Estimating Southeast Alaska Tanner Crab Abundance using Pot Survey and Commercial Catch Data

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ABSTRACT: A catch–survey analysis was developed for 11 Tanner crab stocks in Southeast Alaska. The models were applied to pot survey and commercial catch data time series ranging from 1999–2005 to 1978–2005, depending on the availability of data for each stock. The models fit the pot survey data very well for 9 out of 11 stocks. The models estimated absolute abundance for mature and legal males and relative abundance for mature females. The trends of absolute male abundance estimates differed among some stocks, and there was no a consistent pattern of male recruitment to the model for all 11 Tanner crab stocks. Mature male abundance and recruitment to the model declined during recent years for several stocks. Although legal harvest rates have been lower during the recent 10 years than for the previous period, overall harvest rates are still very high for some stocks.

INTRODUCTION

Tanner crabs *Chionoecetes bairdi* support a small and relatively stable fishery in Southeast Alaska. The directed pot fishery began in the 1960s, and the catch peaked at over 3 million lb in the 1981/1982 season and has fluctuated between 1 and 3 million lb since then (Bishop and Stratman 2006). The season length for this fishery has gone from year-round in the 1960s and 1970s to only a few days in recent years. In addition to size and sex limits, the fishery has been regulated by limited entry for pot gear, a vessel pot limit, and a guideline harvest level of 2 million lb since the 1981/1982 season.

Tanner crabs occur in many bays and inside waters of Southeast Alaska. No comprehensive study of stock identification has been conducted. Because Tanner crabs distribute discretely within the inside waters of Southeast Alaska, and survey-area-specific management measures have been taken, we assume, for the purpose of this study, that Tanner crabs within each survey area constitute a discrete stock.

Many Tanner crab stocks in Southeast Alaska have been surveyed annually during summer or fall since 1979. Yet the survey data have not been modeled to obtain abundance estimates. In this study, we conducted catch–survey analyses for 11 stocks for which survey data are available.

DATA AND METHODS

Data

Two kinds of data are used for a catch–survey analysis: survey catch rate and commercial catch data. In the summer red king crab *Paralithodes camtschaticus* survey, 8 distinct areas (stocks) are surveyed with pots (Figure 1). The survey was designed for assessment of red king crab stocks, but the pots also caught Tanner crabs and provided an abundance index of Tanner crabs as well. The annual summer survey started in 1978 for Pybus and Gambier Bays and in 1979 for the other areas. No survey was conducted in 1990 or 1992 for any area, or in 1987 for Gambier Bay, Seymour Canal, Lynn Canal and Port Frederick; likewise in 1989 for Pybus Bay, Lynn Canal, Port Frederick and Excursion Inlet. Before 1986, 2.06×2.06 m (7×7 ft) square pots were set at fixed locations within a survey area each year (Clark et al. 2003). Beginning in 1986, each area was stratified based on red king crab catches, and pot locations within each stratum were randomly selected each year (Clark et al. 2003). From 1995 to 1999, a small number of conical pots with a 2.06 m (7 ft) base diameter were used along with the square pots in the survey. Preliminary analysis of square and conical pot catches from this time period indicates that the survey catchability of these pot types is very similar

(Clark et al. 2003). Therefore, only conical pots have been used in the survey since 2000.

Annual fall pot surveys targeting Tanner crabs were initiated in 1997 in Southeast Alaska. The survey in 1997 covered Icy Strait and northern Stephens Passage, which is part of the Juneau red king crab survey area. The survey was expanded to Holkham Bay in 1998, to Glacier Bay in 1999, and to Port Camden and Thomas Bay in 2001 (Figure 1). Because of the short time series, Tanner crab stocks in Port Camden and Thomas Bay were not modeled in this study. Conical,

top-loading pots with a 2.06 m (7 ft) base diameter were used in the survey. Like the red king crab survey, each area was stratified; pot locations were determined first systematically on a grid, then, beginning in 2002, randomly selected within each stratum.

Sampling methods for these pot surveys have been consistent over time (Clark et al. 2001, 2003). Soak times ranged from 16 to 24 hr. Sex, carapace width, shell condition, length condition, presence of parasites, and reproductive status were recorded. Carapace width was measured to the nearest millimeter. Crab shells
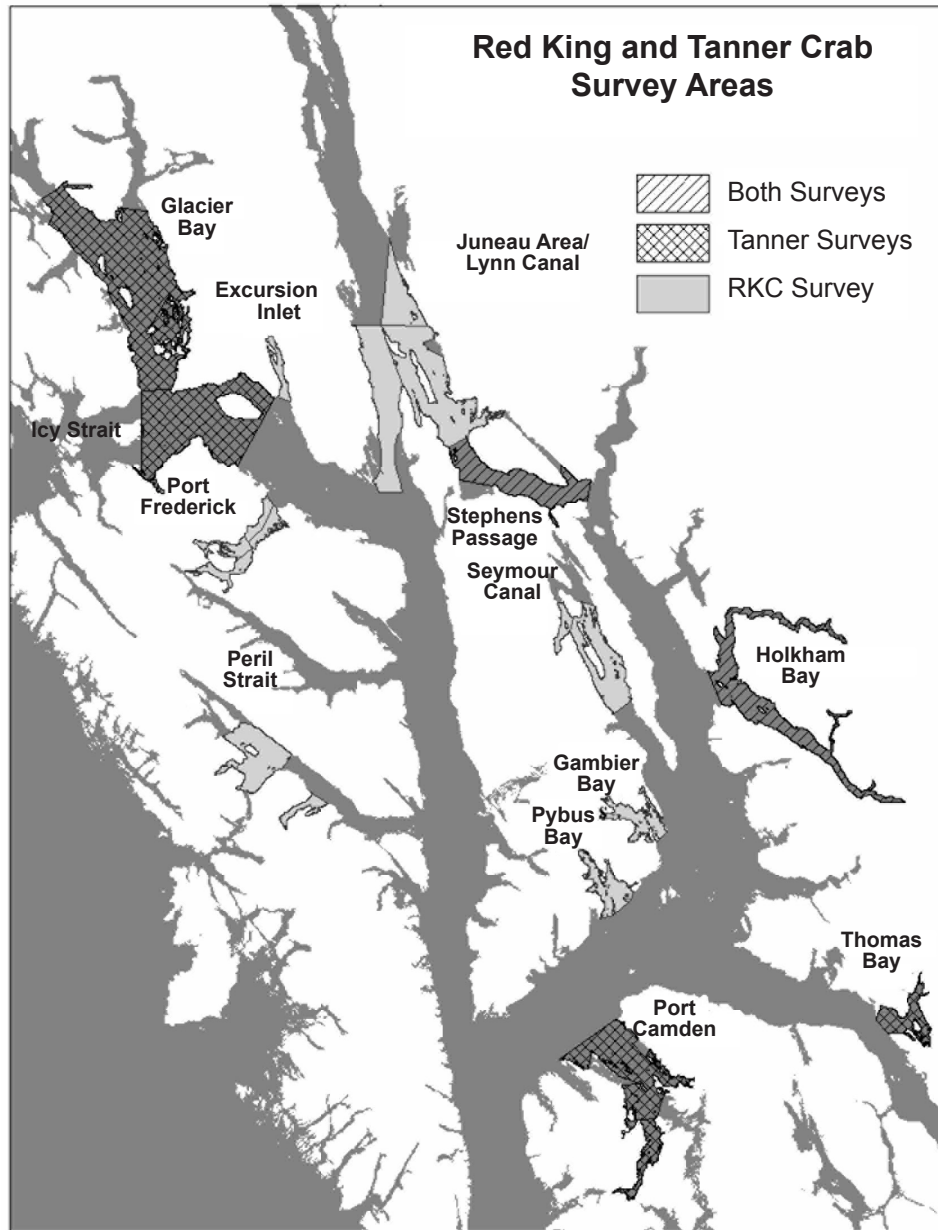

Figure 1. Areas currently surveyed by Alaska Department of Fish and Game in the Southeast red king and Tanner crab stock assessment surveys.

were classified into 5 conditions, soft, light, new, old and very old, based on a combination of factors which include the accumulation of epifauna, scratches, discoloration, and spine sharpness (Clark et al. 2001). Abundance indices by sex, shell condition, and size, $N_{s,h,l}$, were standardized by soak times and stratum areas: $N_{s,h,l}$ (number of crabs per potlift with 24 hr of soak time) is equal to the number of crabs per potlift by sex, shell condition, and size times the proportion of stratum area, divided by the soak time (day).

