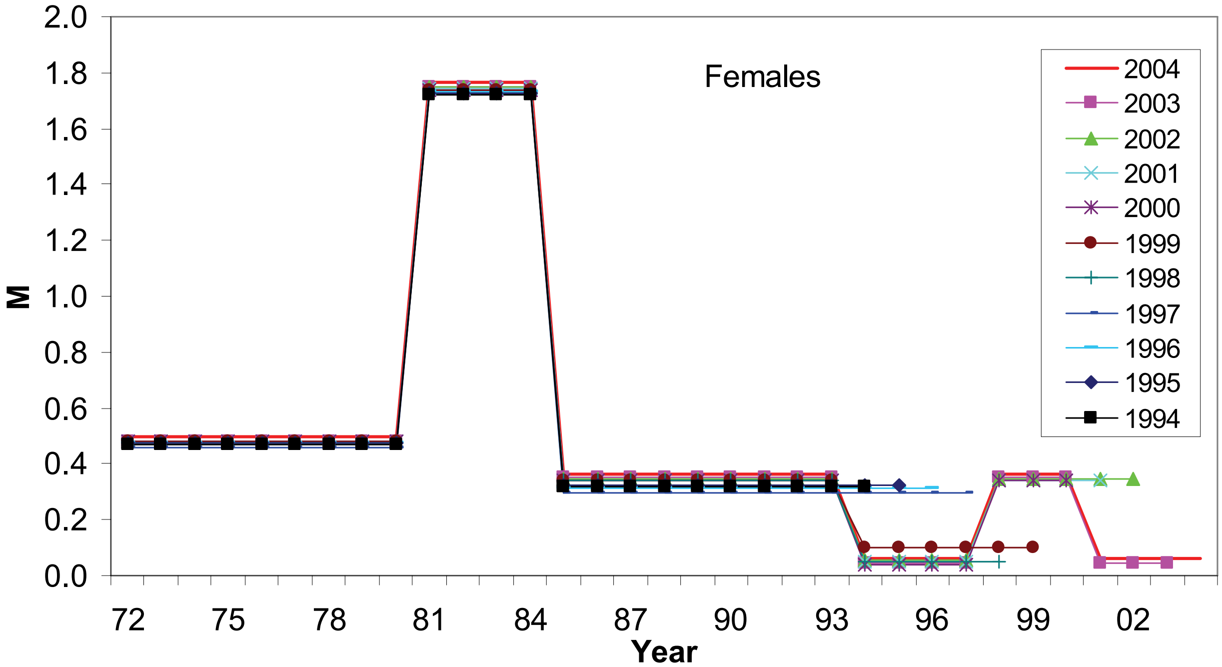

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