4K90-36

MANAGEMENT PLAN FOR WESTWARD REGION KING CRAB STOCKS:

KODIAK ISLAND RED KING CRAB
BRISTOL BAY RED KING CRAB
ST. MATTHEW BLUE KING CRAB
PRIBILOF ISLANDS BLUE KING CRAB

By

Dana Schmidt
and
Douglas Pengilly

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Alaska Department of Fish and Game
Division of Commercial Fisheries
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Kodiak, Alaska 99615

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[1]The Regional Information Report Series was established in 1987 to provide and information access system for all unpublished division reports.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

PREFACE

This report documents the background information distributed by Alaska Department of Fish and Game staff to support the changes in management of Westward Region king crabs that were adopted by the Alaska Board of Fish (ABOF) on March 23, 1990. The principal change in harvest strategy that was advocated to the ABOF was to manage the harvest of king crabs on the basis of a fixed rate of removal from the mature portion of the male population. Prior to the march 1990 ABOF meeting, various portions of this informational packet were distributed to the public at ABOF Advisory Committee meetings in Kodiak, Dutch Harbor, and Seattle and to National Marine Fisheries Service staff in Kodiak and Seattle. Appendix B of this report had been presented earlier at the 1989 International Symposium on King and Tanner Crabs, which was held in Anchorage on November 28-30, 1989, and is reproduced here from the proceedings of that symposium. At the time of the March 1990 ABOF meeting, the informational packet presented to the public and the ABOF was as presented in this report; i.e., a statement of the management plan accompanied by four supporting appendices.

Douglas Pengilly
Kodiak, AK
24 November 1992

Management Plan for Westward Region King Crab stocks:
Kodiak Island Red King Crab
Bristol Bay Red King Crab
St. Matthew Blue King Crab
Pribilof Islands Blue King Crab

- Draft Date: April 15th, 1990

Executive Summary

This document provides information to assist the public in understanding the current procedures used for management of selected king crab fisheries in the westward region. Significant changes are proposed only for the development of guideline harvest levels, with the intent to simplify the current method of calculating these guidelines, and to remove ambiguity from the current management strategy. An additional Appendix D has been added to this document, based on public comments. This appendix provides a broader comparison of alternative harvest rate strategies in a format more readily understood by the public. The following is a summary of the measures to be followed. These measures specifically address the proposed policy statement on king and Tanner crab fisheries for the westward region management areas:

Kodiak Management Area (Area K) Red King Crab

Harvest Rates

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. In these management plans, the harvest rate is the percentage removal of the legal portion of the population. The term "exploitation rate" refers to the percentage of mature males which are to be harvested. Mature males are defined as all male crab greater or equal to 130 millimeters in carapace length. If the exploitation rate of 20% results in a harvest rate of legal males greater than 60%, then the harvest rate is capped at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%. The threshold is not changed from the previous plan. Minor alterations have been made in the language of the plan.

Guideline Harvest Levels

The guideline harvest level for the Kodiak area is determined by multiplying the harvest rate times the best estimate of the legal population of red king crab available for each management district of the Kodiak management area. Other than the change in estimating the harvest rate, this method of estimating guideline harvest levels is unchanged from the previous methods used.

Other management measures for the Kodiak management district are listed and discussed in the management plan. They do not reflect changes from the previous management activities.

Bristol Bay Management Area (Area T) Red King Crab

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 120 millimeters in carapace length. If the exploitation rate of 20% results in a harvest rate of legal males greater than 60%, then the harvest rate is capped at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%.

Other management measures for the Bristol Bay red king crab management area are discussed in the management plan. They do not reflect changes from the previous management activities.

Pribilof Islands Management District (Area Q) Blue King Crab

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 120 millimeters in carapace length. If the exploitation rate of 20% results in a harvest rate of legal males greater than 60%, then the harvest rate is capped at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%.

Other management measures for the Pribilof Islands management district are discussed in the management plan. They do not reflect changes from the previous management activities.