Some parts of the Juneau area were not surveyed before 1996, and it appears that the indices before 1996 and after 1995 are not comparable. Therefore, we used the data only from 1996 to 2005 for the Juneau stock. Although survey indices are available for most years for Port Frederick and Pybus Bay from 1979 to 1991; they look quite different from indices after 1992. Therefore, we modeled only data after 1992 for these two stocks.

The annual commercial catch was summarized as number of crabs for each stock from the catch database of Alaska Department of Fish and Game. After 1973, the fishery occurred during the winter and spring, so year t is defined as from June 1 of year t to May 31 of year $t+1$ for modeling purposes. Data on the bycatch of sublegal males and females during the fishery are not available.

Male Model

A 3-stage catch survey analysis (CSA) for crab stocks is principally similar to a full length-based analysis (Zheng et al. 1995, 1998) with the major difference being broader length groups for the CSA. Because of the large size categories, the CSA is particularly useful for a small stock, such as the Tanner crab stocks in Southeast Alaska, with low survey catches each year. In this study, we modified the CSA to include bycatch mortality.

Only male crab abundance is modeled by a typical CSA because the analysis requires commercial catch data and only males may be retained by the fishery. Male crab abundance was divided into 3 groups: prerecruits (P1), recruits (R), and postrecruits (P). Legal size for Southeast Tanner crabs is ≥138 mm carapace width (CW). Based on growth increments per molt (Stone et al. 2003), we categorized Southeast Tanner crabs into P1 (109–137 mm CW), R (newshell 138–169 mm CW), and P (oldshell ≥138 mm CW and newshell ≥170 mm CW). In this study, we defined the size at maturity for male Tanner crabs ≥109 mm CW, based on the cutoff CW for prerecruits. This size at maturity is similar to the size at which 50% of the males are estimated to be functionally mature for Ko-

diak Tanner crabs (Brown and Power 1972; Donaldson et al. 1981; Stevens et al. 1993).

The molting portion of prerecruits "grows" into different stages based on a growth matrix, and the non-molting portion of prerecruits remains at the same stage. The model links the crab abundances in 3 stages in year $t+1$ to the abundances, catch, and bycatch mortality in the previous year through natural mortality, molting probability, and a growth matrix:

$$P1_t^b = P1_t \{1 - [h\, H^q\, C_t\, /(R_t + P_t)] \quad e^{(y_t-1)M}\},$$
$$P1_{t+1} = P1_t^b [(1-m_t) + m_t G_{P1,P1}]\, e^{-M_t} + \gamma_{t+1}\ ,$$
$$R_{t+1} = (P1_t^b\, m_t\, G_{P1,R})\ \ e^{-M_t},$$
$$P_{t+1} = (P_t + R_t + P1_t^b\, m_t\, G_{P1,P})\ \ e^{-M_t} - C_t\, e^{(y_t-1)M_t}, \qquad (1)$$

where $P1_t^b$ is prerecruit abundance after handling mortality in year t, h is handling mortality rate, H^q is fishery catchability for prerecruits, γ_t is the number of crabs entering the model (recruitment to the model) in year t, m_t is molting probability for prerecruits in year t, $G_{i,j}$ is a growth matrix containing the proportions of molting crabs growing from group i to group j, M is the instantaneous natural mortality rate, C_t is commercial retained catch (number of crabs) in year t, and y_t is the time lag from the survey to the mid-point of the fishery in year t. By definition, all recruits become postrecruits in the following year.

Survey catchabilities were used to scale absolute abundances to relative (survey) abundances for parameter estimation. Selectivities relative to legal crabs were estimated for prerecruits, and survey catchabilities were estimated for scaling legal crabs per potlift to absolute crab abundance. Legal harvest rate is defined as the ratio of retained catch to estimated legal abundance adjusted by natural mortality to the midpoint of each fishing season.

We modeled molting probability for prerecruits, m_t, as a random walk process:

$$m_{t+1} = m_t e^{\eta_t}, \qquad (2)$$

where η_t are independent, normally distributed random variables with a mean of zero.

Female Model

The model for female crabs is somewhat simpler than the male model. To avoid survey catchability problems, we modeled only mature female abundance and grouped them by shell condition only. Female sexual maturity was defined by presence of eggs or by the width of the

abdominal flap if eggs were not present (Jadamec et al. 1999). Bycatches of female Tanner crabs in the directed crab fisheries in the eastern Bering Sea were very low (Moore et al. 2000) and may be low in Southeast Alaska also; thus we ignored female bycatches in this study. Because mature females do not molt, newshell mature female abundance is equal to recruitment into the model, and oldshell mature females are the survivors of mature females in the previous year:

$$N_{t+1}^f = \gamma_{t+1}^f$$
$$O_{t+1}^f = (N_t^f + O_t^f) e^{-M^f}$$

(3)

where N_t^f and O_t^f are newshell and oldshell mature female abundances in year t, γ_t^f is female recruitment in year t, and M^f is female instantaneous natural mortality rate. Without commercial catch, the female model cannot scale the relative index to absolute abundance for females. Therefore, the model is just a means to smooth the survey catch per unit effort (CPUE) to reveal their trends. The male and female models are completely independent.

Parameter Estimation

Measurement errors of survey estimates of relative abundances were assumed to follow a lognormal distribution. A nonlinear least squares approach that minimizes the residual sum of squares (RSS) was used to estimate parameters:

$$RSS = \sum_t \{[\ln(P1_t \, q \, s + 0.001) - \ln(p1_t + 0.001)]^2$$

$$+ \; [\ln(R_t \, q + 0.001) - \ln(r_t + 0.001)]^2$$

$$+ [\ln(P_t \, q + 0.001) - \ln(p_t + 0.001)]^2$$

$$+ 10 \; \eta_t^2 + 0.1[\ln(\gamma_t) - \ln(\hat{\gamma})]^2\}$$

$$RSS^f = \sum_t \{[\ln(N_t^f \, s^f + 0.001) - \ln(n_t^f - 0.001)]^2$$

$$+ [\ln(O_t^f + 0.001) \; - \ln(o_t^f + 0.001)]^2$$

$$+ 0.1[\ln(\gamma_t^f) - \ln(\hat{\gamma}^f)]^2\}$$

(4)

where $p1_t$, r_t, and p_t are relative pot survey abundance indices (crabs/potlift) of prerecruits, recruits, and postrecruits in year t; n_t^f and o_t^f relative pot survey abundance of newshell and oldshell mature females; s is selectivity for prerecruits; q is pot survey catchability; s^f is selectivity for newshell mature females; $\hat{\gamma}$ is the mean of γ_t, and $\hat{\gamma}^f$ is the mean of γ_t^f. Survey

catchability, q, is a scaling parameter to convert crabs per potlift to absolute crab abundance. Values 10 and 0.1 are weights assumed for molting and recruitment variability over time.

Parameters estimated by the model include: molting probabilities, catchabilities, selectivities, crabs entering the model for the first time each year except the first, and prerecruit, recruit and postrecruit abundances in the first year. Using AD Model Builder (Otter Research Ltd. 1994), we estimated parameters using the quasi-Newton method to minimize RSS.

Because survey catchabilities are estimated within the model, M has to be estimated independently of the model due to parameter confounding. M is difficult to estimate and may not be constant over time and shell condition. For Bering Sea Tanner crabs, Somerton (1981) estimated M to be 0.35 for males smaller than the legal size and 0.22 and 0.28 for legal males based on survey and catch data, Zheng et al. (1998) obtained M estimates of 0.49 for males and 0.52 for females based on a length-based model, and the NPFMC Crab Plan Team produced an M estimate of 0.3 for both males and females using a maximum age of 15 (NPFMC 1999). For this study, we assumed $M = 0.3$ for Southeast Alaska Tanner crabs and examined model sensitivities to $M = 0.25$, 0.35 and 0.4.

The growth matrix is also confounded with many parameters in a length-based model (Sullivan et al. 1990). Fortunately, growth data are available to estimate a growth matrix for Southeast Alaska Tanner crabs (Stone et al. 2003). For the prerecruit group, we estimated that 4.1% of molting crabs remained in that group, while 92.3% grew into the recruit group and 3.6% into the postrecruit group.