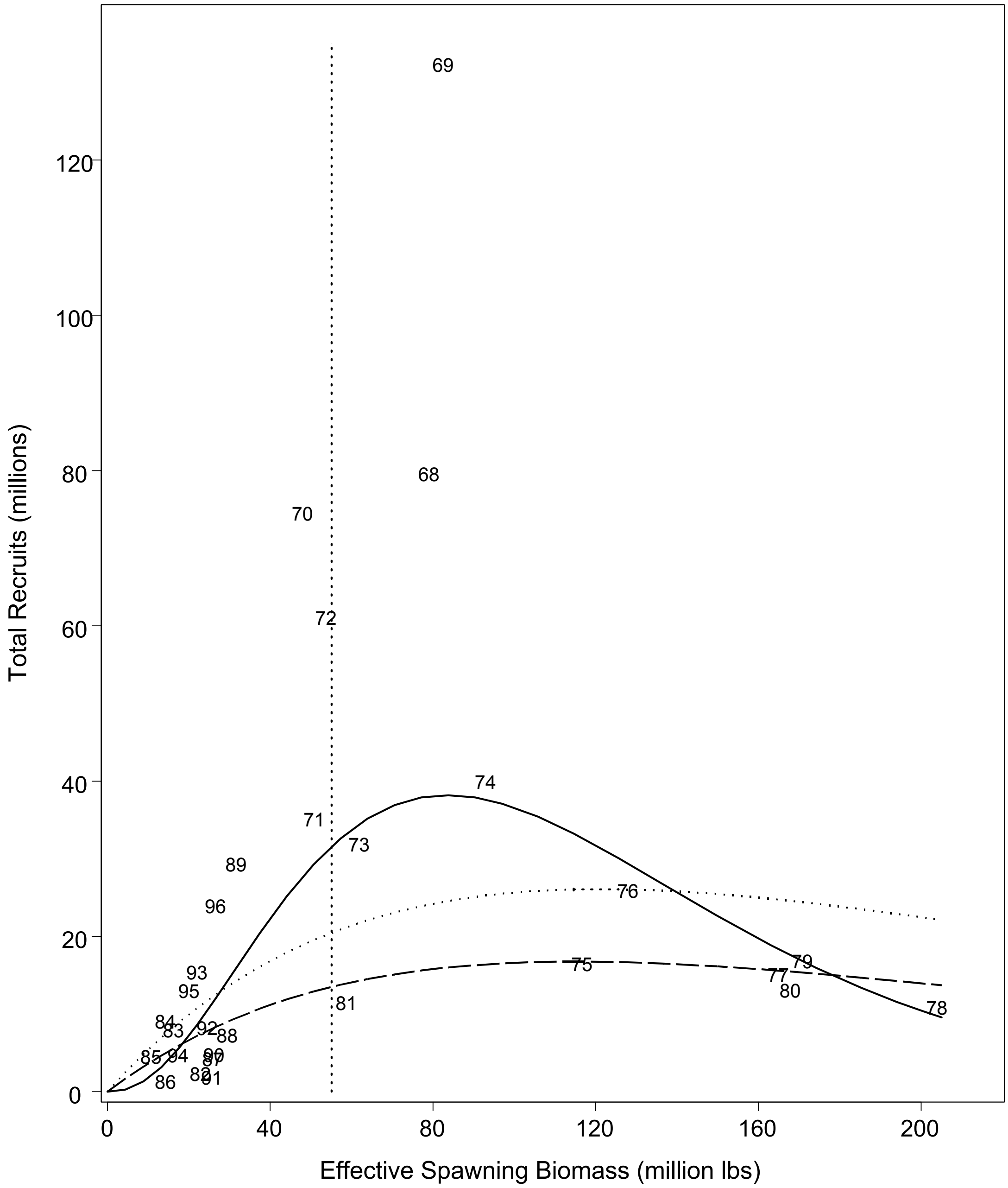

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