St. Matthew Management District(Area Q) Blue King Crab

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 105 millimeters in carapace length. If the exploitation rate of 20% results in a harvest rate of legal males greater than 60%, then the harvest rate is set at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%.

Other management measures for the St. Matthew management district are discussed in the management plan. They do not reflect changes from the previous management activities.

Introduction

The current proposal package contains a draft policy statement for the Board of Fisheries review. The following management plans are provided for review pursuant to this policy statement. These management plans are limited to blue and selected red king crab fisheries within the westward region only. Management plans for Tanner crab will not be submitted during this board cycle. Management of Tanner crab fisheries will not be altered during the next two years. It is anticipated that the management plan for Tanner crab in the Westward region will be developed by the 1992 Board shellfish meeting.

The management plans for king crab are specifically designed to address the proposed policy statement. Note that this policy statement is similar to that currently in place for westward region king crab. The management plans stipulate minimal changes in current management practices, with the exception of the method used to determine guideline harvest levels for red and blue king crab. The changes provide a strategy that is consistent with the proposed Board of Fisheries policy statement.

Kodiak Management Area (Area K) Red King Crab

The management measures identified in the proposed policy statement are addressed in this management plan for red king crab in the Kodiak Management Area. The measures identified in the plan are operable with the assumption that periodic surveys of the stock will be completed and will provide sufficient information to estimate the required parameters.

I. Harvest Rates

In these management plans, the harvest rate is the percentage removal of the legal portion of the population. The term "exploitation rate" refers to the percentage of mature males which are to be harvested. A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 130 millimeters in carapace length. If this exploitation rate results in a harvest rate of legal males, greater than 60%, the harvest rate is set at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%. Threshold values are listed in Appendix A.

Rationale:

A technical report describing the ramifications of this harvest strategy is included in Appendix B. This method is considered superior to previous methods to estimate harvest rate for the following reasons:

1. Ambiguous terms used in the previous harvest strategy (Table 2, Appendix B) are eliminated.

2. Calculations are simplified.

3. The reproductive male crab are maintained at reasonable levels, when compared to unharvested populations, regardless of recruitment patterns such as the multiple year failure of recruitment experienced over the past decade in Kodiak.

4. The effect of fishing on the reproductive potential of the stock is limited, regardless of the size limit in place, or its degree of enforceability. The harvest of small crab, either illegally, or by a change in size limit, will result in fewer pounds available for harvest, and potentially, a decrease in price per pound of the product. Violations of the size limit will continually lower the value of the fishery to the fleet and should provide incentives for the fleet to follow size limits.

5. The stability of annual landings will improve.

6. The average long term harvest rate under reasonable recruitment assumptions, will be approximately 40%, the midpoint on the current table.

The following discussion provides a detailed explanation of the above points. Harvest rates for king crab in Kodiak have been calculated since 1982 using a table that was adopted as a regulation by the Board of Fisheries (See Appendix B, Table 1). The table has the following problems:

1. Terms used to determine stock condition are ambiguous.

The term "population" is not defined and could refer to all crab, regardless of size or sex, females only, males only, legal males only, reproductive males, or any other permutation of the above components. The terms "depressed, average, and peak", are also left undefined. As abundances change over time, our concept of what a population size is under "average" conditions, changes. For example, if a fishery is developed when a population is at a peak level, a decline to average abundance in later years may appear as a "depressed" condition. Likewise, if data collection begins when abundances are low, and the number of crab increases, a "peak" population, may actually be average, after a large number of years of data are collected. Determining quantitative criteria to apply these terms to survey or landings data provides even greater challenges. King crab populations in the Kodiak Management Area have usually had either high or low abundance. Average abundance rarely occurs. With such a distribution in abundance values, statistical terms describing average, such as standard deviation, provide very poor criteria for defining the status of a stock.