RESULTS

Mean RSS (RSS divided by the number of observed data points) measures of the goodness of fit of the models to the data and changes very slightly with $M = 0.25$ to 0.4 for 11 Tanner crab stocks (Figure 2). Generally, mean RSS is slightly lower for a higher M with some exceptions. $M = 0.3$ appears to fit the data well and is close to the low end of estimated M for Tanner crabs in the literature. All results reported below are based on models with $M = 0.3$. Stocks with shorter time series generally have lower mean RSS except for Tanner crabs in Holkham Bay and Pybus Bay and females in Port Frederick and Icy Strait.

Estimates of survey catchability, selectivity, and molting probability of sublegal males vary greatly among stocks (Table 1). Estimates of male pot survey catchability range from a low of 0.00004158 for the
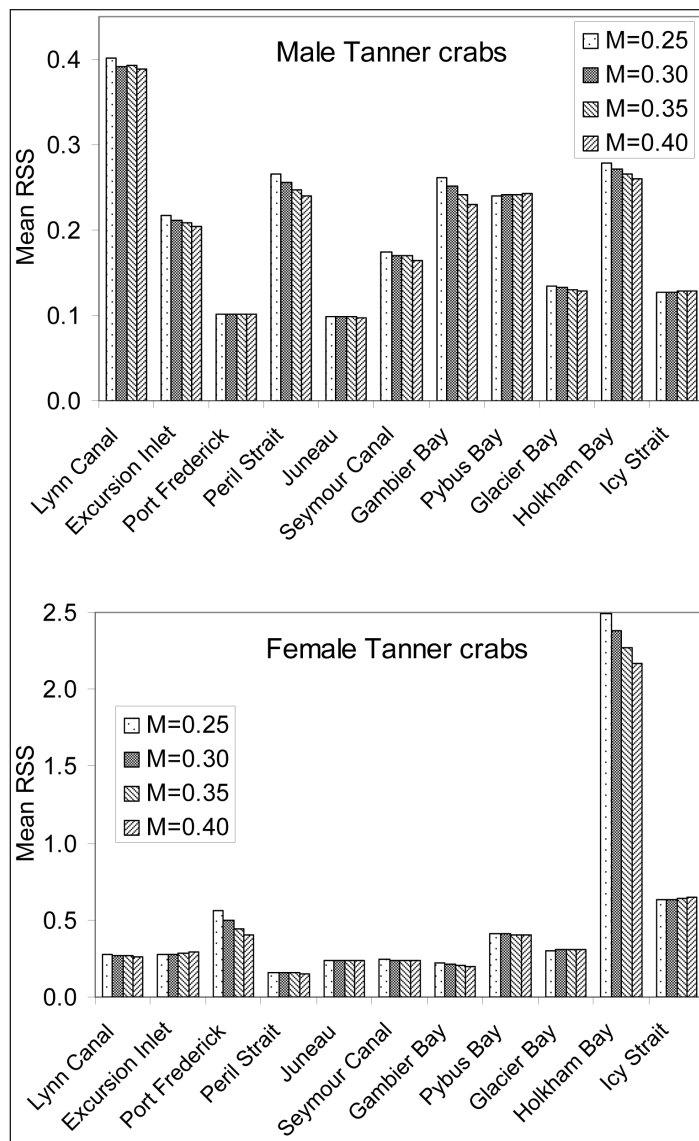
Figure 2. Comparison of the effects on mean residual sums of squares (RSS) due to varying natural mortality from 0.25 to 0.4 for the catch-survey model fit to 11 Tanner crab stocks in Southeast Alaska.

Table 1. Parameter estimates for CSA and female models for Tanner crab stocks in Southeast Alaska.

Stock	Male Pot Survey Catchability	Sublegal Male Selectivity	Mean Sublegal Male Molting Probability	Newshell Female Selectivity
Lynn Canal	3.304E-04	0.407	0.660	0.871
Excursion Inlet	6.461E-05	0.900	0.854	0.232
Port Frederick	6.031E-04	0.528	0.921	1.000
Peril Strait	8.608E-05	1.000	0.459	0.831
Juneau	6.774E-05	0.522	0.932	1.000
Stephens Passage	5.970E-05	0.678	0.932	0.549
Seymour Canal	7.121E-05	0.690	0.873	0.475
Gambier Bay	1.952E-04	0.815	0.786	0.779
Pybus Bay	2.394E-04	0.437	0.897	0.538
Glacier Bay	4.158E-05	1.000	0.320	0.628
Holkham Bay	6.538E-05	1.000	0.927	1.000
Icy Strait	3.691E-04	0.473	0.925	0.298

Glacier Bay stock to a high of 0.0006031 for the Port Frederick stock. Estimates of selectivity for sublegal males range from 0.407 for the Lynn Canal stock to 1.000 for the stocks in Peril Strait, Glacier Bay, and Holkham Bay. Mean molting probability for legal males varies from 0.320 for the Glacier Bay stock to 0.932 for the Juneau stock. Estimates of selectivity for newshell mature females also differ greatly among stocks: from 0.232 for the Excursion Inlet stock to 1.000 for the stocks in Port Frederick, Juneau, and Holkham Bay.

The male model fit the pot survey data very well for most stocks (Figures 3 and 4). No systematic patterns were detected in the residuals. The trends and variations of survey CPUE (catch/potlift) for mature and legal males were similar for 9 stocks but differed for the stocks in Glacier Bay and Pybus Bay (Figures 3 and 4). Relative to the other stocks, prerecruit CPUE from the survey data after 2000 was much higher than legal CPUE for the Glacier Bay stock.

The female model also fit the survey CPUE data for mature females very well except for the stocks in
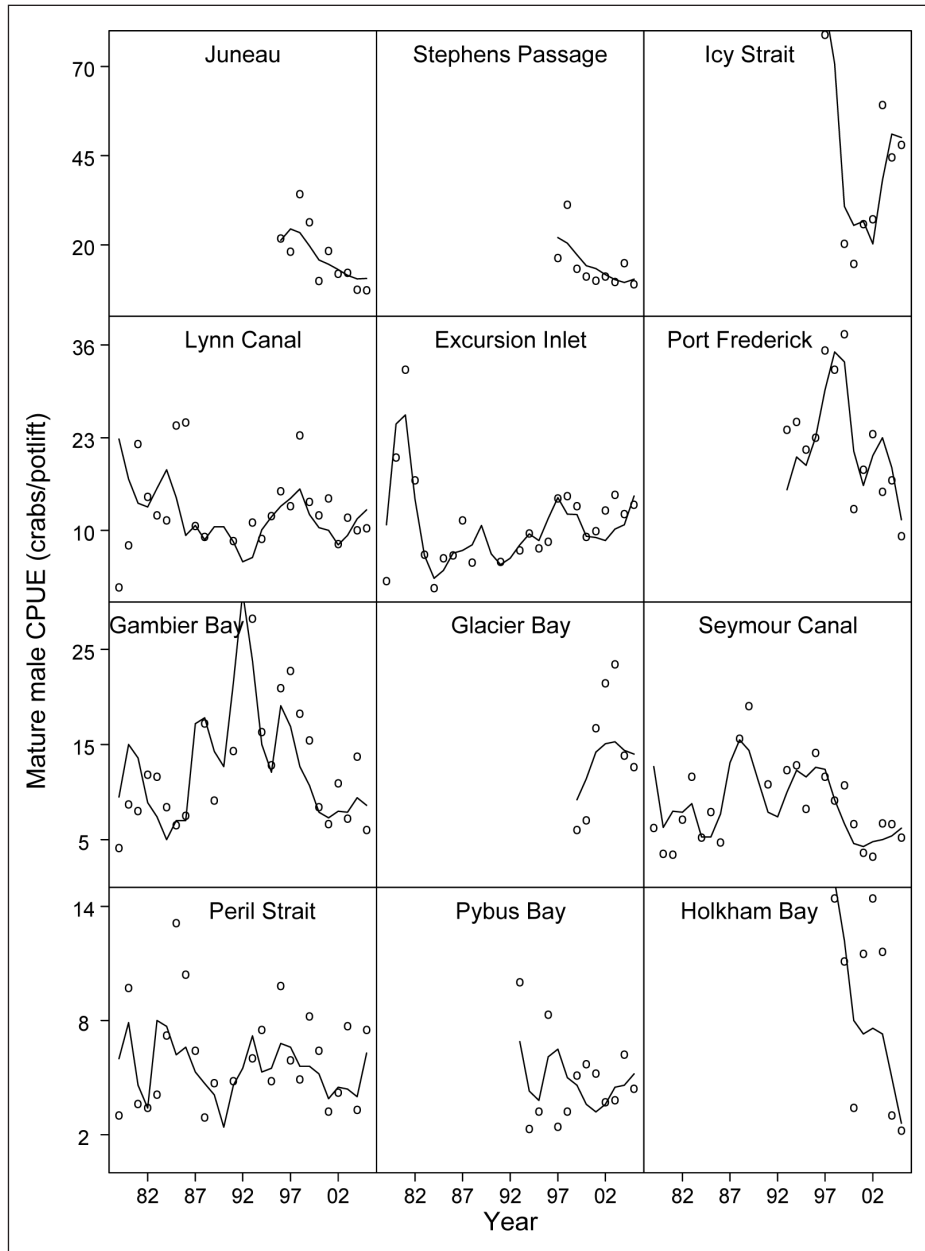

Figure 3. Comparison of survey- and model-estimated mature males per potlift for 11 Tanner crab stocks in Southeast Alaska.