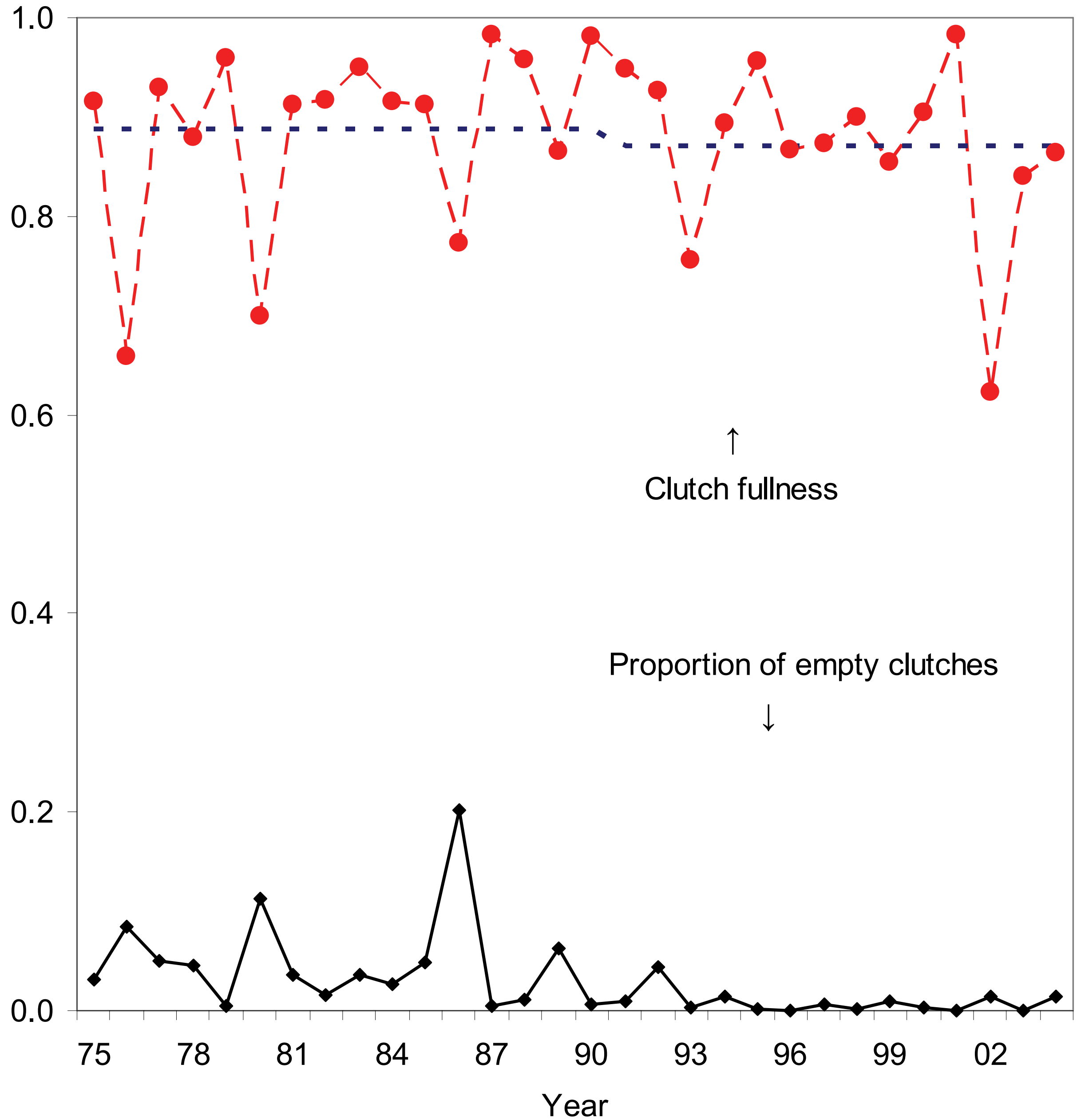

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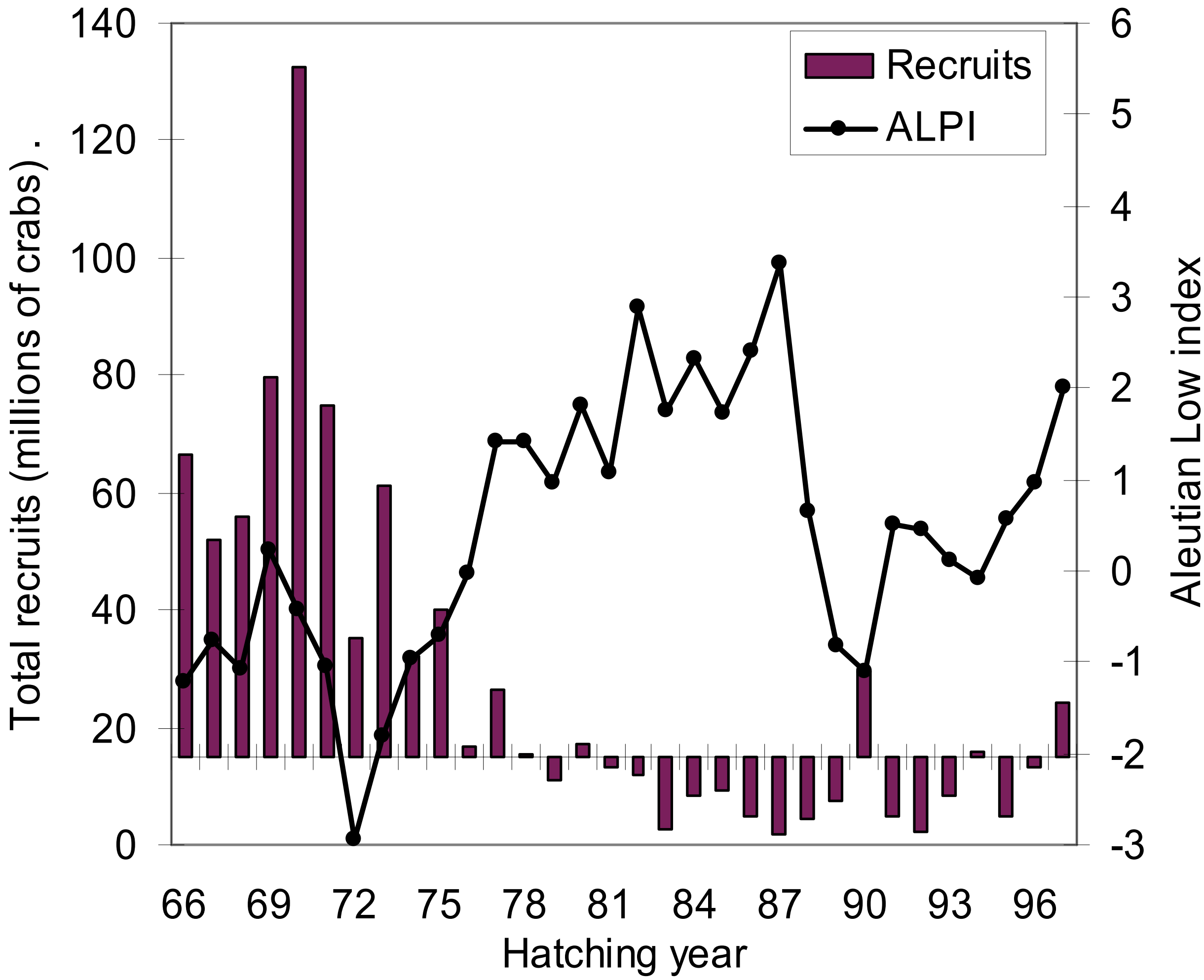

