Special Publication No. 06-12

Southeastern Alaska Red King Crab Stock Assessment Review

by

Terrance J. Quinn II

Thomas C. Shirley

and

Timothy M. Koeneman

May 2006

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

SPECIAL PUBLICATION NO. 06-12

SOUTHEASTERN ALASKA RED KING CRAB STOCK ASSESSMENT REVIEW

by

Terrance J. Quinn II,
Juneau Center, School of Fisheries and Ocean Sciences, Juneau

Thomas C. Shirley,
Juneau Center, School of Fisheries and Ocean Sciences, Juneau

and

Timothy M. Koeneman
Alaska Department of Fish and Game (retired), Petersburg

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

May 2006

The Division of Sport Fish Special Publications series was established in 1991 for the publication of techniques and procedures manuals, informational pamphlets, special subject reports to decision-making bodies, symposia and workshop proceedings, application software documentation, in-house lectures, and other documents that do not fit in another publication series of the Division of Sport Fish. Since 2004, the Division of Commercial Fisheries has also used the same Special Publication series. Special Publications are intended for fishery and other technical professionals. Special Publications are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm. This publication has undergone editorial and peer review.

Terrance J. Quinn II
Juneau Center, School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
11120 Glacier Highway
Juneau, AK 99801-8677 USA

Thomas C. Shirley
Formerly with Juneau Center, School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
11120 Glacier Highway
Juneau, AK 99801-8677 USA

Now with Harte Research Institute
Texas A&M University-Corpus Christi
6300 Ocean Drive, Unit 5869
Corpus Christi, TX 78412-5869
(361) 825-2030

and
Timothy M. Koeneman
Alaska Department of Fish and Game (retired)

This document should be cited as:
Quinn II, T. J., T. C. Shirley, and T. M. Koeneman. 2006. Southeastern Alaska red king stock assessment review. Alaska Department of Fish and Game, Special Publication No. 06-12, Anchorage.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

In cooperation with the Southeast Alaska King and Tanner Crab Task Force (hereafter referred to as the Task Force), the Alaska Department of Fish and Game (ADF&G) assembled an expert panel to review the Southeast Alaska red king crab stock assessment program. Panelists are Professor Terrance Quinn (chair), Mr. Timothy Koeneman, and Professor Thomas Shirley.

ADF&G distributed survey documents and related materials to the panel in early June 2005. Panelists and ADF&G personnel participated in the red king crab survey June 6–8 aboard the R/V Medeia in Holkham Bay, in order to become familiar with the survey. Panelists met in Juneau on June 27 for a presentation by staff and input from the Task Force and user groups. The panel subsequently met on June 28-29 for deliberation and drafting a response to questions. Various additions to the report were made through the end of 2005.

The Task Force and ADF&G staff developed six issues and questions for consideration related to: (1) survey pot locations, (2) survey pot gear, (3) survey timing, (4) survey bait, (5) stock assessment methodology, and (6) biological threshold and harvest rates. It became clear at the presentation meeting that observations of commercial harvesters do not match the trends from the stock assessment; harvesters believe that there are more crabs than the ADF&G assessment indicates. Therefore, it is of interest to determine whether the stock assessment methodology is providing useful scientific advice.

The panel reviewed written material and presentations given by ADF&G staff and industry. The panel requested additional information from shellfish biometrician Dr. John E. Clark. The panel used a Checklist for Stock Assessments (NRC 1998) as one basis to evaluate the stock assessment approach. The panel also considered norms derived from the North Pacific Fishery Management Council and Alaska Board of Fisheries, fisheries management around the world, and scientific publications and practice.

The panel believes that the overall architecture of the survey and stock assessment of red king and Tanner crabs in Southeast Alaska is sound: there is standard data collection, survey information, modeling, and harvest management. Nevertheless, the panel shares industry concerns over various aspects of the survey and stock assessment and recommends that improvements be made in all areas. In particular, ADF&G needs to establish better communication mechanisms to convey the rationale, justification, and results that lead to its management of this important resource.

Key Words: Red king crab, stock assessment, Southeast Alaska, crab pot, crab bait, catch-survey analysis, harvest rate

ANSWERS TO THE SIX ISSUES AND QUESTIONS ADDRESSED BY THE TASK FORCE

1. **Pot location.** *Does this issue affect the reliability of the abundance estimates produced by the Alaska Department of Fish and Game (ADF&G) stock assessment program? If so, what corrective measures are appropriate?* This is probably the most important issue. The panel determined that the random stratified survey methodology is appropriate for determining a relative index of abundance. Major improvements in survey methodology have been recently made by restratification of the survey area based on prior abundance and depth. The goal of the survey is to establish a consistent and comparable index of abundance from year to year, rather than to maximize catch of legal crabs. Further improvements related to pot locations should be considered.

2. **Pot type.** *Does this issue affect the reliability of the abundance estimates produced by the ADF&G stock assessment program? If so, what corrective measures are appropriate?* The type of pot gear used in the survey since its inception has changed from square pots to cone pots. ADF&G has conducted many comparative studies between these two gear types, suggesting that there is no significant difference in catch rate for typical survey soak times. However, due to sample size limitations in these comparisons, further study is needed to

confirm this result. Additionally, intermediate soak times between 12 and 24 hours should be investigated, as well as how the relationship between catch rate and soak time is affected by the abundance of crabs or the structure of the crab population.

3. **Survey timing.** *Would changing the survey timing to a period after September 1, but before the November 1 fishery opening date for areas with both species improve the abundance estimates produced by the ADF&G stock assessment program?* Historically the survey has been conducted at different times of the year from summer to fall, and in some years, it was conducted in both. However, there does not appear to be any advantage in changing to a fall survey, in that fall survey results are not better correlated with fishery performance. The panel believes that the survey should continue to be conducted in the summer.

4. **Bait.** *Should ADF&G modify its baiting procedures, or would this impact the reliability of the stock assessment abundance estimates?* The panel does not believe that ADF&G should modify its baiting procedures. The goal is not to maximize catch but to maintain constant catchability of the survey over time. Any change in baiting procedure would require a calibration study.

5. **Analytical method.** *Is the catch survey method applied appropriately and is it the best method among the alternatives? One of the concerns of the Task Force is that the personal use catch is seriously under-reported, whereas the catch-survey analysis (CSA) method assumes no error in fishery catch data.* The CSA method is appropriate for the king and Tanner crab stock assessments. But there is need for additional work to validate the stock assessment methodology, as well as to determine statistical uncertainty in the stock assessment. Also, underreporting of the personal use catch could have dramatic impact on stock assessment results. The panel recommends a comprehensive data collection system for personal use crab harvests in Southeast Alaska.

6. **Biological threshold and harvest rates.** *Unlike the federal crab fishery management plans, there is no biological threshold comparable to a minimum stock size threshold or minimum female biomass, although there is an economic threshold of 200,000 lb harvestable surplus for Southeast Alaska as a whole. Harvest rates are capped for mature males and for legal males. Do you have any recommendations on these issues (biological thresholds and harvest rates)?* The panel did not evaluate the economic threshold but suggests that ADF&G management needs to justify and explain this threshold. A biological threshold could be developed for each bay, but this would require additional data collection and modeling to establish reproductive potential as the basis. A formal management strategy evaluation needs to be conducted in order to validate the conservatism of the current harvest rate policy establishing guideline harvest level (GHL). In addition, ADF&G needs to develop more objective criteria when they decide to make adjustments to the harvest rate based on other biological performance measures.

OTHER RECOMMENDATIONS

1. ADF&G needs to publish a modern stock assessment document ("cookbook") explaining the details of data collection, survey approach, data analysis, modeling, and harvest advice. Also, this would be an excellent place to present the history of ADF&G research and management and evolution of the fishery.

2. ADF&G should institute a public process for presenting stock assessment results. Such a process could lead to improvements in the stock assessment as well as increasing confidence in the management process.
3. ADF&G needs to initiate efforts to improve the survey and validate assumptions necessary to use survey catch rate as a relative measure of abundance. Our review below contains several suggestions for field studies and analysis of existing data.
4. Stock assessment currently relies on historical parameters (e.g., growth, natural mortality, recommended harvest rate) derived from studies in Kodiak and the westward region. Efforts are needed to develop these parameters from information collected in Southeastern Alaska.
5. Assessment research should develop an additional focus on reproductive potential through the study of females and juvenile males. The sustainability of the red king crab fisheries requires the understanding and preservation of sufficient reproductive potential.
6. Oceanographic data needs to be collected during the survey to help identify factors affecting catch rates and distribution. Furthermore, time series of this information may be critical in identifying causal effects on recruitment and survival due to climate change.
7. ADF&G will eventually need to evolve its modeling to a fully length-based assessment approach. This new approach will be necessary to achieve the goal of monitoring reproductive potential of each red king crab stock, because it will necessarily require better information on both the female and sublegal male components of the population.
8. ADF&G should validate whether its management of Southeastern Alaska red kind crab stocks is sufficiently conservative. One avenue would be to conduct a management strategy evaluation to show that harvest rates and other management actions ensure the long-term sustainability of the population.
9. ADF&G should establish a system to provide reliable and robust estimates of personal use harvests from all important red king crab areas. This system should include estimates of catch per unit effort (CPUE) and dockside sampling to ensure the basic premises of management (legal males only and bag limits) are satisfied.
10. The panel was impressed with the quantity and quality of work conducted by the ADF&G staff. In order to make further improvements, ADF&G will need to allocate additional scientific expertise, support, and resources.

PANEL REVIEW

INTRODUCTION

In cooperation with the Southeast Alaska King and Tanner Crab Task Force (hereafter referred to as the Task Force), the Alaska Department of Fish and Game (ADF&G) assembled an expert panel to review the Southeastern Alaska (SEAK) red king crab (RKC) stock assessment program. Panelists are Professor Terrance Quinn (chair), Mr. Timothy Koeneman, and Professor Thomas Shirley.

ADF&G distributed survey documents and related materials to the panel in early June 2005. Panelists and ADF&G personnel participated in the red king crab survey June 6–8 aboard the R/V Medeia in Holkham Bay, in order to become familiar with the survey. Panelists met in Juneau on June 27 for a presentation by staff and input from the Task Force and user groups. The panel subsequently met on June 28-29 for deliberation and drafting a response to questions. Various additions to the report were made through the end of 2005.

The Task Force and ADF&G staff developed six issues and questions for consideration related to: (1) survey pot locations, (2) survey pot gear, (3) survey timing, (4) survey bait, (5) stock assessment methodology, and (6) biological threshold and harvest rates. It became clear at the presentation meeting that observations of commercial harvesters do not match the trends from the stock assessment; harvesters believe that there are more crabs than the ADF&G assessment indicates. Therefore, it is of interest to determine whether the stock assessment methodology is providing useful scientific advice.

The panel reviewed written material and presentations given by ADF&G staff and industry. The panel requested additional information from shellfish biometrician Dr. John E. Clark. The panel used a Checklist for Stock Assessments (NRC 1998) as one basis to evaluate the stock assessment approach. The panel also considered norms derived from the North Pacific Fishery Management Council and Alaska Board of Fisheries, fisheries management around the world, and scientific publications and practice.

ISSUES (THE SIX QUESTIONS)

Specific issues identified by the Task Force and ADF&G are listed below. The order of the issues does not indicate priority, except that issue 1 is the highest priority.

1. **Pot locations.** The Task Force maintains that only a small proportion of the survey pots are set on good crab grounds, resulting in a high number of pots with zero catch. Good grounds are limited, and highly localized in some areas. Random pot locations might work if confined to the appropriate areas. Also, it is important to make sure that pots land where intended: tides and current can cause a pot to drift significantly when being set. Future surveys would benefit from having an experienced crab fishermen present when pots are set.

   Question: Does this issue affect the reliability of the abundance estimates produced by the ADF&G stock assessment program? If so, what corrective measures are appropriate?

2. **Pot Gear.** The switch from square (7’ by 7’) pots to stacking cone pots was made, but a correction factor is not used to make the old square pot catch rate data commensurate to the cone pot data.

   Question: Does this issue affect the reliability of the abundance estimates produced by the ADF&G stock assessment program? If so, what corrective measures are appropriate?

3. **Timing.** Survey timing is an issue, particularly where grounds are shared at times by king and Tanner crabs. The industry expects that summer surveys in mixed grounds will give inaccurate results. The industry proposed survey timing would be after September 1 when the species are more segregated but before the red king crab fishery in November. It was mentioned that surveys could be conducted in some areas in the summer where Tanner and RKC do not mix. The Juneau area was identified as one such area.

   Question: Would changing the survey timing to a period after September 1 but before the November 1 fishery opening date for areas with both species improve the abundance estimates produced by the ADF&G stock assessment program?

4. **Bait.** The industry believes that ADF&G uses too little bait to effectively catch crab, particularly for relatively short soaks of 18 hours. For each pot, ADF&G uses a standard of two canisters each containing approximately 2 pounds of chopped herring.

   Question: Should ADF&G modify its baiting procedures, or would this impact the reliability of the stock assessment abundance estimates?

5. **Analytical method.** ADF&G uses a modified catch-survey analysis (CSA) to estimate abundance.

   Question: Is the catch survey method applied appropriately and is it the best method among the alternatives? One of the concerns of the Task Force is that the personal use catch is seriously under-reported, whereas the CSA method assumes no error in fishery catch data.