Holkham Bay and Icy Strait (Figure 5). The CPUE trends were quite different for some stocks. The Lynn Canal and Peril Strait stocks during 1985–2005 and Juneau, Stephens Passage, Port Frederick and Pybus Bay stocks during the 1990s and 2000s were relatively constant, but both the Icy Strait and Excursion Inlet stocks increased sharply. The trends for Gambier Bay and Seymour Canal stocks were similar to each other. The CPUE data for the Holkham Bay stock were most variable, which resulted in the highest mean RSS from the fit (Figure 2).

The trends of survey CPUE for some stocks differed between mature males and females (Figures 3 and 5). The most notable differences occurred for the Excursion Inlet stock, which showed high CPUE in the early 1980s with only a slight increase during 1984–2005 for males and low CPUE in the early 1980s and a sharp increase during 1984–2005 for females. Opposite trends between mature males and females in CPUE also occurred for Juneau, Stephens Passage, Port Frederick and Holkham Bay stocks (Figures 3 and 5).
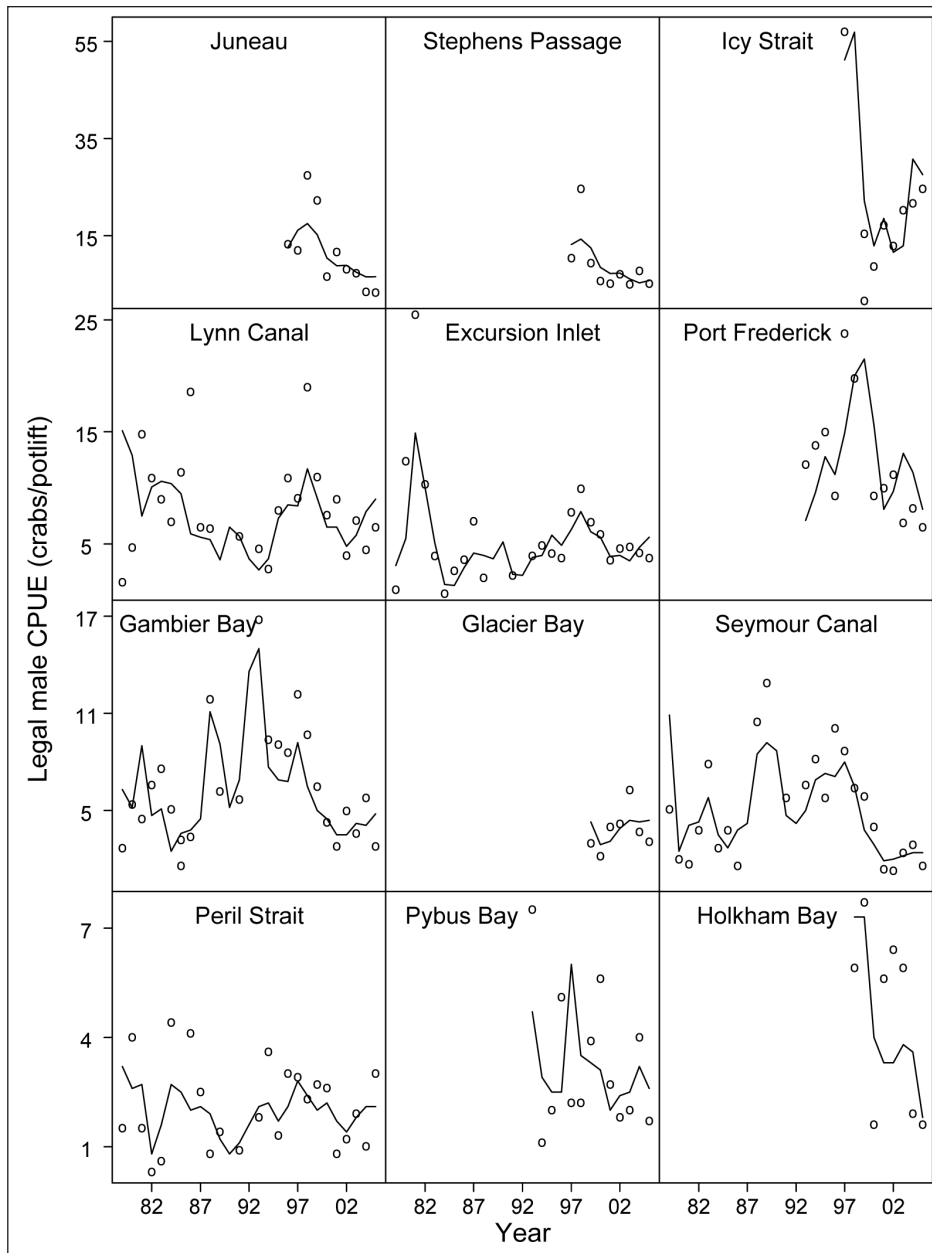

Figure 4. Comparison of survey- and model-estimated legal males per potlift for 11 Tanner crab stocks in Southeast Alaska.

The trends in absolute abundance estimates differed among some stocks (Figures 6 and 7). After a sharp decrease during the early 1980s, estimated mature male abundance slowly increased for the Excursion Inlet stock. Estimated mature male abundance fluctuated over time and remained at a low level in recent years for Seymour Canal and Gambier Bay stocks. Estimated abundance for Lynn Canal and Peril Strait stocks was relatively constant over time. Estimated mature male abundance declined sharply in recent years for Juneau, Holkham Bay, and Port Frederick stocks. The trends of legal male abundance estimates were similar to those of mature males (Figures 6 and 7).

Estimated legal male harvest rates fluctuated greatly and were relatively high for Southeast Alaska Tanner crab stocks (Figure 8). Estimates of legal harvest rates for recent years were very high for Icy Strait and Port Frederick stocks, but were relatively low for Gambier Bay, Glacier Bay, and Peril Strait stocks. For all modeled stocks combined, estimated legal harvest rates ranged from 0.38 to 0.84, with a mean of 0.60, and the highest estimated harvest
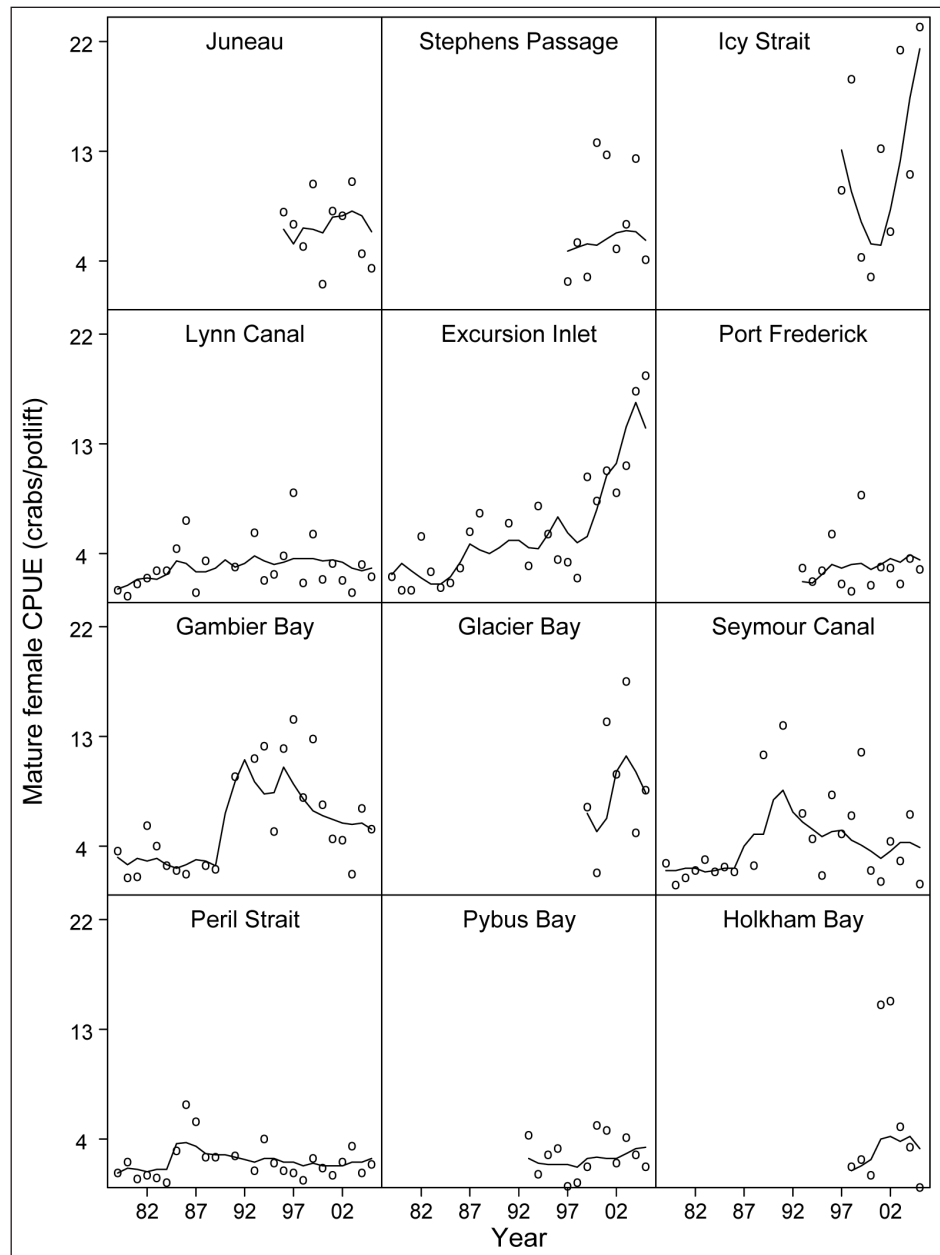