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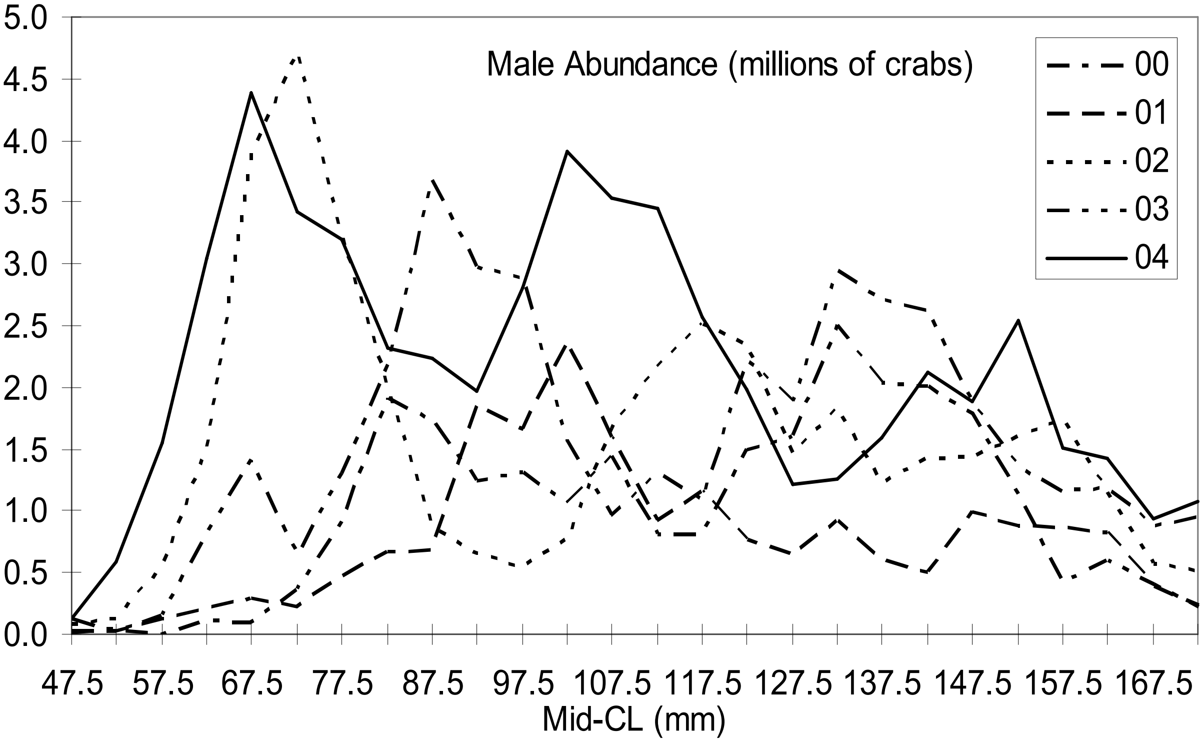