6. **Biological threshold and harvest rates.** Unlike the federal crab fishery management plans, there is no biological threshold comparable to a minimum stock size threshold or minimum female biomass, although there is an economic threshold of 200,000 lb harvestable surplus for Southeast Alaska as a whole. Harvest rates are capped for mature males and for legal males.

   Question: Do you have any recommendations on these issues (biological thresholds and harvest rates)?

SOUNDNESS OF THE STOCK ASSESSMENT

The main issue of this review is to determine whether or not the SEAK RKC stock assessment program is basically sound. The panel used the Checklist for Stock Assessments (Appendix D, p. 137, and included as an attachment Appendix C to this review) in the report “Improving Fish Stock Assessments” by the National Academy of Sciences (NRC 1998) to address this issue. Following the checklist, we examined the stock assessment program in regard to stock definition, data (including removals, whether the index of abundance from the crab survey is reliable, and age, size, and sex structure), assessment modeling, and policy evaluation.

Stock definition

For SEAK RKC, ADF&G treats each major bay as a stock unit for management. Consequently, separate surveys and assessments are conducted by bay. The review panel notes that there are clear differences in morphology and growth of crabs by bays, supporting this separation. Furthermore, having GHLs by individual bay lessens the possibility of overfishing, compared to having a single GHL for Southeast Alaska. However, there is need for additional genetic study using new genetic techniques to confirm that each bay has a separate stock. Existing genetic data were gathered with isozyme techniques, whereas newer mitochondrial DNA/RNA techniques might reveal more pronounced differences in stock separation.

Data

A reliable stock assessment should have accurate (unbiased) and precise (low variability) information from a variety of sources.

Removals: First, estimates of removals from all fisheries must be available. For SEAK RKC, the commercial catch has been well determined through fish tickets and port interviews. Discards have been studied many times in the past, and results from those studies suggest that bycatch of females and small males is not a major problem when crabs are handled appropriately, timely, and returned to the sea. The personal use or recreational harvest around Juneau is well determined through permits and subsequent reporting but no other area has a similar program. Thus, monitoring the personal use catch in areas outside of Juneau needs major improvement.

Indices of abundance

A reliable stock assessment should have at least one accurate and precise index of abundance. For SEAK RKC, the survey provides this source of information. As described below, the design of the survey (stratified random sampling) is completely appropriate for determining an index of legal and mature male abundance. Auxiliary survey effort may be needed to better understand sub-legal and female abundance changes. Also additional gear studies should be conducted to ascertain whether the survey has been suitably standardized (see below). For example, does the presence of Tanner crab affect the catchability of the survey?

Age, sex, and size

The ability to routinely age king crab and many other invertebrates is limited, so that size is the major source of information about distribution. The SEAK RKC survey routinely samples the size and sex of king crab. Surprisingly, the size information is not used in assessment modeling, for which a growth submodel from Kodiak is used. There is a strong need to develop growth models for SEAK RKC, because the growth rates from Kodiak may not apply to SEAK. This problem needs immediate attention.

Tagging data

Various studies have been conducted, in which RKC have been tagged and recaptured. Tagging and recapture data assists in the development of growth models, provides supporting information for stock definition determinations, and can provide estimates of fishing mortality for the commercial and personal use fisheries. These studies should be analyzed summarized, and published. There is little published information about movement of SEAK RKC. What information that has been examined suggests that interchange of legal male RKC among bays is very limited, growth of some SEAK stocks is similar to Kodiak Island stocks, and initial estimates of fishing mortality have been significant. ADF&G should develop movement models from existing data and determine whether additional movement studies are needed. ADF&G should estimate SEAK RKC growth parameters and determine if additional growth studies should be undertaken. ADF&G should review the available fishing mortality information relative to the available population estimation data as assess the usefulness of this tool in future fisheries.

Environmental data

While environmental data are not used in the stock assessment model, key processes of recruitment and mortality cannot be understood in the absence of environmental information. Good environmental conditions can result in good recruitment and growth. ADF&G could take advantage of the opportunity to collect oceanographic data during its survey operations to assess life history events that may be occurring. The abundance and distribution of crabs may be correlated with hydrographic variables such as water temperature or salinity. Collecting this data is relatively inexpensive during the survey and could provide the basis for a long term data set that might be invaluable to a variety of different biotic surveys. Temperature has a profound affect on survival and growth of female RKC and on the developmental rates of RKC embryos, the timing of hatching (Shirley et al. 1990) and survival of RKC zoeae in the plankton (Shirley and Shirley 1989, 1990).

Fishery information

Fundamental understanding of the actions and perceptions of the fishing industry can be obtained by examining the catch per unit of effort (CPUE) of the commercial fleet. Harvesters view the condition of the resource through this information, which is influenced by the condition of the stock as well as technological and logistic changes in the fleet. We recommend that analysis of logbook data should be undertaken to understand changes in fleet catchability and perhaps even be used in the stock assessment model. This interchange of information between harvesters and ADF&G could improve communications. The basis of the CSA model is the fishery catch data as reported on ADF&G fish tickets. If fishery catch data are erroneously reported on fish tickets, it could have a very significant effect on the model. Fish ticket data should be verified using vessel overflights at various times during the fishery, on-the-ground vessel surveys, and on-board sampling opportunities. Similar tools can be used to verify the value of personal use fishery reporting data. This is especially needed given the wide range of personal use harvest estimates obtained from the three reported methods (Statewide Harvest Survey, Dockside Creel Census, and Personal Use Permits) for the most significant personal use fishery in Section 11-A. There are no reliable personal use harvest data from other important fishing districts in Frederick Sound and Peril Strait.

Assessment model

There are a variety of stock assessment models, including surplus production, dynamic pool, age-structured, and size-structured (NRC 1998). Contemporary models contain population dynamics equations, statistical development of data sources, and an objective function for parameter estimation. For SEAK RKC, a catch-survey analysis model contains these three components, using removal and survey index information primarily. Size information is used to separate male abundance into different life stages. Complete use of the size information in a full size- and age-structured model has not been attempted to date. Information from females and small males is not used in the model. The model is spatially explicit by bay, although movement (thought to be minor) is not considered.

The key parameters in the model are annual prerecruit abundances, natural mortality (M=0.32), a conversion parameter from prerecruit abundance to recruit abundance, and survey catchability. Natural mortality M is considered constant and known, having been obtained from the Kodiak RKC assessment. The other parameters are estimated internally. Our review panel recommends that a research priority is to examine existing information to determine a better value of M for SEAK.

The statistical formulation of the model is a standard least squares approach with weighting of individual data sources. The weighting scheme is somewhat subjective and the rationale could be improved. ADF&G should determine the standard errors (SEs) for the data sources and investigate inverse variance weighting as a more objective scheme.

Major improvements are needed in addressing uncertainty in parameter estimation and the sensitivity of assessment results to choices made in the stock assessment. In particular, SEs should be provided for all assessment outputs (such as recruitment, abundance, biomass, and GHL) through bootstrapping or other means. The sensitivity of the stock assessment to natural mortality M and possible underestimation of personal use catch should be investigated.

Retrospective evaluation of the stock assessment model is needed. A retrospective evaluation could include a simple comparison of common parameter estimates in the current assessment to those from past assessments. A second approach is to repeat the current assessment procedure on reduced data sets, in which the most recent years are removed one year at a time, and examine the stability of the assessment results. The panel notes that this retrospective evaluation should receive a lower priority than other activities (such as evaluating restratification of the survey and model sensitivity evaluation).

POLICY EVALUATION

Alternative hypotheses

Given the important issues of survey and model improvements, there has been little time for ADF&G staff to consider alternative hypotheses and mechanisms affecting RKC. The staff would like to do this in the future.

Alternative actions

The current GHL procedure is to set a constant harvest rate of 20% of mature males or 35% of legal males. These values apparently were derived for Kodiak RKC by Pengilly and Schmidt (1995) and the Crab Plan Team of the North Pacific Fishery Management Council, based on limited information. An investigation specific to SEAK RKC needs to be conducted, so that there is a better rationale for the choice of harvest rate.

ADF&G staff is concerned that the upper limit on harvest rate of 20% mature males may be too high. To definitively answer this question, one would need a formal Management Strategy Evaluation (as described below) that evaluates reproductive potential. The basic principle of 3S (sex, size, season) management is that restricting harvest to legal males above mature male size (allowing older males to breed) is conservative. This principle obviously requires that effects on immature males and females are unimportant. The time lag from egg production to the onset of maturity and entry into the fishery is an important component in determining the effectiveness of current actions. Therefore, there is no clear answer to this question at this time.

The most innovative way to evaluate management strategies is to conduct a formal management strategy evaluation (MSE) using extensive computer simulations (Butterworth et al. 1997; Cooke 1999; Smith et al. 1999; Goodman et al. 2002). Management strategy evaluation assesses the performance of a range of management strategies and evaluates the tradeoffs across a range of management objectives. The performance of each strategy is determined in a simulated “real” world. Data are generated in this “real world” and then used in the assessment model. Assessment output is used with the management strategy to produce harvest and population outcomes. The best strategy is one that produces desired outcomes across the range of potential “real” world events.

Adjustments

ADF&G makes adjustments to harvest rate *a posteriori* based on staff concerns about stock status. A traffic light matrix (green, yellow, red) of stock status indicators is put together and the staff makes adjustments when they see too many red lights. The connection of these indicators to future stock status has not been made in a rigorous way. Therefore the adjustments are subjective and need better justification. The staff should evaluate quantitatively how these indicators might affect future recruitment and abundance of RKC.

Biological threshold

Declines in at least mature and legal males have occurred for SEAK RKC during two time periods; 1982 through 1989 was a gradual decline, and 2001 through 2004 was a relatively rapid decline. Additionally, significant and relatively rapid increases in mature and legal male biomass occurred between 1989 and 1991 (Bishop 2005). But the reasons for the declines or increases in mature and legal abundance have not been identified. Is there a biological threshold for crabs that should not be crossed? Cause(s) of crab declines may be environmental, due to fishing, related to biological or epizootic or ecological (other species) events, or interactions of these mechanisms. Methods do exist for determining thresholds [say 20% of pristine biomass (Quinn and Deriso 1999)] but would require better understanding of egg production and subsequent recruitment. (spawner-recruit relationships). There is precedent for determining biomass-based adjustments to harvest rates and thresholds for crab stocks (e.g., Bering Sea red king and Tanner crabs).

Tier system

ADF&G and the Alaska Board of Fisheries (BOF) may wish to develop a system similar to groundfish and federal crab fisheries, in which harvest rate is specified according to tiers defined according to amount of information available. Tier 1 could be a full data set with size and sex and spawner-recruit determination. Tier 2 could be for standard assessment (survey CPUE, catch, and CSA). Tier 3 could be for areas with only survey information. Tier 4 could be for areas with only catch information. For example, could an estimate of abundance for Holkham Bay be determined from Tier 3 from the current survey CPUE divided by a proxy catchability from a related area?

Performance indicators

The BOF "POLICY ON KING AND TANNER CRAB RESOURCE MANAGEMENT GOAL AND BENEFITS" (90-4-fb, March 23, 1990), the "Red King Crab Management Plan in shellfish regulations (5 AAC 34.113), and the goal of the SEAK RKC stock assessment survey (John Clark, presentation to panel June 27, 2005) are basically nested. See Appendix A for extracts or outlines of these documents. All focus on the continued viability of healthy stocks and the need to manage conservatively if necessary. The SEAK RKC management plan is in accordance with the BOF Policy.

The management system in place, as mentioned earlier in this document, has developed from the basic management approaches used in other regions of the state. Since RKC in SEAK are in the southern extreme of the known range, the parameters used in other regions may not be appropriate. Harvesting 35% of the legals or 20% of mature males may not be sufficiently conservative to maintain viable fisheries on a long-term basis without experiencing possible recruitment overfishing. In a long-lived species like red king crab, with apparently intermittent recruitment, and population declines that may or may not be related to the commercial fishery, it is pertinent to ask if the current harvest rates are too high.

However, the BOF policy specifically refers to "reproductive potential" under the section on management goals and "maintain long-term reproductive viability" and "maintain adequate brood stock" under the section on policies. The SEAK RKC management plan speaks to "abundance of males and females" and "factors affecting stock reproductive viability". Obviously, sufficient numbers of mature males are necessary to mate with the available mature females, and sufficient numbers of mature females are paramount to some minimum level of egg production, and subsequent larval hatch. The SEAK RKC survey enumerates females, and makes qualitative determinations on clutch size, but does not identify a metric for "reproductive potential". The survey is primarily designed to gather the necessary metrics to support management decisions related to the GHL and the commercial fishing season. It gathers reproductive potential data by enumerating the number of females in the survey, and a qualitative measure of female egg production.

The SEAK RKC survey should more fully satisfy the BOF policy on reproductive potential. This could be accomplished by sub-sampling females for further laboratory evaluation with respect to egg viability, egg predators, and numbers of eggs by size of females, and by sampling females at different times throughout the egg production cycle. Resulting information could be used to determine a policy, subsequently reiterated in the management plan, based on protecting the stock "reproductive potential". Possible metrics are numerous and might vary through the spectrum of stock abundance. One possible metric on the upper end of the spectrum could be the maximum number of eggs just prior to hatching when all segments of the stock are healthy and fishing is occurring at relatively high harvest levels on mature or legal males. A metric in the mid-range of the spectrum could be the minimum number of viable eggs required to rebuild relatively low stocks while continuing to fish. At the lower end of the spectrum is some minimum number of viable eggs required to rebuild very distressed stocks where fishing should not be allowed by any user group.