Under the column "prerecruit abundance", the terms "declining, stable, and increasing" are used. These terms are particularly ambiguous, when applied to survey data, the only source of prerecruit information. For example, depressed populations which have few or no prerecruit crab for several years in succession could be considered stable (i.e., no changes occurring). The previous table of harvest rates could be interpreted to mandate an exploitation rate of 30 or 35% on a stock that is in a state of total collapse. In addition, because of survey imprecision, year to year changes in recruitment may not be detectable, even though a declining trend is quite evident. A "declining" population could be considered stable, if long term sets of data are not used in the determination of stock status. More important, the short term trend in recruitment is of much less consequence to management than the actual population size. Very small increases in numbers in a severely depressed stock have little consequence to management decisions.

The adoption of the proposed method of calculation of the harvest rate, eliminates the need to define ambiguous terms.

2. Calculations are simplified by multiplying the exploitation rate of 20% times the number of sexually mature male crab. Sexually mature male crab are defined as those crab with a carapace length greater than or equal to 130 mm (about 6 inches in carapace

width). This value is determined from grasping pair data collected from the Kodiak Management Area and is illustrated in Figures 3 and 4 of Appendix B. Losses in future crab production due to excessive sorting and handling when large recruitment of sublegal males occurs are avoided by restricting harvest rate to a maximum of 60% of the legal population. This maximum rate limits the amount of handling of juvenile crab with minimal impacts on long term yield. If the population of female crab is below threshold, the harvest rate is set to zero. The following example depicts the calculations necessary to determine a guideline harvest level.

Survey Population Data

- Adult females-10 million animals (Above threshold)
- Legal males- 5 million animals
- Sexually mature males (130 mm carapace length) 10 million animals
- Sexually mature exploitation rate = .20 or 20%
- Allowable removals = 10 million x .20 = 2.0 million animals
- Average weight legal males = 7.5 lbs.
- Harvest rate of legal males = 2 M / 5 M = .4 or 40%

(The harvest rate is less than 60%. If greater or equal to 60% then 60% would have been established as the harvest rate).

- Guideline harvest level = 2 M x 7.5 lb = 15 million lbs.

If the average weight of legal animals decreased, because of changes in the legal size limit, the guideline harvest level (GHL) would decrease proportionate to the decrease in average weight. If the harvest is monitored by numbers of crab harvested, illegal landings of small crab would lower the number of pounds harvested, in a similar manner.

3. The rate of exploitation on the sexually mature males does not exceed 20% using the proposed method. Even if recruitment of young crab to the sexually mature population fails to occur over many consecutive years sufficient males should remain for reproduction. The analysis of a simulated history of variable recruitment of crab (Appendix D), indicates an acceptable sex ratio is maintained. This example of recruitment simulates the declines of king crab observed in the Kodiak Management Area. When populations are very low (below threshold), closing the fishery further reduces mortality from ghost fishing of lost pots, handling mortality, and errors in allowable exploitation rates because of survey error estimates. The combined effects of these two methods of harvest control provide a conservative approach to management of the crab stocks with comparable small affects on the physical yield obtained from the fishery.

4. The exploitation rate on mature males is essentially independent of the size of males being harvested. Consequently, the effect of errors in establishing the optimal size limit, or in its enforcement, will primarily affect the economic value of the fishery and the number of pounds available for harvest. The numbers of reproductively mature males remaining after the harvest will not be affected by changes in the size limit. Note that this does not lessen the burden for enforcement of the size limit. Decreasing the size limit does not provide any increase in total pounds landed, only a decrease, because of the decrease in average weight of crab. Further reduction in the value of crab may occur because of reduced average weight. Optimal size limits can best be established by coupling yield data with economic data on the value of crab as a function of size.

5. Stability in landings will increase from the current harvest strategy. This is completed with comparably small losses to long term yield (Appendix B). Long term periods of recruitment failure will continue to result in fishery closures and large annual variations in landings. No harvest strategy can prevent these types of variations, given the apparent variability of the stock-recruitment relationship in the Kodiak area.