Figure 5. Comparison of survey- and model-estimated mature females per potlift for 11 Tanner crab stocks in Southeast Alaska.

rate occurred during 1979–1981 with estimates of 0.79–0.84.

Estimated recruitment to the model differed greatly among stocks (Figure 9). Like the estimates of mature male abundance, estimated recruitment declined during recent years for Juneau, Glacier Bay, Port Frederick and Holkham Bay stocks. Recruitment was also estimated to be at a low level during recent years for Seymour Canal and Gambier Bay stocks.

Sensitivities of abundance estimates to handling mortality rates and natural mortality are illustrated in

Figures 10 and 11 for the Excursion Inlet stock. Handling mortality rates have little impact on estimates of legal abundance and legal harvest rates, whereas higher handling mortality rates result in higher estimates of mature male abundance (Figure 10). Although not shown here, the biggest impact of handling mortality rate is on estimates of recruitment to the model—higher handling mortality leads to higher recruitment estimates. Higher natural mortality also results in higher abundance estimates and lower legal harvest rate estimates (Figure 11).
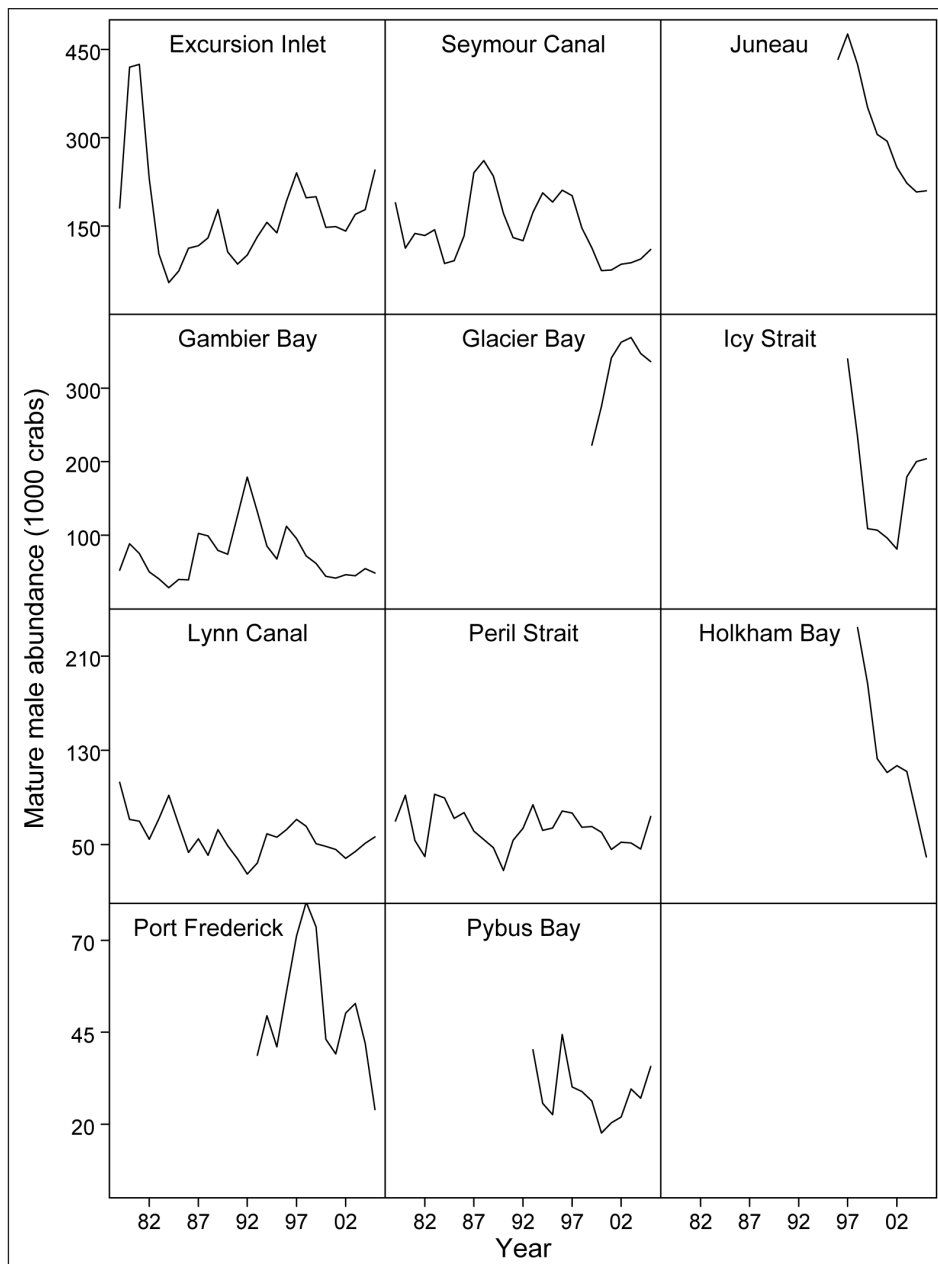

Figure 6. Estimated absolute mature male abundances for 11 Tanner crab stocks in Southeast Alaska.

DISCUSSION

Common survey gears for crabs are trawl and pot. For a trawl survey, areas swept by trawls can be calculated and used to convert the survey CPUE into abundance estimates (Stevens et al. 2002). If an assessment model is not developed, the survey abundance estimates can be used for setting the catch quota under a conservative assumption that trawl survey catchability for mature males is equal to 1 (Griffin and Ward 1992). However, some Tanner crab fishing grounds, such as Southeast