Presentation of results and communication

ADF&G needs to establish better communication mechanisms to convey the rationale, justification, and results that lead to its management of this important resource. At present, the amount of information provided to the public is miniscule; there is not even an annual stock assessment document. The most recent pertinent document is the Regional Information Report (RIR) for the 2001/2002 fishing season by Clark et al. (2003). ADF&G needs to publish a stock assessment document ("cookbook") explaining the details of data collection, survey approach, data analysis, modeling, and harvest advice. Also, this would be an excellent venue to present the history of ADF&G research and management and evolution of the fishery.

Currently, ADF&G conveys information to the public through short press releases. ADF&G should institute a public process for presenting stock assessment results. Such a process could lead to improvements in the stock assessment as well as increasing confidence in the management process.

ADF&G needs to rethink the framework in which its stock assessment concerns are expressed. Currently, many concerns are handled in a subjective adjustment process. A move to risk assessment procedures by considering Bayesian models would be one way to make the process more objective. A better focus on reproductive potential and the effects of management strategies on the risks to that potential may clarify conservation concerns. There is a need to show the tradeoffs between economic and biological sustainability.

The State of Alaska should also reconsider its Release of Information statute (AS 16.05.815). For example, ADF&G keeps survey data on spatial locations confidential in the current year. What is the rationale for this? Is there a culture within ADF&G to withhold information from its user groups? Could this be contributing to the lack of confidence in the ADF&G assessment? Could ADF&G develop a method to release the survey data but mask the individual bay areas and still meet the statutory intent? A more open explanation of the assessment and management policy may allow user groups to better understand management rationale.

Conclusion

The review panel notes that the primary ingredients in a stock assessment from the Checklist are indeed found in the SEAK RKC assessment. Therefore, the basic program is sound and rationale in the areas of stock, data, modeling, and harvest policy. However, in each of those areas, there are improvements that should be made. In the next section, we provide additional recommendations as to how the SEAK RKC stock assessment program could be improved.

IMPROVEMENTS TO THE STOCK ASSESSMENT

The following enhancements and auxiliary efforts are needed to improve the stock assessment.

1. **Add a new assessment focus**: preserving reproductive output.

    a. **Fecundity.** The relationship between fecundity and size of RKC is known for Bristol Bay and Norton Sound (Otto et al. 1990) but fecundity of RKC in SEAK has not been reported. Although an excellent laboratory study on the relationship between female size and numbers of zoeae hatched was conducted, results of the experiment were never published (M. Carls, NMFS, Auke Bay Lab, personal communication). The relationship between female size and fecundity should be determined. The number of eggs lost to parasites, disease, and predators during the 11-month incubation should also be determined.

    b. **Egg fertilization success.** Female RKC will carry unfertilized eggs attached to abdominal setae for up to several months; determining whether an egg was fertilized and contains a developing embryo in the early stages of development is difficult or impossible in field observations. Unfortunately, surveys of RKC in both the Bering Sea and in SEAK occur shortly after eggs have been extruded, and the percentage of the eggs that have been fertilized remains unknown. All surveys measuring clutch fullness and fecundity have assumed that the eggs were fertilized. A pilot study is currently being conducted by Dr. Jie Zheng (ADF&G) to determine the feasibility of measuring fertilization success of clutches of RKC in SEAK.

    c. **Mating size relationships of male and female red king crab.** Female RKC mated by smaller males (<110 mm CL) in laboratory studies had a lower percentage of eggs that successfully developed, and the percentage decreased drastically with increasing number of mates (up to four mates). Larger males (> 120 mm CL) had a higher percentage of eggs that successfully developed but also had difficulty with their fourth mate (Paul and Paul 1990, 1997). The current management practice of harvesting the largest males while assuming that smaller males will successfully fertilize all mature females, may not be biologically sound. Perhaps some percentage of larger males should be protected from harvest. Powell, et al. (2002) documented the importance of large, old-shell males in the mating process by collecting 3,616 mating pairs from 22 different locations in the Kodiak Archipelago between January and May from 1960 through 1984. Most mating pairs were captured by SCUBA divers during the months of April and May, 63 and 32%, respectively. The mean size of males grasping females was 159 mm CL, and only 4% of males were smaller than 130 mm CL. Old and very old shell males predominated in both the legal and sublegal size classes. These data indicate that older and larger males are very important to successful reproduction, and suggest that regulations should protect a significant portion of the current legal male population from harvest. Regulations providing for harvesting eight-inch or larger crabs when recruitment is low may be very inappropriate given the BOF Policy addressing stock reproduction. Slot limits, in which harvest is permitted only for intermediate-sized males, are commonly used in lobster fisheries throughout the world to insure that larger females have sufficient numbers of large mates. Female fecundity increases geometrically with carapace size, and reproductive potential of the population is enhanced dramatically if larger females have adequate mates.

2. **Data improvements (PU catch).** The stock assessment method is very dependent upon accurate harvest data from all users. The personal use catch in Section 11-A is currently about 50% of the total regional commercial fishery threshold of 200,000 pounds. Data presented on the personal use harvest estimates are highly variable, and may contribute a significant source of unknown error in the stock assessment results (Bishop 2005). The statewide harvest survey data consistently underestimates the creel census program estimates. Further, the creel census program consistently underestimates the catch compared to the permit reporting program, by as much as 43% in some years (2001). It is likely that significant personal use harvests are occurring in areas where the only estimates available are from the statewide harvest survey data, and these estimates are probably gross underestimates. Data from Section 11-A shows that the reported catches from the statewide harvest survey are extremely small. The personal use harvests from other locations may be significantly contributing to stock declines throughout the region. ADF&G should establish a system to provide reliable and robust estimates of personal use harvests from all important red king crab areas. This system should include estimates of CPUE and dockside sampling to ensure the basic premises of management (legal males only and bag limits) are satisfied. A better understanding of the characteristics of the personal use fishery throughout the region – time of harvest, meat fullness, gear type, by-catch, and other factors could prove important in the future management decisions related to this fishery.

3. **Survey improvements.** While the basic design of the red king crab survey is sound, there are a number of improvements that should be made to increase the precision and utility of the survey. Our panel is confident that restratification of the survey area by subareas of high and low relative abundance in the last few years (John Clark personal communication) has greatly improved the precision of the survey and will do so in the future as well. The key assumption related to the survey is that it provides an index of relative abundance of male mature and legal crab over years. This means that the change in the survey over years is more important than the absolute number and that the catchability of the survey must be constant over years. Therefore, consistency in the survey design is mandatory for its use in stock assessment. Aspects of survey design that enhance this consistency are described in detail throughout the sections below.

   There are many factors affecting pot catch as a reliable measure of abundance. A flow chart from Olsen and Laevastu (1983) shows many of these factors affect catch rates from capture fisheries (Appendix B). The main point is that many factors affect catch rate of crabs, so that for an effective survey, these factors must be controlled or understood.

4. **Model improvements.** The catch-survey analysis (CSA) approach has been widely used around the world to perform stock assessments of hard-to-age invertebrate populations, such as crab. Its application to SEAK RKC is straightforward and appropriate. Nevertheless, there are substantial improvements that can be made to the assessment and presentation of results. These improvements are described in detail below. Furthermore, there should be an evolution from CSA to a more complex length-based assessment approach that utilizes more of the information on size and growth of RKC (see Issue 5 below).

5. **Communications.** Currently the Commercial Fisheries Division provides SEAK RKC assessment results through press releases just prior to, and sometimes during, the commercial fishing season and also with occasional documents and publications. This process does not provide the commercial fleet with the information they desire to fully understand survey results and ADF&G decisions. ADF&G should develop a public presentation program that reports survey results to all cities with a significant number of red king crab commercial permit holders, personal use participants, or interested public. The presenter should appropriately be the regional shellfish staff. Representation by the regional and state ADF&G leadership, and the Board of Fisheries, and local advisory committee leaders might help to maintain focus and understanding. As mentioned earlier in this review, survey results should be fully documented. The King and Tanner Task Force was established to improve communications between ADF&G and the commercial fleet. Where this process has resulted in some success, it appears that further improvements are needed. In order for the Task Force process to succeed, all parties must have a common goal – which should be the conservation of the red king crab resource for the present and future. There may be a charter document covering the Task Force process, goals, objectives, and meeting schedule. If so, this document was not available to the review panel. If such a charter has not been developed, it should be developed. The commercial fleet representatives should be responsible to ensure that all commercial users are represented equally and issues are well-developed and focused.

   Our panel recommends that the following components be included in the presentation process:

   a. Cookbook describing complete assessment process from data collections and surveys, data processing, assumptions and hypotheses, model development and execution, harvest strategy evaluation, and distribution of information to user groups. Examples of such cookbooks include the SAFE documents produced by the North Pacific Fishery Management Council, and Scientific Reports of the International Pacific Halibut Commission (e.g., No. 72 by Quinn et al. 1985).

   b. Annual stock assessment report (flowing from Cookbook) with summary statistics by bay and information at how management recommendations were developed (survey CPUE statistics, estimates of catchability, estimates of abundance, GHL calculations, adjustments for uncertainty and rationale).

   c. Public process to present stock assessment to user groups and public and entertain suggestions (say in early September).

   d. Scientific report on stratification algorithm: covariance structure, kriging details, rationale for choices, and statistical significance of results. This could be part of the cookbook, but the panel believes that this work is innovative enough, that it may be a suitable article for the Canadian Journal of Fisheries and Aquatic Sciences or another noteworthy journal.

FACTORS AFFECTING THE SURVEY

Many variables influence crab pot catchability and efficiency, including soak time, time of day of pot soaking, pot density and distribution, water temperature, changes in barometric pressure, molt cycle of the crabs, diurnal and lunar cycles, speed and duration of water movements, interspecific and intraspecific agonistic interactions, bait quantity, quality and placement of bait within the pot, mesh size, and pot design (Miller 1990). Although many of these variables remain unstudied for red king crab, a few have been investigated (Zhou and Shirley 1997a, 1997b, 1997c, 1997d). Pot type or pot design will be treated separately in Issue 2, Pot Gear, below.

1. **Soak duration and time of day of deployment.** In pot fisheries, catch per pot haul does not increase steadily with duration of fishing, or soak time (Miller and Rodger 1996; Zhou and Shirley 1997a). Bait quantity and quality usually decrease with increasing soak time, so that attraction of crabs to the pot decreases (Zhou and Shirley 1997b). The release rate of amino acids from bait decreases by an order of magnitude during a 24 hour period (Mackie et al. 1980). The retention rate of crabs in pots generally decreases with increasing soak time; even in pots with retention devices such as inward opening triggers, both legal and sublegal crabs escape over time (Zhou and Shirley 1997c). Also, as pots begin to fill, the attraction and retention efficiency of the pot changes as a result of crab behavior and mechanical characteristics of the pot. For many crab species, smaller crabs and females hesitate to enter a pot with more and larger male crabs (Miller 1989; Taggart et al. 2004). The SEAK RKC survey has a standardized soak time and deployment and retrieval schedule for pots, which reduces variability associated with timing and duration issues. The duration of the soak time used (approximately 18 hours) appears to be a suitable time to allow sufficient time for pot location by crabs, while precluding pot saturation.

2. **Pot density and distribution.** Pots have an effective fishing radius that changes with current, crab density and other variables (Miller 1989, 1990). If too many pots are used, the pots may compete with each other. If too few pots are used, pot saturation may occur (Castro and DeAlteris 1990). Pot saturation is the phenomenon in which a maximum number of crabs fills a pot so that a true CPUE or index of abundance is not attained. Pots placed outside of suitable habitat (e.g., in unsuitable substrate or bathymetric ranges) provide little information on abundance of a species other than to help define the habitat preferences of the species. The SEAK RKC survey deploys a set number of pots within a survey area, using a stratified, random protocol that distributes pots minimum distances apart, within strata determined from crab CPUE from prior years. The standardized deployment protocol and standardized number of pots effectively eliminates most concerns of pot density, pot distribution and pot saturation.

3. **Water temperature.** Crab activity and therefore pot catchability varies greatly with water temperature (Miller 1990). The SEAK RKC survey occurs at approximately the same time of year annually, which should eliminate most variability associated with water temperature. However, deployment of a thermal recorder (e.g. Tidbit) attached to a pot frame would provide water temperature data for each study area and might contribute

to understanding interannual variability. In our ongoing academic crab studies, we typically deploy a thermal recorder on selected pots within each study area. Alternately, a CTD (Conductivity, Temperature, Depth) cast could be deployed once at each study site to provide hydrographic measurements; however, CTD measurements are usually 5 m above the bottom. Having an instrument package in each survey area that would record temperature throughout the year would provide additional oceanographic data that might be applied to a variety of crab issues: average, minimum and maximum water temperatures for the year might help explain embryonic development, hatching times, and habitat suitability. These recording instruments are cheap and reliable.

4. **Barometric pressure.** Trap catch rates of golden king crab were negatively related to sharp changes in atmospheric pressure Nizyaev and Bukin (2002). These changes in catch rate were most likely related to changes in catchability related to changes in weather conditions (storms and frontal systems) and water movements. Measurement of barometric pressure during the SEAK RKC survey would be simple and might help explain catch variability.

5. **Effectiveness of pots varies with crab molt cycle**; crabs in a soft shell condition are less likely to enter pots (Miller 1990). The SEAK RKC survey occurs at approximately the same time of year annually, eliminating most variability that might be associated with crab molt cycle. However, little is known about interannual variability in red king crab molting times.