6. In the long term, the harvest rate strategy developed does not provide appreciable changes from that observed in the past. In addition, the 20% exploitation rate on the sexually mature portion of the population is similar to that applied to finfish species in the Bering sea with similar longevity. Appendix B provides simulated harvest rates on the legal portion of the stock using a range of recruitment assumptions. Although harvests vary from 20% to 60% of the legal portion of the stock for any given year, long term harvest rates average near 40%, a value near the midpoint of the current table. Current thresholds listed in Appendix A for all Kodiak districts have not been changed. As the stocks in the Kodiak area recover, the proposed strategy may allow a fishery to occur a year earlier than one which uses only abundances of legal males as the criteria for establishing a harvest rate. The presence of an adequate number of females coupled with assured recruitment of sublegal but sexually mature males would allow a fishery to occur at a comparable high exploitation rate on legal crab. This could potentially provide sufficient crab to provide for an orderly harvest, one year prior to the bulk of the crab molting to legal size.

II. Size Limits

The minimum size limit established by regulation for red king crab in the Kodiak Management Area is 7 inches in carapace width (including spines).

Rationale:

Historically, the seven inch size limit was established to provide for several years of breeding potential after reaching sexual maturity. The legal size limit of seven inches is approximately 148 mm in carapace length which is the measurement used in research studies.

Previous industry comments to the Board of Fisheries indicated a desire to have large crab (current legal size), which have a premium market value. Appendix B, provides analysis of variable size limits on long term yield. These analyses indicate yield changes relatively little over a wide range of size limits. In addition, the size of males participating in breeding (Appendix B, Figures 3 and 4) indicate that the current size limit provides minimal protection of breeding males. Over 85% of the grasping pair males included in the analysis were legal size. This suggests that controlling exploitation rates is a preferable method for maintaining a reproductive stock of male crab, rather than using size limits as the primary tool. Size limits can be most appropriately established using economic data, such as the effect of size on price per pound, coupled with yield per recruit data. The size limit that is currently established appears to provide for long term physical yield near the optimum, under the natural mortality assumption used in the analysis presented in Appendix B.

III. Sex restrictions

Harvest of red king crab in the Kodiak Management Area is limited to males only.

Rationale:

Sex restrictions have been standard practice in crab management for decades. Historically, they were established to provide maximum female reproductive capacity to insure conservation of the resource. When crab were abundant, industry was resistant to harvesting females because of market value. During periods of low numbers, females were not harvested to preserve the maximum reproductive potential of the depressed crab stock.

Other than market considerations, there is little justification for not exploiting female red king crabs, when females numbers are in excess of reproduction requirements. Harvesting females also provides the only management tool available with the potential to stabilize recruitment of crab to the sexually mature population. Harvesting females would stabilize recruitment if the recruitment of young crab is dependent upon the density of adult females producing eggs. Excess egg and larval production could potentially depress recruitment because of density dependent interactions. Competition for food, spread of disease, and cannibalism are some of the density dependent mechanisms which could influence recruitment. In the Kodiak Management Area, the prohibition of female harvest should be repealed in the future, when stocks recover sufficiently to allow a directed harvest. When this occurs, a revised management plan supplement regulating harvests of females will occur.

IV. Fishing Seasons

The Kodiak Management Area fishing season for red or blue king crab begins September 25th, 12:00 Noon, and is closed by emergency order, in accordance with 5 AAC 34.410.

Rationale:

The biologically acceptable fishing season for red king crab is established during a period that minimizes handling mortality of newly molted crab. Maintaining a harvest within this period decreases wastage of legal animals due to deadloss, and decreases undocumented fishing mortality on sublegal and female crab. For crab that are vulnerable to pot gear, molting in the Kodiak area generally encompasses a period from January 15th up to June 1, with the peak of molting in April. Animals less than 5 years of age may molt at any time during the year. Of the adult sized animals, the smaller animals tend to molt early and older animals molt later in the spring. In addition to biological concerns for wastage, optimal product quality may occur when carapaces are well hardened and crab have had an opportunity to fill the shell. Input from the processing industry in determining this period has resulted in fishery opening dates later than the period where handling mortality would be unacceptable. In addition, the current season opening date addresses allocative concerns, and conflicts with the opening date of other fisheries. Common opening dates among areas, limits effort in any particular area. Opening dates in late winter may adversely affect small boat owners who are less able to fish later in the year because of weather.