Alaska, are not suitable for a trawl gear, and pot surveys have to be used for sampling crabs. In order to estimate population abundance from pot survey CPUE, the pot survey catchability must be estimated from information independent of the routine survey. An assessment model, such as the catch–survey analysis, integrates survey, catch, and tagging data to estimate the survey catchability and absolute abundance. Our models fit the Tanner crab pot survey data in Southeast Alaska well and should provide important information for fisheries management in the future.
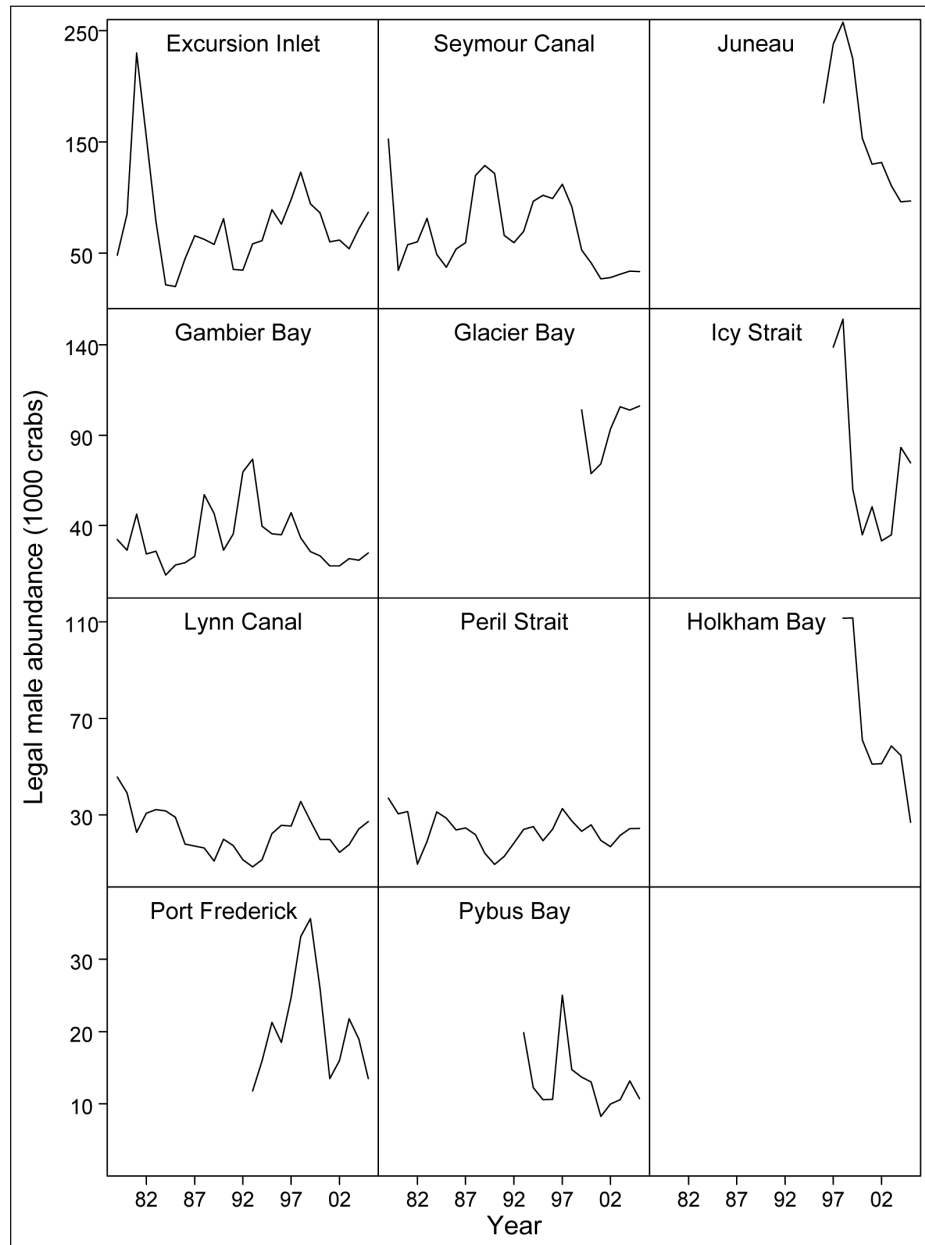

Figure 7. Estimated absolute legal male abundances for 11 Tanner crab stocks in Southeast Alaska.

Parameter confounding is a challenge for a population model, especially for a length-based model (Sullivan et al. 1990). Survey catchability and natural mortality are highly confounded, and typical survey and catch data alone can estimate only one of them. For the Southeast Alaska Tanner crab model with the pot survey data, the survey catchability has to be estimated in the model. Therefore, natural mortality must be estimated outside of the model. Because crab natural mortality may be a function of age, shell condition, size, and sex and may change over time (Zheng

2005), it is difficult to estimate. In this study, we assumed natural mortality to be 0.3 for both sexes, close to the low end of the estimated range in the literature for Tanner crabs (Zheng 2005). A low natural mortality results in low estimates of mature and legal male abundance and high estimates of legal harvest rates, leading to conservative management decisions.

Molting probability and survey selectivity of prerecruits (sublegal males) and recruitment to the model for a 3-stage catch–survey analysis are also highly confounded. Estimates of survey selectivity may be
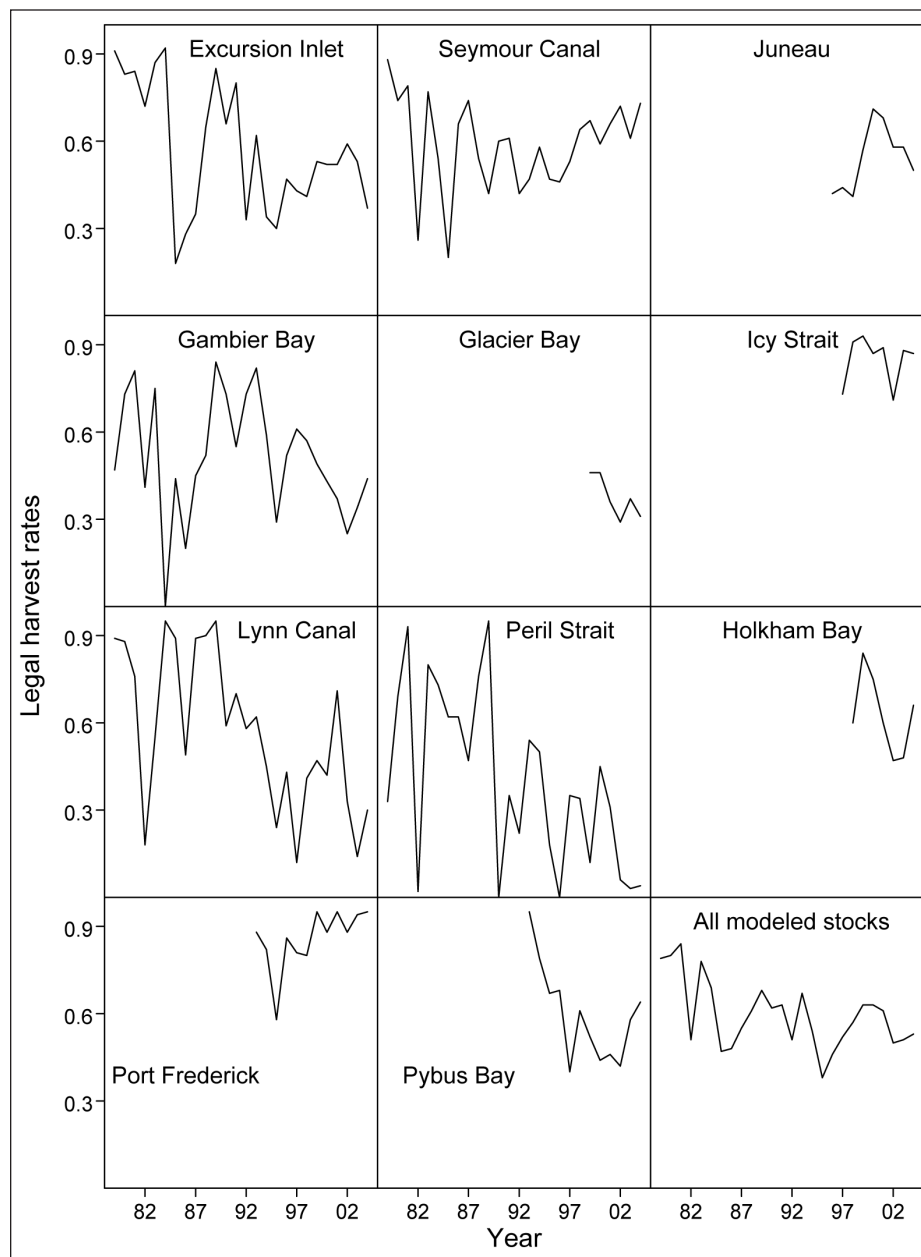

Figure 8. Estimated legal harvest rates at fishing time for 11 Tanner crab stocks in Southeast Alaska.

negatively correlated with estimates of recruitment and positively correlated with molting probability. The survey selectivity impacts only the absolute estimates of recruitment, not recruitment patterns or trends. Because some males in the prerecruit group may have reached terminal molt, estimates of molting probability may be a little too high for some stocks (e.g., Port Frederick, Juneau, Holkham Bay and Icy Strait). Interestingly, these 4 stocks all have a short time series of survey data. Future improvements in these parameter estimates may depend on our understanding of pot

selectivity for sublegal males. A mark and recapture experiment could help estimate pot selectivity independent of the assessment model.