6. **Water movements, diurnal and lunar cycles.** Variation in tidal current speed affects the odor plume from bait jars and the effective fishing radius of a pot. Also, some crustaceans cease or decrease movements in high current speeds. (Howard and Nuny 1983). Tidal ranges and approximate tidal current velocities can be readily determined from tables if the sampling date is known. CPUE should be analyzed with respect to tidal variations, if it has not been.

7. **Intraspecific and interspecific interactions.** Many interactions occur within and between species that affect pot catchability. Some species such as amphipods (sand fleas) can devour bait rapidly, decreasing pot efficiency. Other crab species can compete for bait or space within the pot. Larger or more agonistic crabs can decrease CPUE for target crabs. Video studies have demonstrated that some crab species will defend a pot, keeping other crabs and a variety of species from entering the pot. All species collected within pots are recorded by the SEAK RKC survey, so these variables can be analyzed to explain catch variation.

8. **Bait quality, quantity and placement within the pot.** Red king crabs have different sensitivities and responses to different kinds of baits (Zhou and Shirley 1997b). The quantity and placement of bait within a pot affects the bait plume and effectiveness of the pot (Zhou and Shirley 1997c; Miller 1990). The SEAK RKC survey has standardized the kind, amount and placement of bait within pots, eliminating these possible sources of variation. We strongly recommend that the kinds and amounts of bait continue to be standardized. More or better bait might increase the CPUE, but this would impair the standardization that has allowed interannual comparisons.

9. **Pot design and mesh size.** Pot design and mesh size greatly affect pot catchability, crab retention, and overall CPUE (Zhou and Shirley 1997d; Miller 1990). Many changes to

pot design may affect catchability in unanticipated ways. For instance, increased numbers of larger red king crabs may be caught in pots with smaller mesh, because the crabs enter the pot with less effort expended trying to get through the mesh (Zhou and Shirley 1997d). The popular notion that larger mesh and escape rings or slots will allow smaller crabs to escape may be true, but it may not result in a higher catch rate of large crabs. The SEAK RKC survey uses a standardized pot design and mesh that allows for interannual comparisons. Although escape rings are sealed to retain smaller crabs, which may affect the survey catch in comparison to commercial catch rates, the standardization allows valid interannual comparisons, while providing valuable information on relative abundance of prerecruit crabs. The issue of pot design is treated in greater detail below.

Conclusion: The SEAK RKC pot survey is likely an effective measure of king crab abundance, as pot sampling has been demonstrated to be a reliable index of crab abundance for other crab species in southeastern Alaska (Taggart et al. 2004). Many of the variables which affect pot CPUE have been eliminated or decreased by the SEAK RKC pot survey standardization of sampling protocol and timing. Nevertheless, more variability might be explained by measurement and inclusion of hydrographic and meteorological variables and perhaps by analyzing CPUE as a function of bycatch and tidal phenomenon.

ADDRESSING THE FIRST FOUR ISSUES RELATED TO THE SURVEY

Issue 1: Pot locations

This is probably the most important issue before the panel. It would be helpful if ADF&G could describe the objectives of the survey formally. In most stock assessments, the main objective of a survey is to obtain an absolute or relative index of abundance for use in determining the status of the stock. For SEAK RKC, the main objective seems to be to develop a relative index of mature and legal male abundances. ADF&G also appears to have an objective related to determining the relative abundance of females and sublegal males. Finally, ADF&G appears to have an objective of determining the size distribution of these population components.

In order to validly obtain an index of abundance, a proper sampling design must be implemented using the science of Sampling Theory. One reference for the principles of Sampling Theory is Thompson’s book (Thompson 2002). The key aspect of Sampling Theory is to choose sampling units at random according to a design such as simple, stratified, systematic, cluster, or adaptive. Formulae applicable to each design allow estimates to be calculated, along with estimates of precision. The randomization that is done results in unbiased estimators. Unbiased means that if the sampling design were repeated over and over, the estimator would on average be equal to the true value. Thus, a random sampling design is crucial in achieving accuracy in the estimator.

In the case of SEAK RKC, the panel determined that the random stratified survey methodology is appropriate for determining a relative index of abundance. Proper randomization techniques are utilized, so that the survey is accurate. Major improvements in survey methodology have been recently made by restratification of the survey area based on prior abundance and depth. Therefore, the current survey appears to produce precise estimates of relative abundance, as well as being accurate. In summary, the goal of the RKC survey is to establish a consistent and comparable index of abundance from year to year, rather than to maximize catch of legal crabs. The sampling design used by ADF&G is totally consistent with the principles of Sampling Theory. Further improvements related to pot locations should be considered, and ADF&G

intends to continue doing this by further investigating spatial aspects of the previously collected information.

While the current design is acceptable, there are other sampling designs that may be useful for comparison and validation. First, a mark-recapture study (Thompson 2002) could be conducted in which crabs are tagged during the survey and later recaptured in the commercial fishery and future surveys. From the recapture of tagged crabs, an estimate of population abundance can be made. It would be interesting to see how this estimated compared with the abundances produced from Catch Survey Analysis.

Secondly, a technique called adaptive sampling (Thompson 2002) is useful for highly clustered populations. In adaptive sampling, additional sampling is conducted in areas of relatively high abundance according to formal rules. These rules then permit a valid estimator of relative abundance to be determined from the additional (nonrandom) sampling.

Issue 2: Pot gear

Estimates of abundance are difficult to derive from CPUE. However, CPUE from pot sampling has been demonstrated to be a reliable index of crab abundance in other crab species in southeastern Alaska (Taggart et al. 2004). Dungeness crab abundance was quantified by scuba divers in 15 to 20 randomly selected transects in each of six bays twice annually from 1992 to 1997, and annually from 1998 through 2000. The belt transects were 2 x 100 m and conducted perpendicular to the shoreline from the intertidal (0 m, mean lower low water) to a maximum of 18 m depth or until the end of the 100 m transect. Divers counted all Dungeness crabs located within 1 m of each side of the transect; an effort was made to locate buried crabs. Commercial pots were used to sample crabs in the same bays the day after dive transects were conducted, to avoid gear interactions; beginning in 1995, dive transects were conducted one week after pot sampling. Fifty pots were set in each bay in identical locations determined with GPS with an accuracy of ±3 m throughout the study. Pots were set in strings parallel to shore, with 25 pots set in 0-9 m depth and 25 pots set in 10-25 m depth. Every fifth pot had a shrimp pot attached, which have proved to be more effective for sampling smaller juveniles. Bait type and amount, set time and soak time was standardized. All organisms collected in pots were recorded, and standard measurements collected for crabs. Pots had much higher power in detecting population trends than direct counts of crabs by divers. Despite their lower power, the dive transects proved to be extremely useful in for detecting bias in the pot sampling for female and juvenile crabs.

Given that pots are effective for detecting population trends of crabs, which pot design (if any) is optimum? Do square (rectangular) pots have higher catchability for red king crab than conical pots, and might they be more effective in detecting population trends?

The type of pot gear used in the SEAK RKC survey changed from square pots to cone pots. ADF&G conducted several comparative studies between these two gear types. No publications of direct comparisons of differences in catch rates for red king crab could be found for the two pot types. Typical survey soak times are between 0.7 to 1.0 day, as illustrated with data from Peril Strait (Figure 1).

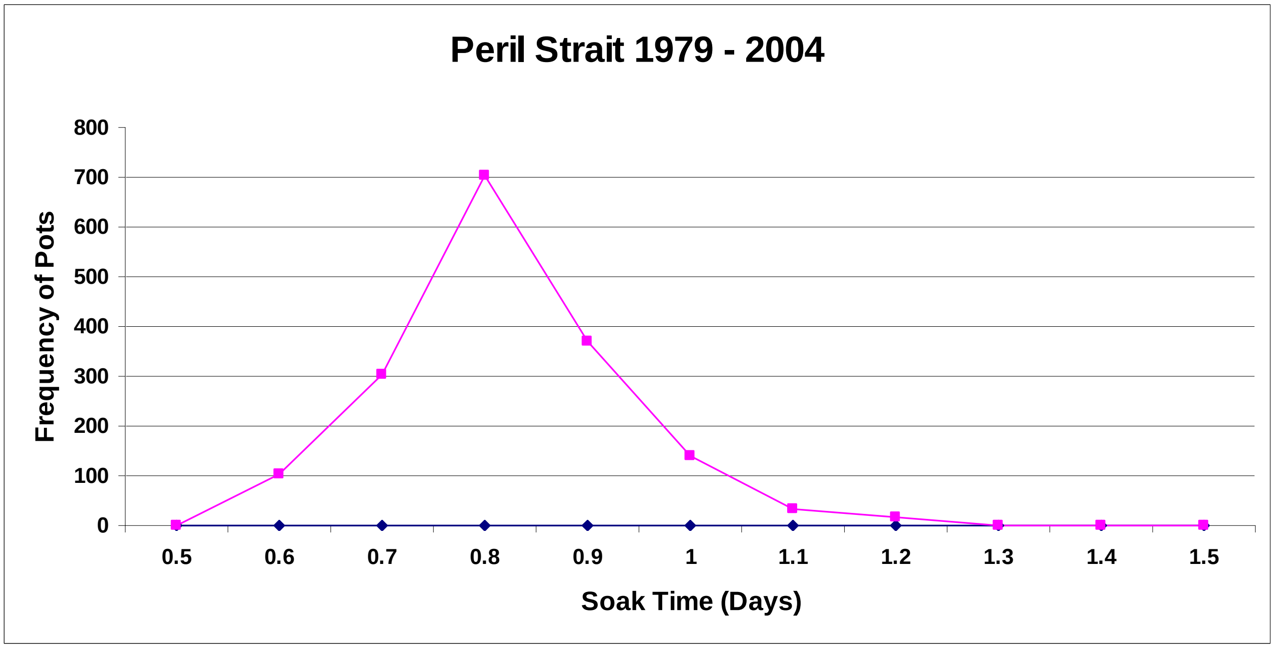


Figure 1.–Summary of survey soak time frequencies for the red king crab survey in Peril Strait, accumulated over years.

ADF&G staff summarized results from a study in Barlow Cove, with three treatments (12 hr, 24 hr, and 36 hr) and 10 pots per treatment. No significant difference in catch rate occurred for typical survey soak times of 12 and 24 hours, but cone CPUE was substantially lower for the 36 hour soak (Figure 2).

However, the small sample size in this study is problematic. We recommend that further soak time studies be conducted with intermediate soak times between 12 and 24 hours, as well as investigating how the relationship between catch rate and soak time is affected by the abundance of crabs or the structure of the crab population. The inclusion of hydrographic and meteorological measurements may help explain catch variability.

In a study of golden king crabs, comparison of 23 paired sets of pyramidal (conical) and rectangular (square) pots, with each set containing a minimum of 25 pots of each pot design, showed that the larger rectangular pots consistently had higher catch rates than conical pots, often by several multiples (Nizyaev and Bukin 2002). The difference in catch rates by the rectangular pots increased with decreasing crab size, i.e., more smaller crabs were caught by the larger pot. The higher catch rates and bias towards more smaller crabs is most likely a function of pot volume (Miller 1980). Larger pots are less likely to become saturated, and smaller crabs are more likely to enter pots containing lower densities of crabs. Another consideration is that the Russian comparison of pot designs (Nizyaev and Bukin 2002) used 3-4 day soak periods and standardized their results to a 24 hour period; smaller pots would more likely have become saturated over the longer soak periods.

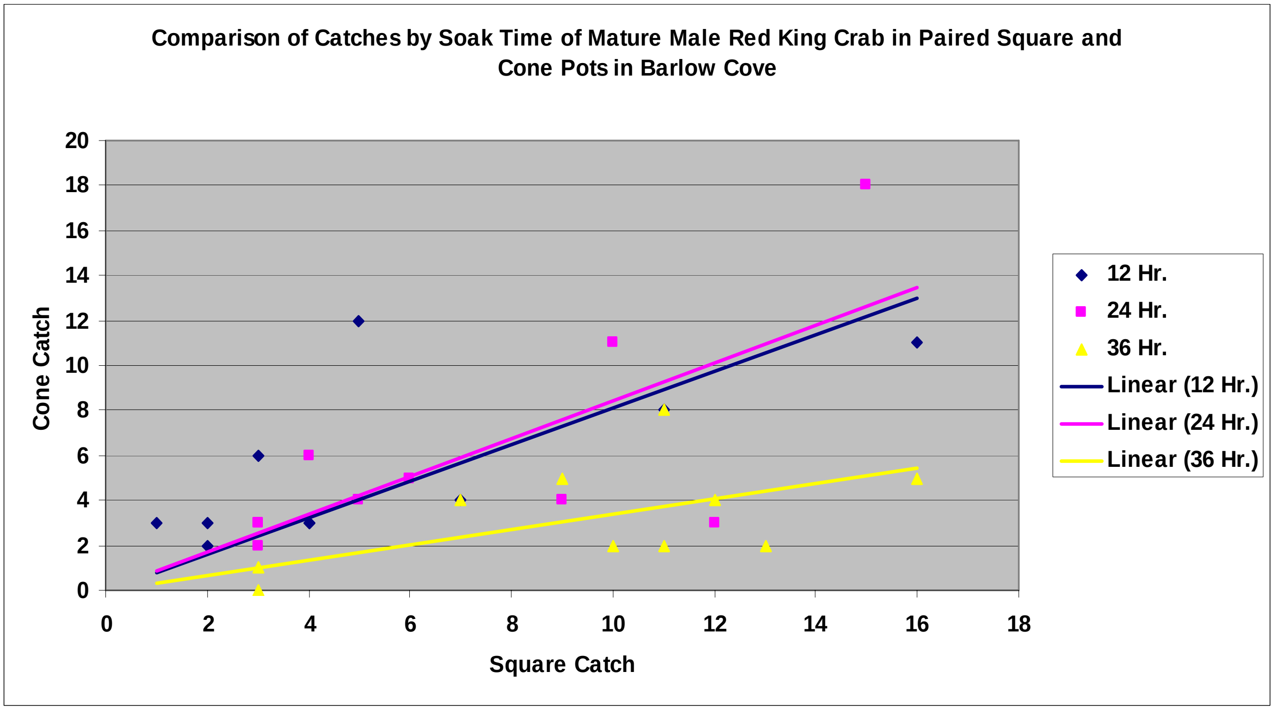


Figure 2.–Comparison of CPUE from paired cone and square pots in Barlow Cove.