V. Guideline Harvest Levels

The guideline harvest level for the Kodiak area is determined by multiplying the harvest rate times the best estimate of the legal population of red king crab available for each management district of the Kodiak Management Area.

Rationale: The determination of a harvest rate is discussed previously in detail. This rate is set using data from surveys and commercial fisheries. It is set to zero when the population of female crab, estimated by survey, is below threshold or other conditions

exist which indicate a fishery is not warranted. The threshold policy is further described in Appendix A. The most current data available is used in conjunction with other pertinent information in determining if a population is above threshold, and determining the population estimate to which a harvest rate is applied. The preseason guideline harvest level forecast is revised, when inseason fishery data can be used to improve accuracy of the population estimate. See Appendix B and the harvest rate section for further rationale on the harvest rate estimate.

VI. Closed Areas

The Kodiak Management Area has no areas closed to pot fishing for red or blue king crabs, other than those established by normal season openings and closures.

Rationale: The red king crab fishery in the Kodiak Management Area has not resulted in excessive sorting of nonlegal or molting crabs during the regular season that would require closed areas. Also, there are no areas that conflict with other fisheries that warrant special closure areas for red and blue king crab fishing. Areas have been closed to bottom trawling and restrictions have been made on the season dates for other crab species to reduce bycatch mortality on red king crab.

VII. Gear types

Pot and ring nets only are allowed for the taking of red king crab as defined under 5 AAC 34.425.

Rationale: Red king crab harvests in Kodiak can be completed efficiently, with minimal mortality to sorted nonlegal crab by use of pot gear. This gear is cost effective when compared with other gear types capable of catching crab and minimizes wastage. Wastage is further reduced by requiring biodegradable panels to insure lost pots do not ghost fish.

VIII. In-season adjustments

In-season adjustments are made in accordance with emergency order authority, as established in 5 AAC 34.035.

Rationale: In-season emergency order authority provides ADF&G with flexibility to close fisheries based on a variety of foreseen and unforeseen circumstances. In general, adjustments made to the fishing season in-season are based upon attainment of the guideline harvest level. If in-season data indicate that the preseason estimate of the guideline harvest level is in error, then the fishery is prolonged or shortened, to allow attainment of the revised guideline harvest level. Exceptions to this are made when extenuating circumstances arise. Examples of such exceptions are the presence of a significant number of molting animals, high bycatch of nontarget animals (sublegals, females, or other species), large scale misreporting of catch by the fleet, high rates of gear loss due to the presence of ice, etc. This latitude in issuing closures allows ADF&G to immediately compensate for conditions that develop in-season. The closure of fisheries because of high degrees of wastage allows surplus animals to be harvested at a later date. This provision also allows ADF&G to remove surplus animals based on the most current information available on the status of stocks (in-season fishery performance).

IX. Other measures

To provide for an orderly fishery, the Board of Fisheries has adopted additional regulations, such as tank inspections, check out procedures, pot storage areas, etc. The Board has recently enacted a mandatory observer program for all at-sea processors. This requires those vessels operating at sea to comply with the sex and size-restrictions established for the management area as well as other regulations. These measures are specified in subsections under 5 AAC 34.0, 5 AAC 34.4 and 5 AAC 39.

Bristol Bay Management Area (Area T) Red King Crab

The management measures identified in the proposed policy statement are addressed in this management plan for red king crab in the Bristol Bay management area. The measures identified in the plan are operable with the assumption that periodic surveys of the stock will be completed and will provide sufficient information to estimate the required parameters.