Growth increment per molt is important information for a catch–survey analysis because it provides a basis for separating male crabs into different size categories and provides information to estimate the growth matrix. The growth increment-per-molt data in this study were collected from crabs in Fritz Cove, Southeast Alaska (Stone et al. 2003), and the growth rates are 2.3% to 6.2% greater than those observed for
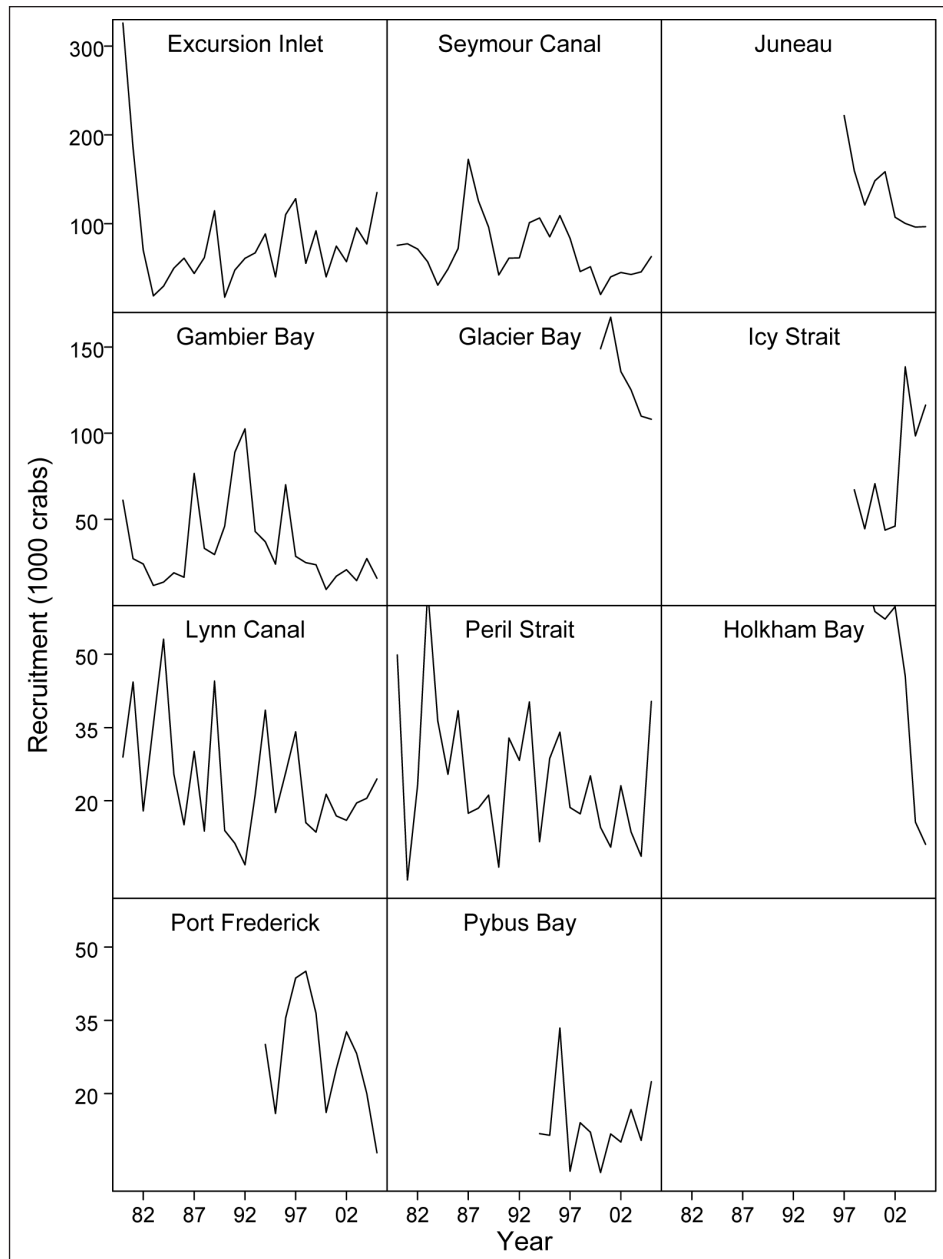

Figure 9. Time series of recruitment to the model for 11 Tanner crab stocks in Southeast Alaska.

Kodiak Tanner crabs during the 1970s (Donaldson et al. 1981). We assumed that the growth increments per molt are the same for all Tanner crab stocks in Southeast Alaska. That assumption remains to be tested. Based on pot survey data, Glacier Bay male Tanner crabs may have different growth rates or size-at-maturity schedules from the other stocks. Sublegal male CPUE relative to legal male CPUE from the pot survey was much higher for the Glacier Bay stock than for the other stocks, resulting in a very low estimate of molting probability for sublegal males (0.32). On the

other hand, the pot survey in Glacier Bay did not cover all areas where Tanner crabs occur; the difference of pot survey CPUE patterns between the Glacier Bay stock and other stocks may also have been caused by sampling problems. Growth and size-at-maturity data for male Tanner crabs should be collected from different stocks in Southeast Alaska for improving stock assessments.

Lack of bycatch data makes it impossible to accurately estimate bycatch mortality in the model. Because of high harvest rates, only a small proportion of legal males can reach the very very oldshell condition, so the
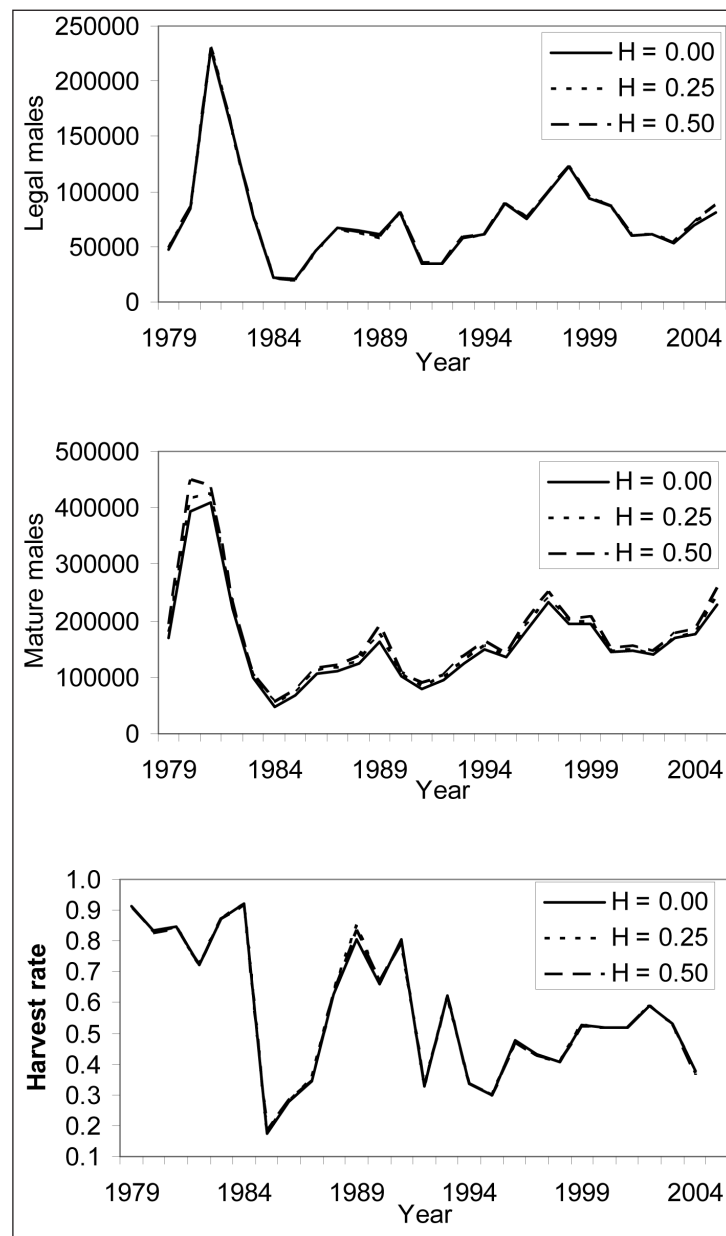

Figure 10. Comparison of estimated mature and legal male abundances and legal harvest rates for Excursion Inlet Tanner crabs with three levels of handling mortality rates (0, 0.25 and 0.5).

discard rates of legal males may be very low, and the assumption in the model that bycatch mortality occurs only in sublegal males appears to be reasonable. In our 3-stage catch–survey analysis, bycatch mortality primarily affects recruitment estimates and has little impact on estimates of legal male abundance and legal harvest rates. When bycatch data are available, the selectivity of sublegal males in the pot fishery can be estimated and used in the model.