However, higher catch rates are not directly related to higher statistical power. The rectangular pots inherently have higher catch variability for a number of reasons. Crabs almost always approach pots from down stream, following the bait odor trail. Conical, top-loading pots, have a consistent percentage of crabs entering the pot in laboratory studies conducted in large tanks. With side entry pots, the percentage of crabs that entered the pots varied greatly (an order of magnitude) depending upon whether the entrances were parallel to the current such that the bait odor trail led crabs directly into the pot, or were turned 90° to the current (Miller 1980, 1990). Conical pots appear to produce more consistent catches than rectangular pots.

Therefore, more analysis of data is needed (errors in variables analysis), and new field studies might be useful. Additional field studies with larger sample sizes might allow for more robust comparisons of the two pot designs, However, the inherent catch variability in rectangular pots (described previously) and pots in general may preclude determining a calibration factor between the CPUE of the two designs. Hydrographic and meteorological measurements should be recorded and included in analysis to determine if they might help explain catch variability.

The objective of estimating abundance (the survey objective) is different from maximizing catch per pot (the harvester's objective). Higher catch rates are not always related to higher power; a decrease in catch variation, or measurement of abiotic and biotic factors explaining the variability is the primary objective of the survey.

If a significant difference exists between the pot designs, then ADF&G should attempt to develop a calibration factor for early data. However, even if new field studies allow the determination of a calibration curve between the two pot types, the calibration factor may not be applicable to older survey data if other meaningful data (e.g., supporting hydrographic, meteorological, or biotic data) are not available.

If additional field tests are undertaken to calibrate different pot designs, independent methods of assessing crab abundance, not involving pots, should be considered. For example, photographic surveys of the areas might be conducted with an ROV (remotely operated vehicle) prior to or after pot deployment. In comparison to pot surveys, photographic surveys are relatively expensive and not efficient in areas of high current flow or low visibility; they are also subject to their own sampling biases. Alternately, mark and recapture studies might provide useful information of crab abundance.

Issue 3: Survey timing

The majority of survey timing information is summarized in an apparently unpublished draft provided to the review panel in their document binders on June 27, 2005 (Anonymous 2005) under Tab 5. The panel also had a Department News Release dated October 29, 2004 titled "Southeast Alaska Red King Crab Supplemental Survey Results" to review. Generally, the summer and fall surveys tend to show either no significant differences, or slightly better results during summer surveys. All available data should be more fully analyzed and documented. Nevertheless, analysis of existing data does suggest that survey timing is a second order issue.

There are eight years where comparative surveys during summer and fall have been accomplished, and nine different bays were surveyed (Anonymous 2005). Surveys of seven different bays (Barlow Cove, Pybus Bay, Gambier Bay, Seymour Canal, Excursion Inlet, Port Frederick, and Deadman Reach) occurred in 1987 and 1988, and of these bays only Barlow Cove was surveyed in both years. Only two different bay areas (Juneau and Holkham Bay) were compared between 1997 and 2002, and Holkham Bay was only surveyed in 2002. No comparative surveys occurred from 1989 through 1996. The major bay areas contributing to the overall harvest have not been surveyed in the fall since 1988. The 1987 and 1988 surveys were conducted during years of low abundances of mature and legal male crabs (Bishop 2005). The years 1990 through 2001 represent years of relatively high abundance, but comparative surveys were only conducted in the Juneau Area. Comparative surveys have not been conducted during periods of low and high abundances. It is possible that during periods of good survival and growth, the large number of juvenile males and females could saturate pots resulting in fewer mature or legal males, and underestimating the legal population. A survey design where the 10 major bay areas are surveyed in the summer and fall for a number of successive years, and/or during periods of low and high abundance, could result in a more robust analyses and conclusions.

As mentioned above, the red king crab survey is apparently designed to accomplish two basic objectives: (1) to assess the abundance of the mature and legal male red king crab population components, and (2) to assess the overall health of the red king crab population, including the juvenile males, females, and relative ovigerity of the mature females. These objectives are best accomplished when the stock has completed significant life history stages and the distribution is homogeneous. The survey should occur as soon as possible after the mature males have molted, mature females have molted, been mated, exoskeletons of all population segments have hardened so they can be safely handled, and eggs have been extruded.

To avoid confounding future survey data and results, each bay area should be surveyed during the same time and the set of tides each year. This would tend to reduce the effects of the survey time variable. During years of large abundance, it is possible that juvenile males and females overwhelm pots and underestimate mature or legal males.

Issue 4: Bait

The current baiting protocol is sufficient to control the bait variables and provide a reliable estimate of relative abundance. The bait issue is most likely a second order effect with respect to the more important issues of pot locations, survey timing, and type of gear.

The goal of the SEAK RKC survey is different from that of commercial fishers. It is not to maximize catch but to determine the relative abundance and population changes from year to year using a standard and reproducible method. The baiting protocol was developed by the Westward staff and used successfully during a number of years of both high and low abundance in the Westward Region. This method was adopted when SEAK RKC surveys began in 1978. Historic survey results provide contrasting data sufficient for management decisions throughout the range of experienced high and low populations.

The baiting protocol attempts to reduce bait quality variables by using a consistent bait source from the Ketchikan winter herring fishery. It also reduces the quantity variable by using a standard container and measurement. It is important to ensure the bait is in a "just thawed" condition when each pot is set. This ensures a maximum amount of blood, oil, and scent is available for the pot soak. Bait that has "bled out" when chopped too early, or during warm days is probably less effective than "just thawed" bait. This may mean that bait is chopped at variable times based on the setting rate and running time between pot sets. Also, it may be significant to observe the condition of the bait in the containers when a pot has been lifted and the bait containers are emptied. A bait container full of sand fleas might indicate the bait might not have persisted sufficiently long to attract crab throughout the length of the soak, so that the results of that particular pot set may not be reliable.

Crabs have different sensitivities to different baits; however, crabs respond to bait in ways not consistent with their sensitivity (Miller 1990; Zhou and Shirley 1997b). For example, red king crabs were more sensitive to tissues of conspecifics than to any other bait, but would not initially eat it. Instead, red king crab flesh appeared to act as warning and repellent rather than an attractant (Zhou and Shirley 1997b). It would be interesting to study the effect of hanging bait, the types of hanging bait (fresh cod, halibut heads, frozen salmon, or bagged salmon eggs) and the location of the hanging bait in the pot for both the fishery and the survey. If such a study produced a difference, then the current baiting protocol should only be changed after considerable study and evaluation. The most important consideration is consistency of bait type, amount and deployment over time to permit interannual comparisons of CPUE. Other factors affecting catch are found in Appendix B.

Other Issues Related To The Pot Survey

1. **Extensive research has already been conducted**; this research should be amalgamated and summarized. There are data that have not been added to the computer archive and should be. There are several datasets that have not been analyzed.

2. **Female/Juvenile directed studies** (one objective of the Board of Fisheries). The objectives of the SEAK RKC survey have been to sample adult and prerecruit crabs, primarily males, and little attention has been given to sampling smaller size classes and females. Neither conical pots nor square pots effectively sample juvenile or small female red king crabs. The

larger mesh sizes allow smaller crabs to enter and leave, and pot biases prevent an accurate assessment of their abundance. A commercial shrimp pot attached to a conical pot with a 20 m tether is effective for sampling juveniles of red king crab and Tanner crab. The smaller mouth openings preclude larger crabs from entering, and the smaller mesh of the shrimp pot retains the smaller crabs. Knowledge of the abundance and distribution of smaller size classes of crabs could increase the lead time for understanding recruitment success and its relationship to environmental variables. In Thomas Shirley's research on crabs, use of shrimp pots did not adversely affect the time or cost of conducting field surveys. The shrimp pots stack easily, take up little deck space, and do not require separate floats. Most of the survey expense is vessel time and fuel, and if additional data can be gathered without increasing the length of the survey, it should be attempted. If the additional work load impedes an efficient SEAK RKC survey, perhaps ADF&G should strive to undertake the research independent of the survey. The optimum distribution of juveniles and females probably occurs in different depths and habitats than for adult males, and separate studies might be more efficient. Light trap surveys for sampling glaucothoe should also be considered. These traps for settling larvae are relatively inexpensive and easily attached to crab pot lines. The timing of glaucothoe settlement (usually occurring in June and July) overlaps with the survey, and could add additional data on year class strength, recruitment and relationships to environmental variables.

3. **Viability of eggs related to female size.** The relationship between egg size and female size has not been investigated for red king crab. More importantly, the relationship between egg size and the size and viability of hatched larvae has not been examined. For many other taxa, female size is critical in determining larval survival. In the red snapper *Lutjanus campechanus*, female size was dramatically related to survival of offspring (Berkeley et al. 2004). A female of 61 cm SL produced the number of eggs of 212 females of 43 cm SL. Perhaps more importantly, the eggs were larger, providing the larvae with increased energetic stores and higher survival rates. Survival rates of larvae from large females were 3.5 times greater than survival of larvae from smaller females; ergo, a single large female would produce as many surviving larvae as 742 smaller females. Similar results were reported for *Sebastes melanops* and yelloweye rockfish *Sebastes ruberrinmus* and other *Sebastes* spp. (Berkeley et al. 2004; Palumbi 2004). Egg size has been directly correlated to larval survival for the estuarine crab *Chasmagnathus granulata* (Gimenez and Anger 2001) but in general, the phenomenon is not well studied in crabs. Research should be initiated on egg size, larval survival and maternal size.

4. **Movement** (both seasonal and annual). There needs to be a summary of existing knowledge and new analysis of existing data.

   Four ADF&G tag and recapture data sets are available that may provide significant information on movement of Southeast Alaska red king crab. These data could assist comparisons between Southeast Alaska and Kodiak stocks, and perhaps validate the use of current growth, natural mortality, fishing mortality, and migration assumptions in the model. These tagging projects were conducted using the same methodology developed in Kodiak. Legal red king crabs showed no significant movement between bay areas.

   A recent query of the Region 1 red king crab survey database showed that tagging or recovery data do not exist in the database. Further investigation indicated that the tag and recapture data were inadvertently omitted from the database during a software change, but that the original hardcopy data are available for re-entry into the database (Bishop personal communication). Re-entry and subsequent analysis of the tag and recapture data are needed before analysis can occur. A brief summary of each tag and recapture project follows:

a. Red king crabs were tagged between approximately 1970 and 1974, with tags recovered through 1976. Biologists, while aboard commercial fishing vessels, conducted tagging during commercial fishing seasons. Bay areas with significant numbers of tags include Gambier Bay, Pybus Bay, Seymour Canal, and central Frederick Sound fishing grounds around Brothers Island and Cape Fanshaw. Tags were recovered by commercial vessels during commercial fishing seasons and turned into biologists when the catch was delivered. These data were recorded in three-ring binders, which were filed in the library at the Petersburg Area Office. These data do not include tag or recapture locations by LORAN bearings, GPS or DGPS readings and movement data will be gross. Data suggest no significant movement of legal and pre-recruit crabs between bay areas.

b. Legal red king crabs were tagged from 1979 through at least 1986 in all major bay areas of Southeast Alaska, with tag returns occurring from 1979 through about 1989. Tag returns occurred during commercial fisheries and subsequent red king crab surveys. This database did not show movement of legal crabs from one bay area to another bay area, but needs more formal analysis.

c. Approximately two years of tag and recapture occurred in the Juneau Area, with funding provided by Division of Sport Fish. Recaptures occurred during subsequent red king crab surveys, commercial fisheries and personal use fisheries. No initial summaries of movement have been attempted on this database.

d. A concentrated tag and recapture study conducted in Barlow Cove in association with a submersible study described below. Crab of both sexes and all sizes were tagged and recaptured during the study. Tags were recovered during multiple recapture opportunities during the survey, and during subsequent years of the survey. Tag recovery data also resulted from commercial and personal-use fisheries. Preliminary information showed onshore and offshore movement restricted to Barlow Cove. Additionally, the submersible portion of the program estimated the tag to untagged ratio of both males and females along prescribed transects along the bottom.