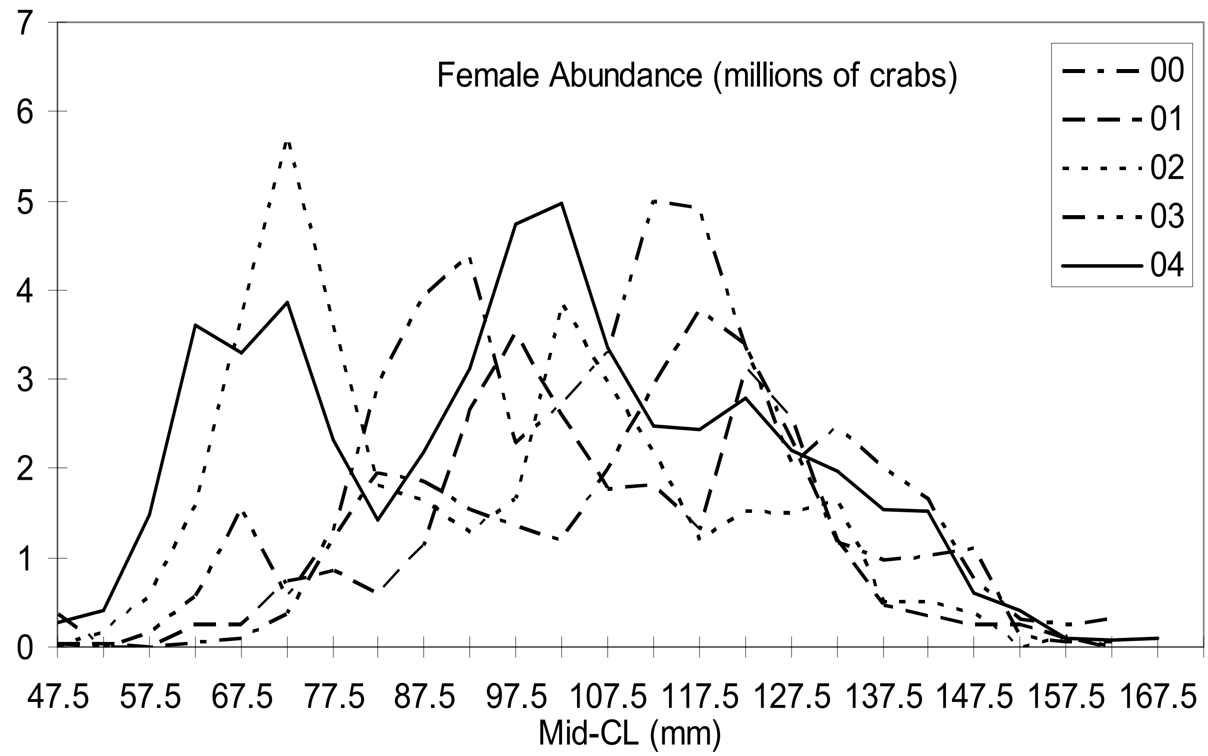

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