It is unexpected that there is no consistent pattern of recruitment to the model for all 11 Tanner crab stocks considering that they all occur within a small geographical area. Koslow (1984) proposed that positive correlations in recruitment within a species over large geographic areas are indicative of large-scale physical forcing on recruitment. Unlike the recruitment correlations among red king crab stocks and between two blue king crab *Paralithodes platypus* stocks in the northern Gulf of Alaska and eastern Bering Sea that suggest a significant role of large-scale physical forcing (Zheng and Kruse 2000), it appears that environmental forcing on Tanner crab recruitment
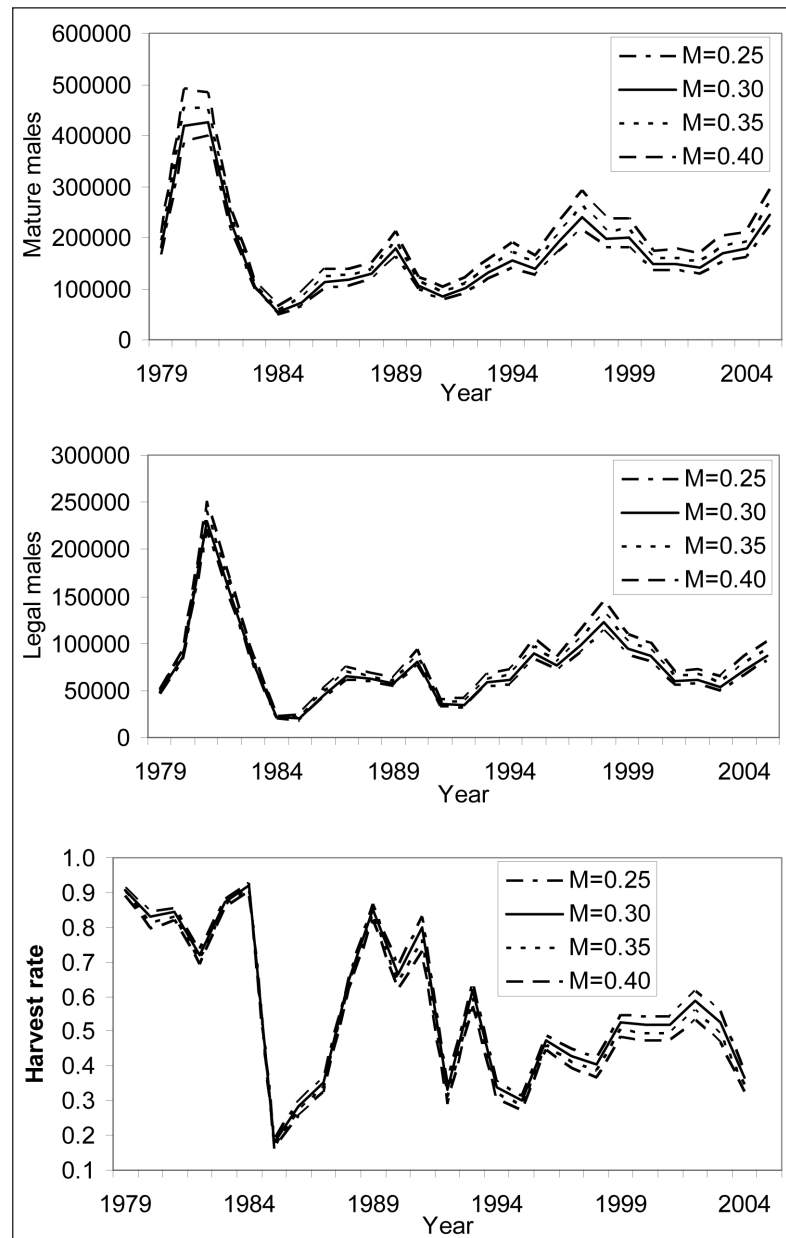

Figure 11. Comparison of estimated mature and legal male abundances and legal harvest rates for Excursion Inlet Tanner crabs with four levels of natural mortality (0.25, 0.30, 0.35 and 0.4)

in Southeast Alaska was highly localized. The local environmental forcing in inside waters of Southeast Alaska may be different from those in the open waters of the Bering Sea and Gulf of Alaska, where Tanner crab recruitment has been very poor during the last 12 years (Zheng and Kruse 2000). On a regionwide basis, Tanner crab recruitment in Southeast Alaska has also tended to be much less variable over time than in the Bering Sea and the northern Gulf of Alaska (Zheng and Kruse 2000).

It is somewhat unexpected that the trends of survey CPUE for some stocks differed between mature males and females. Several factors may be responsible for these differences. First, the survey pots do not catch females as well as males, and the CPUE for females may not be as reliable as those for males. Second, males were subject to high directed and bycatch fishing mortality whereas the bycatch mortality for females was assumed to be low. Finally, the survey strata boundaries were established to target mature males, the spatial distribution of which may differ from females and may differ at the survey times, so the surveys over time may not completely cover the spatial distributions of both sexes.

Estimated harvest rates are an important result derived from the assessment model but may be influenced by errors in shell condition classification. Shell condition for legal males is needed to separate crabs into recruit and postrecruit groups. Tagging data for red king crabs in Bristol Bay showed that some portion of oldshell males were misclassified as newshell. Such a classification error would overestimate the proportion of recruit group and underestimate postrecruit group, which could lead to overestimating harvest rates in a model. The reverse would be true if newshell male crabs were misclassified as oldshells on the survey. Currently we are not able to quantify shell condition classification errors for Tanner crab survey data in Southeast Alaska. For Bering Sea Tanner and snow *Chionoecetes opilio* crabs, softshell (shell conditions 0+ and 1) males were radiometrically aged to be from 0.05 to 0.25 year post molt with a mean of 0.15 year (n=6), old-looking newshell (shell condition 2+) males were aged to be from 0.33 to 1.07 years post molt with a mean of 0.69 year (n=6), oldshell males (shell condition 3) were estimated to be 0.92 to 1.10 years post molt with a mean of 1.02 years (n=3),

and very oldshell and very very oldshell males (shell conditions 4 and 5) were estimated to be 2.70 to 6.85 years post molt with a mean of 4.95 years (n=6; Ernst et al. 2005). If these results are applicable to Tanner crab survey data in Southeast Alaska, shell condition classification errors may not have important effects on harvest rate estimates in the model. Furthermore, harvest rates based on a depletion analysis for all Southeast Tanner crab stocks tended to be higher than those by a catch–survey analysis and the harvest rates estimated in this study (John Clark, Alaska Department of Fish and Game, personal communications). The high variation of estimated harvest rates was caused by the relatively constant guideline harvest level each year.

High harvest rates have been a concern with Tanner crab fishery managers in Southeast Alaska in recent years (Bishop and Stratman 2006). Although harvest rates have apparently been lower during the recent 10 years than the previous period, overall harvest rates are still estimated to be very high, especially for some stocks. The harvest rates estimated for several Southeast Alaska stocks are much higher than estimated harvest rates for Tanner crabs in the eastern Bering Sea and off Kodak Island (Zheng et al. 1998, Urban and Vining 1999). Because of depressed stock conditions, the current harvest strategies for the Bering Sea and Kodiak Tanner crab stocks tend to be more conservative than before and limit legal harvest rates below the historical mean values (Zheng and Kruse 1999, Urban et al. 1999). High harvest rates deplete old, large-sized crabs and make the fishery heavily reliant upon recruitment. Since 1979 a large majority of the commercial Tanner crab catch in Southeast Alaska has come from recruitment to the legal biomass (Clark et al. 2001). If the recruitment fails for even a short period, the stocks can collapse. Without absolute estimates of mature female abundance and stock-recruitment relationships, it is difficult to conduct a computer simulation study to evaluate optimal harvest strategies. Future study should focus on stock identification, reproductive conditions of females, pot survey catchabilities of mature males and females, and stock-recruitment relationships of Southeast Alaska Tanner crabs to develop optimal harvest strategies that can prevent overfishing and produce optimal, sustained yields.

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