Additional tagging and tracking studies of red king crab in southeastern Alaska have occurred outside of ADF&G and should be examined.

a. Seasonal movements and distribution of 10 primiparous and 10 multiparous red king crabs were monitored weekly for a year in the Auke Bay, Alaska area by means of attached ultrasonic transmitters (Stone 1991; Stone et al. 1992, 1993). Primiparous females had a greater annual range (mean of 11.9 km^2) than multiparous females (3.6 km^2). Gradual movements to deep water occurred in spring following mating and egg extrusion, with residence in the deeper waters until early November. Abrupt, synchronous movements to shallow waters occurred in November, with residence there until late February or early March. Gradual movement to intermediate depths followed by movements to shallow waters to molt and mate occurred between late March and late May.

b. Male and female red king crabs fitted with digital, ultrasonic transmitters were tracked seasonally in Glacier Bay National Park and Preserve from 2002 to 2004 (S. J. Taggart, USGS, personal communication). Although the data have not yet been fully analyzed or published, king crabs had extensive seasonal movements within Glacier Bay, but generally moved as a group and did not leave Glacier Bay.

c. Thirty adult and juvenile male and female red king crabs from single location were fitted with digital, ultrasonic transmitters in October, 2005 and are being tracked at approximately monthly intervals in Glacier Bay National Park. Changes in spatial dispersion patterns of the crabs relative to each other over the course of a short time period will be measured in spring 2006 (T. C. Shirley, Unpublished data).

5. **Age/growth studies**. The current assessment model relies on growth studies from Kodiak. This needs to change. Existing SEAK mark-recapture data are available, as described in the above section on Movement, and can be used to develop parameters for southeast Alaska. The datasets include carapace length and width and shell condition. Some tags were at large for up to 60 months and resulting data can be used for annual growth and molting probability. Results should be formally compared with Kodiak growth. New field studies directed toward age and growth should be planned.

   Several laboratory studies of red king crab growth have been conducted in southeastern Alaska. Feeding rates, weight gain and molt increments were examined as a function of molt cycle for 145 males, ovigerous females and non-ovigerous females for a four month period; sizes of crabs ranged from 88 to 125 mm CL (Zhou et al. 1998). Another laboratory study measured changes in growth increment after molting for five groups of multiparous females after incubation for a year at temperatures of 0, 3, 6, 9 and 12°C; maximum growth occurred at 3°C, with minimal growth at the coldest and warmest temperatures (Shirley et al. 1990).

   Probably the most comprehensive studies of growth rates of juvenile red king crabs have been generated from laboratory investigations in southeastern Alaska. Growth rates (wet weight, dry weight and molt increments) of juvenile red king crab beginning in their second or third instar were measured for three months (Molyneaux 1988; Molyneaux and Shirley 1988). An extensive study of growth rates and molt increments of juvenile red king crab two to three years of age, fed a variety of diets, and measured for four to five months through two to three molts was conducted at the Auke Bay Labs of NMFS (Gharrett et al. 1985; Gharrett 1986). Habitat, cohort density and diet had pronounced effects on cannibalism, survival and growth of one and two year old juvenile red king crabs in a laboratory study conducted for more than four months (Rounds et al. 1990; Brodersen et al. 1990). A concurrent study on diet and growth of one and two year old juvenile king crab measured feeding rates, growth rates (wet and dry weights and molt increments), and proximate composition of different organ-systems for juveniles reared on 8 different diets (T. C. Shirley Unpublished).

6. **Submersible work.** A number of manned submersible studies with red king crab have been conducted in southeastern Alaska.

   a. Bathymetric distribution of red king crab and Tanner crab was examined by counts conducted along line transects on 41 dives with the Delta submersible in Barlow Cove, southeastern Alaska, from June 18-22, 1991 (Zhou and Shirley 1997e, 1998). Red king crab abundance was reported as a function of depth and habitat; abundance approximated a bell-shaped curve, with maximum abundance at 75 m depth on sand and mud substrates. An intensive tagging project by ADF&G was conducted synoptically with the submersible study. Crabs were tagged in proportion to their abundance within different sampling strata. Counts of tagged and untagged red king crabs were made to estimate total crab population abundance and to compare to transect abundance estimates (Unpublished data, T. C. Shirley). The abundance estimates should be completed for comparison to CPUE results from the SEAK RKC survey conducted in Barlow Cove.

b. Dispersion patterns of red king crab were studied in Auke Bay, southeastern Alaska in June, 1990 with the Delta submersible. Thirty-six red king crab were tagged and fitted with ultrasonic transmitters to permit location of crabs using a hydrophone positioned on the submersible. Observers within the submersible attempted an adaptive sampling scheme to observe the number, sex, size and dispersion patterns of crabs associated with the ultrasonically tagged crabs. The adaptive sampling technique was not efficient because of decreased visibility resulting from increased turbidity in the vicinity of the tagged crabs (Unpublished data, T. C. Shirley).

c. A manned submersible (DSV Delta) was used to track 26 ultrasonically tagged golden king crabs at six different sites in Frederick Sound, southeastern Alaska, from May 12-19, 2000 (Hoyt 2003; Hoyt et al. 2002). Although the research focused on habitats and movements of golden king crab, red king crab were observed and counted on some of the shallower transects. Information on distribution of red king crabs has not been published.

d. A manned submersible (DSV Delta) was used to measure the abundance and bathymetric distribution of crabs encountered along 61 transects conducted in 8 bays along Icy Strait, Chatham and Lynn Canal (Scheding 2004). The focus of the research was Dungeness crabs, but depth distribution and habitat of all crabs were recorded along approximately 30 km of transects.

7. **Sample size**: Are enough pots being used to estimate a reliable abundance index? A retrospective study should be conducted for all SEAK areas, examining coefficients of variation. If findings from the retrospective study warrant, a field study could be conducted to test different sample sizes.

8. **Barlow Cove study**: A comprehensive field experiment involving several research vessels and multiple, complementary techniques was conducted in Barlow Cove, southeastern Alaska, June 18-22, 1991 to examine population abundance and relationships between CPUE and abundance (Zhou and Shirley 1997e; 1998). Square king crab pots were set in a random stratified design, with pot densities varying according to strata determined from historical SEAK RKC Survey results. All crabs collected were measured, tagged with isthmus spaghetti tags and released; approximately 1800 crabs were tagged. The numbers of tagged crabs recovered in pots each successive day of sampling and tagging was recorded. A synoptic study using the manned submersible Delta conducted 41 line transects across Barlow Cove, with transects apportioned among the strata in a manner similar to the pot apportionment. Total numbers of tagged and untagged crabs observed in transects were recorded. Distributions of red king crab and Tanner crab with depth and habitat have been published, but the more critical information on crab abundance, relationships between different population estimation techniques, possible correlation between CPUE and

abundance and pot and visual transect biases have not been published. The tagged king crabs continued to be recaptured during subsequent SEAK RKC surveys, commercial and personal use fisheries for more than a decade. This valuable data contains information on growth, migration, movement, and population estimations and should be analyzed. Comparison of population estimations derived from the tagged/untagged ratio from pot surveys to the submersible transect methods (which could also estimate abundance from tagged/untagged ratios) might be invaluable in evaluating relationships between CPUE and population abundance, and revealing biases of the different estimation methods. All pot data remain available from SEAK RKC survey, and all submersible data and the videos made during the transects remain intact. A somewhat similar but more temporally and spatially extensive study conducted for Dungeness crabs using scuba transects and crab pots validated that CPUE from pot sampling was a reliable index of crab abundance (Taggart et al. 2004). Although the two techniques had a number of biases, crab pots had a much higher statistical power in detecting trends of abundance of Dungeness crabs in comparison to scuba transects.

9. **Standard errors** need to be calculated for historical relative indices of abundance (catch per pot) for all areas. These standard errors are easily obtained from Sampling Theory (Thompson 2002) and are crucial to understand whether the survey is precise. As a general rule, estimates of catch per unit of effort should always be reported with standard errors. At the request of the panel, John Clark calculated standard errors for the Peril Straits area (Deadman Reach and Rodman Bay) for the years 1979s–2004 (Figure 3). The average relative error (standard error divided by CPUE) was 38% across years. This exercise should be repeated for all areas and all years. Furthermore, an analytical study should be conducted to determine how the magnitude of relative error translates into estimation error in catch-survey analysis.

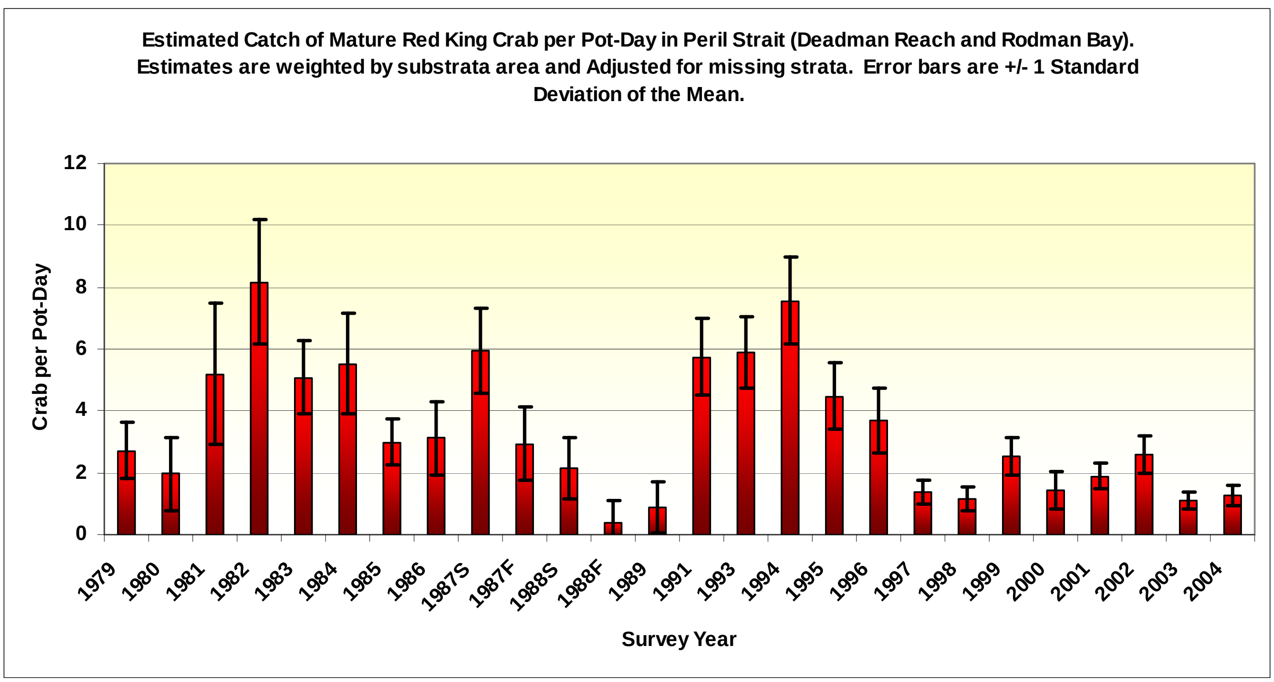


Figure 3.–CPUE and standard error of mature male red king crab across years for Peril Strait.

10. **Uncertainty**: No scientific study can control for all factors. The best one can do is to reduce errors due to factors other than changes in abundance. The methodology in catch-survey analysis can explicitly handle uncertainty. But if the survey is too inaccurate (biased) or too imprecise (too variable if it were repeated), then the stock assessment will not be informative.

11. **Stratifications**: The panel considered the following questions related to survey stratification. Is the current 75% male /25% all other allocation of survey effort toward males/other appropriate? How often should restratification be done? (revisit every 5 years?) Should restratification be reconsidered, if there is an objective to provide more precise information on females and sublegal males?

    The red king crab survey is apparently designed to assess the strength of the mature and legal male red king crab population and to assess the overall health of the juvenile males, females, and relative ovigerity of the mature females. Both assessments need to be accomplished with a specified degree of confidence. Survey restratification based primarily on mature or legal male red king crab segments may not meet the needs for other segments of the population. However, restratification has not yet been fully implemented and it may be too early to answer the question. Survey data should be fully analyzed with both goals in mind. If the estimates of and confidence intervals around the "reproductive potential" of the females are imprecise, it may be necessary to conduct one survey to assess the strength of the mature and legal male red king crab, and another to satisfy the reproductive potential goal.

    How often restratification should occur can be viewed in two ways. First, restratification could occur every year. Then the survey design would accommodate changes in abundance and distribution. This would be a systematic way of restratifying, similar to adaptive sampling techniques. Another alternative would be to only restratify when necessary to improve the metrics of the survey, or when data shows stock distribution is changing.

    It might be necessary to survey females at different times of the year, such as just prior to egg-hatch. Surveying mature females just prior to egg-hatch would provide a "bottom line" estimate of "reproductive potential" after egg parasites, egg absorption, female natural mortality, etc. have occurred. The downside of this later assessment is that the management decisions would have already been made.

12. **Continue to monitor fleet distribution in relation to survey abundance** (to assure that the bulk of the vulnerable population is assessed). Because the CSA model is based on harvests by bays, districts, or subdistricts, it is extremely imperative that fleet distribution, fishing effort, and catches are fully understood for each fishing season. If harvests are not represented by fish ticket data, then available data could be a contributing factor to errors in the CSA and management decisions based on CSA results. It is appropriate to validate catch areas on fish tickets with aerial surveys, vessel surveys, on-board surveys, and skipper interviews. Additionally, understanding fleet dynamics within season and between seasons will provide insight to update survey design and could help pinpoint areas of high legal abundance important to the fleet and future surveys.

13. **Logbook analysis** (after 1993). The panel considered the following questions related to the utility of logbook data to supplement the current stock assessment. How does CPUE from the commercial fleet compare with survey CPUE? What is a reasonable effort measure? Does there need to be a reality check between assessment and fishery, in that how can CPUE go up but the quota go down?

The panel recommends that a measure of effort based on potlifts be examined. At the current time only the number of permits is reported, but this is not a good measure of total effort. The staff should perform a finer scale spatial analysis of the distribution of the stock and of the fleet. Are the distributions consistent both within and between areas?

John Clark gave the panel a table and two figures that compare summer and fall surveys for legals and other portions of the population. The figures have a yellow area, summer survey data is red stipple on white background, fall is blue. The table is labeled "*Catch per pot day from logbook data in the red king crab commercial fishery in the first 5 days of the fishery, and catch per pot from pot locations selected by fishermen.*" Since each vessel is currently restricted to a relatively small number of pots, it should be possible to obtain DGPS data on each pot location from the logbook data. This data may help redraw strata for future surveys. It is possible that additionally detailed logbook data would result in an improved survey.

14. **Comparison of Dockside Data and Survey Data**: Harvesters express the argument that the survey does not assess the same population that is commercially fished. This argument has reduced the fleet's confidence in the survey and in some management decisions based on the survey. Resolving this argument might improve communications between the fleet and ADF&G. It may be possible to answer this argument by reviewing tag return data mentioned earlier and to compare survey size and shell condition data to dockside size and shell condition data. The comparison is somewhat limited, because the comparison is restricted to male crabs of legal size or larger. However, preliminary comparisons during past seasons shows that the size and shell condition of male crab 145 mm CL or larger from the survey in one year compared to those in the subsequent commercial season are very similar. These data suggest that the legal portion of the crab population surveyed is comparable to the legal portion landed by the fleet. It may also be possible to look at the data in detail by bay area.

THE LAST TWO ISSUES (5 AND 6) RELATED TO DATA ANALYSIS AND HARVEST STRATEGY

Issue 5: Modeling with Catch Survey Analysis (CSA)

In the section Soundness of the Stock Assessment – Assessment Model above, we described the technical aspects of the CSA approach and made recommendations for refinements to that approach. In this section, we propose that ADF&G evolve its modeling to a fully length-based assessment approach (Quinn and Deriso 1999, chapter 9). This new approach will be necessary to achieve the goal of monitoring reproductive potential of each RKC population, because it will necessarily require better information on both the female and sublegal male components of the population.

In a fully length-based approach, the actual sizes of individual crab are used more effectively than in the CSA approach, for which categories are constructed only for legal and mature male crabs. The length-based model would contain size categories, permitting the inclusion of data from females and sublegal males. Such a model would require precise information on growth, mortality, and recruitment. Such models have been constructed for a wide variety of invertebrates, such as Bering Sea red king crab.

With such a model, reproductive potential is a natural output, allowing for a proper management strategy evaluation to be conducted. The length-based model would also produce estimates of abundance on a finer scale of resolution (size), so that better understanding of the evolving size composition of the population will be obtained.

Issue 6: Harvest Strategy

In the section Soundness of the Stock Assessment – Policy Evaluation above, we described how ADF&G makes recommendations for guideline harvest levels and other management actions. We made several recommendations in that section for improvements. In this section, we provide additional comments related to harvest strategy.

ADF&G requires that an economic threshold of 200,000 lbs. for an area-wide GHL be available before a fishery is allowed to occur. It would be helpful to have a written justification for this economic threshold (How was it determined? How long has it been in effect?) Have alternatives been considered such as area registration, individual quotas, and regulated harvest by individual areas? Current fishing power may not allow management by areas, because GHLs could be exceeded too easily.

Apparently there is a vessel buy-back program in place, but it has not been used. Will the vessel buy-back program ever be used?

Further information is needed about the harvest rate policy. Are the baseline harvest rates within the norms of conservative fishery management used around the world? In order for ADF&G to validate whether its management of SEAK RKC is conservative, three major activities need to be completed: (1) population parameters for growth, natural mortality, and movement need to be constructed from SEAK data, not borrowed from Kodiak, (2) reproductive potential needs to be estimated and analyzed, perhaps necessitating a length-based assessment model, (3) management strategy evaluation needs to be conducted to show that harvest rates and other management actions ensure the long-term sustainability of the population.

REFERENCES CITED

Anonymous. 2005. Untitled document on Summer versus Fall red king and Tanner crab surveys. Under Tab 5. 22 pages.

Berkeley, S., C. Chapman and S. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258–1264.

Bishop, G. 2005. Southeast Alaska commercial red king crab fishery: A presentation to the RKC survey review committee, June 27, 2005, Juneau.

Brodersen, C. C., P. M. Rounds and M. M. Babcock. 1990. Diet influences cannibalism in laboratory-held juvenile red king crabs (*Paralithodes camtschatica*). Proceedings of the International King and Tanner Crab Symposium. Lowell Wakefield Symposia Series 90-04:377–382.

Butterworth, D. S., K. L. Cochrane, and J. A. A. Oliveira. 1997. Management procedures: a better way to manage fisheries? The South African experience. Pages 83-90 [*in*]: E. K. Pikitch, D. P. Huppert, and M. P. Sissenwine, eds. Global trends: fisheries management. American Fisheries Society Symposium 20.

Castro, K. M. and J. T. DeAlteris. 1990. Effects of trap saturation and species interaction of the capture of *Callinectes spp*. crabs in the Guayas Estuary. Fisheries Research 8:223–232.

Clark, John E., T. Koenemen, C. A. Botelho, S. Merkouris and D. Woodby. 2003. Estimation of red king crab (*Paralithodes camtschaticus*) Abundance and available harvest in Southeast Alaska for the 2001/2002 Season using a pot survey, Alaska Department of Fish and Game Regional Information Report 1J03-25.

Cooke, J. G. 1999. Improvement of fishery management advice through simulation testing of harvest algorithms. ICES Journal of Marine Science 56:797–810.

REFERENCES CITED (Continued)

Gharrett, J. A. 1986. Effects of a hydrocarbon-contaminated diet on survival, feeding, growth, and molting of juvenile red king crab, *Paralithodes camtschatica* (Tilesius). M.S. Thesis, University of Alaska Juneau.

Gharrett, J. A., S. D. Rice and M. S. Stekoll. 1985. Influence of an oil-contaminated diet on feeding rates, growth, and molting success of juvenile red king crabs, *Paralithodes camtschatica*. Proceedings of the International King Crab Symposium. Lowell Wakefield Symposia Series 5:371–375.

Gimenez, L. and K. Anger. 2001. Relationships among salinity, egg size, embryonic development, and larval biomass in the estuarine crab *Chasmagnathus granulata* Dana, 1851. Journal of Experimental Marine Biology and Ecology 260(2):241–257.

Goodman, D., M. Mangel, G. Parkes, T. Quinn, V. Restrepo, T. Smith, and K. Stokes. 2002. Scientific review of the harvest strategy currently used in the BSAI and GOA groundfish fishery management plans. North Pacific Fishery Management Council, Anchorage. http://www.fakr.noaa.gov/npfmc/misc_pub/f40review1102.pdf

Howard, A. E. and R. S. Nuny. 1983. Effects of near-bed current speeds on the distribution and behaviour of the lobster, *Homarus gammarus* (L.). Journal of Experimental Marine Biology and Ecology 71:27–42.

Hoyt, Z. N., T. C.Shirley, J. Warrenchuk, C. E. O'Clair and R. P. Stone. 2002. Movements and habitat utilization of golden king crab in southeastern Alaska. Pages 595–608 [*in*]: Paul, A. J., E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby, eds. Crabs in cold water regions: biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Hoyt, Z. N. 2003. Movement and habitat utilization by golden king crab *Lithodes aequispinus* Benedict 1895 in southeastern Alaska. M.S. Thesis, University of Alaska Fairbanks.

Mackie, A. M., P. T. Grant, R. G. J. Shelton, B. T. Hepper and P. R. Walne. 1980. The relative efficiencies of natural and artificial baits for the lobster, *Homarus gammarus*: laboratory and field trials. Journal of Conservation and International Exploration Mer 39:123–129.

Miller, R. J. 1980. Design criteria for crab traps. Journal of Conservation and International Exploration Mer 39:140–147.

Miler, R. J. 1989. Catchability of American lobsters and *Cancer* crabs by traps. Canadian Journal of Fisheries and Aquatic Sciences 46:1652–1657.

Miller, R. J. 1990. Effectiveness of crab and lobster traps. Canadian Journal of Fisheries and Aquatic Sciences 47:1228–1251.

Miller, R. J. and R. S. Rodger. 1996. Soak times and fishing strategy for American lobster. Fisheries Research 26:199–205.

Molyneaux, D. B. 1988. Molting and growth of eyestalk-ablated juvenile red king crabs (*Paralithodes camtschatica*). M. S. Thesis, University of Alaska Fairbanks. 55 pp.

Molyneaux, D. B. and T. C. Shirley. 1988. Molting and growth of eyestalk-ablated juvenile red king crabs *Paralithodes camtschatica* (Crustacea: Lithodidae). Comparative Biochemistry and Physiology 91A(2):245–251.

Nizyaev, S. A. and S. D. Bukin. 2002. Methodological problems associated with assessing crab resources based on trap catch data. Pages 521–536 [*in*] A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby, eds. Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant AK-SG-02-01, Fairbanks. 876 pp.

NRC (U. S. National Research Council Ocean Studies Board). 1998. Improving fish stock assessments: Committee on fish stock assessment methods. Ocean Studies Board, Commission of Geosciences, Environment and Resources, National Research Counsel, National Academy Press, Washington D. C.

Olsen, S., and T. Laevastu. 1983. Factors affecting catch of long lines, evaluated by a simulation model of longline fishing. Draft manuscript for ICES Fish Capture Committee. 13 pp.

REFERENCES CITED (Continued)

Otto, R. S. and R. A. MacIntosh and P. A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (*Paralithodes camtschatica*) in Bristol Bay and Norton Sound, Alaska. Pages 65–90 [*in*]: Proceeding of the International Symposium on king and tanner Crabs, Anchorage, Alaska, November 28–30, 1989. Lowell Wakefield Fisheries Symposium Series. Alaska Sea Grant College Program Report No. 90-04.

Palumbi, S. R. 2004. Why mothers matter. Nature 430:621–622.

Paul, A. J. and J. M. Paul. 1990. Reproductive success of sublegal size male red king crab with access to multiple mates. Pages 37-50 [*in*]: Proceeding of the International Symposium on king and tanner crabs, Anchorage, Alaska, November 28–30, 1989, Lowell Wakefield Fisheries Symposium Series. Alaska Sea Grant College Program Report No. 90-04.

Paul, A. J. and J. M. Paul. 1997. Breeding success of large male red king crab *Paralithodes camtschaticus* with multiparous mates. Journal of Shellfish Research 16(2):379–381.

Pengilly, D. and D. Schmidt. 1995. Harvest strategy for Kodiak and Bristol Bay red king crab and St. Matthew and Pribilof blue king crab. Alaska Department of Fish and Game, Commercial Fisheries Division. Special Publication No. 7. Juneau, Alaska.

Powell, G. C., D. Penguilly, and S. F. Blau. 2002. Mating Pairs of Red King Crabs (*Paralithodes camtschaticus*) in the Kodiak Archipelago, Alaska, 1960–1984. Pages 225–245 [*in*]: Crabs in cold water regions: biology, management, and economics. Lowell Wakefield Fisheries Symposium. University of Alaska Sea Grant, AK-SG-02-01.

Quinn, T. J., II, and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford, New York.

Quinn, T. J., II, R. B. Deriso, and S. H. Hoag. 1985. Methods of population assessment of Pacific halibut. International Pacific Halibut Commission Science Report 72. 52 pp.

Rounds, P. M., C. M. Brodersen and M. M. Babcock. 1990. Effects of cohort density and habitat on survival of juvenile red king crab *Paralithodes camtschatica*. Proceedings of the International King and Tanner Crab Symposium. Lowell Wakefield Symposia Series 90-04:209–218.

Scheding, K. 2004. Dungeness crab depth distribution: effects of sea otters. M.S. Thesis, University of Alaska Fairbanks. 96 pp.

Shirley, S. M. and T. C. Shirley. 1989. Interannual varibablity in density, timing and survival of Alaskan red king crab (*Paralithodes camtschatica*) larvae. Marine Ecology Progress Series 54:51–59.

Shirley T. C. and S. M. Shirley. 1989. Temperature and salinity tolerances and preferences of red king crab (*Paralithodes camtschatica*) zoeae. Marine Behavior and Physiology 16:19–30.

Shirley, S. M. and T. C. Shirley. 1988. Behavior of red king crab larvae: phototaxis, geotaxis and rheotaxis. Marine Behaviour and Physiology 13:369–388.

Shirley, T. C., S. M. Shirley and S. Korn. 1990. Incubation period, molting and growth of female red king crabs: effects of temperature. Pages 51–63 [*in*]: Proceeding of the International Symposium on king and tanner crabs, Anchorage, Alaska, November 28–30, 1989. Lowell Wakefield Fisheries Symposium Series. Alaska Sea Grant College Program Report No. 90-04.

Shirley, T. C. and S. M. Shirley. 1990. Planktonic survival of red king crab larvae in a subarctic ecosystem, 1985–1989. Pages 263–285 [*in*]: Ziemann, D. A. and K. W. Fulton-Bennett, eds. APPRISE–Interannual Variability and Fisheries Recruitment. The Oceanic Institute, HI.

Stone, R. P. 1991. Seasonal migration and distribution of female red king crab in a southeast Alaska estuary. M.S. Thesis, University of Alaska Fairbanks. 142 pp.

Stone R. P., C. E. O'Clair and T. C. Shirley. 1992. Seasonal migration and distribution of female red king crabs in a southeast Alaskan estuary. Journal of Crustacean Biology 12(4):546–560.

REFERENCES CITED (Continued)

Stone R. P., C. E. O'Clair and T. C. Shirley. 1993. Aggregating behavior of ovigerous female red king crabs, *Paralithodes camtschaticus*, in Auke Bay, Alaska. Canadian Journal of Fisheries Aquatic Sciences 50(4):750–758.

Smith, A. D. M., K. J. Sainsbury, and R. A. Stevens. 1999. Implementing effective fisheries management systems – management strategy evaluation and the Australian partnership approach. ICES Journal of Marine Science 56:967–979.

Taggart, S. J., C. E. O'Clair, T. C. Shirley, and J. Mondragon. 2004. Estimating Dungeness crab, *Cancer magister*, abundance: crab pots and dive transects compared. Fishery Bulletin 102:488–497.

Thompson, S. K. 2002. Sampling, 2nd edition. Wiley, New York. 367 p.

Zhou, S. and T. C. Shirley. 1998. A submersible study of red king crab and Tanner crab distribution by habitat and depth. Journal of Shellfisheries Research 17(5):1477–1479.

Zhou, S., T. C. Shirley and G. H. Kruse. 1998. Feeding and growth of red king crab (*Paralithodes camtschaticus* under laboratory conditions. J. Crustacean Biology 18(2):337–345.

Zhou, S. and T. C. Shirley. 1997a. A model expressing the relationship between catch and soak time for trap fisheries. North-American Journal of Fisheries Management 17:482–487.

Zhou, S. and T. C. Shirley. 1997b. Chemoreception and feeding responses of red king crabs to potential bait extracts. Journal of Crustacean Research 26:1–15.

Zhou, S. and T. C. Shirley. 1997c. Behavioral responses of red king crab to crab pots. Fisheries Research 30:177–189.

Zhou, S. and T. C. Shirley. 1997d. Performance of two red king crab pot designs. Canadian Journal of Fisheries and Aquatic Sciences 54:1858–1864.

Zhou, S. and T. C. Shirley. 1997e. Distribution of red king crab and Tanner crab by habitat and depth in a southeastern Alaskan bay. Investigationes Marinas 25:59–67.

APPENDICES

Appendix A.–Extracts of various documents related to management policy for SEAK Red King Crabs.

BOF Policy (90-4-FB, March 23, 1990).

Goal: manage in a manner to protect, maintain, improve and extend resources for the greatest overall benefit to Alaska and the nation. Do this by minimizing:

1. Risks of irreversible adverse effects on reproductive potential.
2. Harvests during sensitive life history periods.
3. Adverse effects on non-targeted portions of the stock.
4. Adverse effects with other fish and shellfish stocks and fisheries.

Benefits (not limited to these benefits):

1. Maintain healthy stocks.
2. Provide sustained and reliable supply to industry and consumers.
3. Opportunities for subsistence and personal use users.

Policies to achieve management goal and provide benefits:

1. Maintain crab stocks of various size and age classes of mature animals to maintain long-term reproductive viability and reduce dependency on annual recruitment which is variable.
2. Routinely monitor crab resources to provide information on abundance of females as well as recruit, recruit, and postrecruit males. Harvests must be conducted in a conservative manner in the absence of adequate information.
3. Protect stocks during biologically sensitive periods. Closure at times surrounding annual molting, molting, egg hatch periods.
4. Minimize handling and unnecessary mortality of non –legal crabs and other non-target animals.
5. Maintain an adequate brood stock to rebuild when stocks are depressed. Takes precedence over short term economic considerations.
6. Manage based on best available information.
7. Establish regulations to help improve socioeconomic aspects of management by harvesting crabs when meat yield is highest.

Board recognizes that these policies man not result in maximization of physical or economic yield.

Red King Crab Management Plan. In BOF shellfish regulations (5 AAC 34.113).

a. SEAK RKC shall be managed consistently with the board’s policy.
b. Close an area if abundance of males and females is inadequate to provide for a sustained harvest, or when high effort precludes and orderly fishery.
c. Close the fishery if the available harvest is below the 200,000 pounds of legal male RKC.

-continued-

d. Determine an appropriate harvest rate. Percentage of legal males that can be harvested while providing for the longterm reproductive viability of the RKC stocks. Base the harvest rate on all segments of stock and factors affecting stock reproductive viability.

e. Determine the GHL before each fishing season. Sum of estimates of sustainable harvest for each fishing district. If stock assessment data are not available the GHL will be based on historical fishery performance, catch, and population information. If lacking, the result will be conservative.

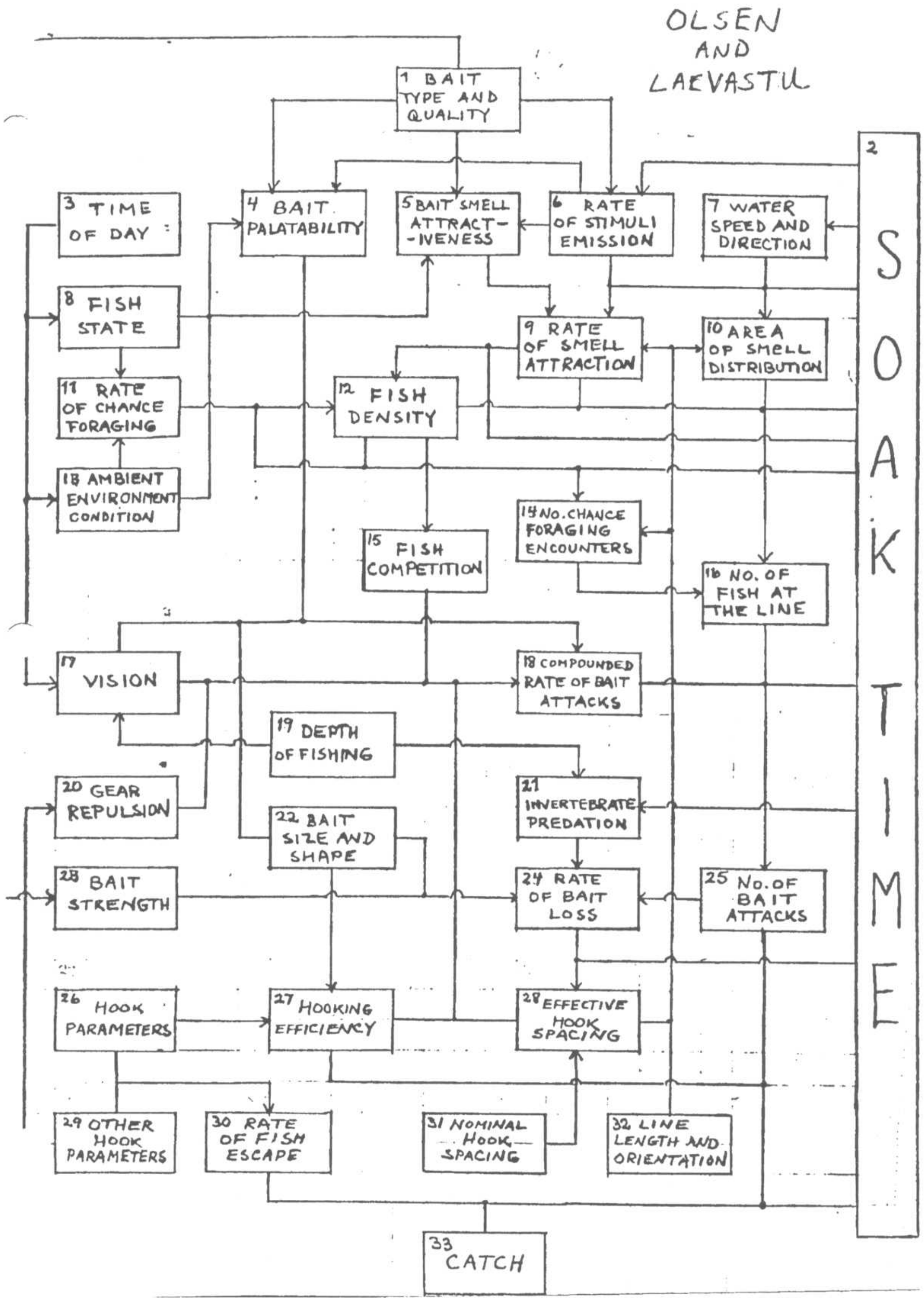
John Clark's presentation June 27, 2005.

Goal of RKC Stock Assessment Survey is to obtain relative measures of abundance, reproductive condition, and overall health of all segments of the RKC stocks in areas where the majority of the harvest occurs and comparable to past survey data.

Survey designed to

1. Collect data that optimally satisfies the assumptions and constraints of the CSA used to estimate the abundance and health of RKC stocks and minimize the variability with the estimators.
2. Maintain survey methods and protocol that is consistent and comparable to historical methods.
3. Distribute survey effort in areas that currently or historically have contributed significantly to the RKC harvest, and have a time series of survey data.
4. Adhere to a time schedule that allows for calculations of biomass estimates and stock condition assessments to provide for a timely determine of GHL and management actions.

Appendix B.–Factors Affecting Catch from Fixed Gear Vessels (reproduced from Olsen and Laevastu 1983).



Appendix C.–Checklist for Fishery Stock Assessments (from NRC 1998).

Table D.1 contains a checklist of items that should be included and/or considered in a stock assessment. The assumptions given in Table D.1 should be considered in choosing a model and specific parameter values.

Table D.1 Checklist for Conducting or Reviewing Stock Assessments

Step		Important Considerations
1.0	Stock Definition	What is the spatial definition of a "stock"?
	Stock structure	Should the assessment be spatially structured or assumed to be spatially homogeneous?
	Single or multispecies	Choose single-species or multi-species assessment?
		Use tagging, micro-constituents, genetics, and/or morphometrics to define stock structure?
2.0	Data	
2.1	Removal	Are removals included in the assessment?
	Catch	Are biases and sampling design documented?
	Discarding	
	Fishing-induced mortality	
2.2	Indices of abundance	For all indices, consider whether an index is absolute or relative, sampling design, standardization, linearity between index and population abundance, what portion of stock is indexed (spawning stock, vulnerable biomass).
	Catch per unit effort (CPUE)	What portions of the fleet should be included and how should data be standardized? How are zero catches treated? What assumptions are made about abundance in areas not fished? Spatial mapping of CPUE is especially informative.
	Gear surveys (trawl, longline, pot)	Is gear saturation a problem? Does survey design cover the entire range of the stock? How is gear selectivity assessed?
	Acoustic surveys	Validate species mix and target strength.
	Egg surveys	Estimate egg mortality, towpath of nets, and fecundity of females.
	Line transect, strip counting	

-continued-

Step		Important Considerations
2.3	Age, size, and sex-structure information	
	Catch at age Weight at age Maturity at age Size at age Age-specific reproductive information	Consider sample design, sample size, high-grading selectivity, and ageing errors.
2.4	Tagging data	Consider both tag loss and shedding and tag return rates. Was population uniformly tagged or were samples recovered?
2.5	Environmental data	How should such data be used in the assessment? What are the dangers of searching databases for correlates?
2.6	Fishery information	Are people familiar with the fishery, who have spent time on fishing boats, consulted and involved in discussions of the value of different data sources?
3.0	Assessment Model	
3.1	Age-, size-, length-, or sex-structured model?	Are alternative structures considered?
3.2	Spatially explicit or not?	
3.3	Key model parameters	
	Natural mortality Vulnerability Fishing mortality Catchability	Are these parameters assumed to be constant or are they estimated? If they are estimated, are prior distributions assumed? Are they assumed to be time invariant?
	Recruitment	Is a relationship between spawning stock and recruitment assumed? If so, what variance is allowed? Is depensation considered as a possibility? Are environmentally driven reductions (or increases) in recruitment considered?

-continued-

Step		Important Considerations
3.4	Statistical formulation	
	What process errors? What observation errors? What likelihood distributions?	If the model is in the form of weighted sum of squares, how are terms weighted? If the model is in the form of maximum likelihood, are variances estimated or assumed known?
3.5	Evaluation of uncertainty	
	Asymptotic estimates of variance Likelihood profile Bootstrapping Bayes posteriors	How is uncertainty in model parameters or between alternative models calculated? What is actually presented, a distribution or only confidence bounds?
3.6	Retrospective evaluation	Are retrospective patterns evaluated and presented?
4.0	Policy Evaluation	
4.1	Alternative hypotheses	What alternatives are considered: parameters for a single model or different structural models? How are the alternative hypotheses weighted? What assumptions are used regarding future recruitment, environmental changes, stochasticity, and other factors? Is the relationship between spawners and recruits considered? If so, do future projections include autocorrelation and depensation?
4.2	Alternative actions	What alternative harvest strategies are considered? What tactics are assumed to be used in implementation? How do future actions reflect potential changes in future population size? Is implementation error considered? Are errors autocorrelated? How does implementation error relate to uncertainty in the assessment model?

-continued-

Appendix C.–Page 4 of 4.

Step		Important Considerations
4.3	Performance indicators	What is the real "objective" of the fishery? What are the best indicators of performance? What is the time frame for biological, social, and economic indices? How is "risk" measured? Are standardized reference points appropriate? Has overfishing been defined formally?
5.0	Presentation of Results	How are uncertainties in parameters and model structure presented? Can decision tables be used to summarize uncertainty and consequences? Is there explicit consideration of the trade-off between different performance indicators? Do the decision-makers have a good understanding of the real uncertainty in the assessment and the trade-offs involved in making a policy choice?