I. Harvest Rates

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 120 millimeters in carapace length. If this exploitation rate results in a harvest rate of legal males, greater than 60%, the harvest rate is set at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%. Threshold values are listed in Appendix A.

Rationale:

A technical report describing the ramifications of this harvest strategy is included in Appendix C. This report also provides the logic for use of 120 millimeters as the minimum size of maturity. This method is considered superior to previous methods for the reasons established under the rationale section of the Kodiak management plan. As with the Kodiak stocks, the harvest rate of legal crab provides values similar to the midpoint of the harvest rate values previously used. The long term average harvest rate of legal sized males would be 42%.

II. Size Limits

The minimum size limit established by regulation for red king crab in the Bristol Bay Management Area is 6.5 inches in carapace width (including spines).

Rationale:

Historically, the six and one-half inch size limit was established to provide for several years of breeding potential after reaching sexual maturity. The legal size limit of six and one-half inches is approximately 137 mm in carapace length which is the measurement used in research studies.

Previous industry comments to the Board of Fisheries indicated a desire to have large crab (current legal size), which have a premium market value. Appendix B, provides analysis of variable size limits on long term yield for the Kodiak area. These analyses indicate yield changes relatively little over a wide range of size limits and are expected to apply to Bristol Bay red king crab. Size limits can be most appropriately established using economic data, such as the effect of size on price per pound, coupled with yield

per recruit data. Optimal size limits for Bristol Bay are probably highly dependent upon marketability of different sizes of crab, coupled with estimates of yield per recruit of crab at different sizes.

III. Sex restrictions

Harvest of red king crab in the Bristol Bay Management Area is limited to males only.

Rationale:

Sex restrictions have been standard practice in crab management for decades. Historically, they were established to provide maximum female reproductive capacity to insure conservation of the resource. When crab were abundant, industry was resistant to harvesting females because of market value. During periods of low numbers, females were not harvested to preserve the maximum reproductive potential of the depressed crab stock.

Other than market considerations, there is little justification for not exploiting female red king crabs, when females numbers are in excess of reproduction requirements. Harvesting females also provides the only management tool available with the potential to stabilize recruitment of crab to the sexually mature population. Harvesting females would stabilize recruitment if the recruitment of young crab is dependent upon the density of adult females producing eggs. Excess egg and larval production could potentially depress recruitment because of density dependent interactions. Competition for food, spread of disease, and cannibalism are some of the density dependent mechanisms which could influence recruitment. In the Bristol Bay Management Area, the prohibition of female harvest should be repealed in the future, when stocks recover sufficiently to allow a directed harvest. When this occurs, a revised management plan supplement regulating harvests of females will occur.

IV. Fishing Seasons

The Bristol Bay Management Area fishing season for red king crab begins November 1st, 12:00 Noon, and is closed by emergency order, in accordance with 5 AAC 34.410.

Rationale:

The biologically acceptable fishing season for red king crab is established during a period that minimizes handling mortality of newly molted crab. Maintaining a harvest within this period decreases wastage of legal animals due to deadloss, and decreases undocumented fishing mortality on sublegal and female crab. For crab that are vulnerable to pot gear, molting in the Bristol Bay area generally encompasses a period from January 15th up to June 1, with the peak of molting in April or May. Animals less than 5 years of age may molt at any time during the year. Of the adult sized animals, the smaller animals tend to molt early and older animals molt later in the spring. In addition to biological concerns for wastage, optimal product quality may occur when carapaces are well hardened and crab have had an opportunity to fill the shell. Input from the processing industry in determining this period has resulted in fishery opening dates later than the period where handling mortality would be unacceptable. In addition, the current season opening date addresses allocative concerns, and conflicts with the opening date of other fisheries. Common opening dates among areas, limits effort in any particular area. Opening dates in late winter may adversely affect small boat owners who are less able to fish later in the year because of weather.

V. Guideline Harvest Levels

The guideline harvest level for the Bristol Bay area is determined by multiplying the harvest rate times the best estimate of the legal population of red king crab available for the Bristol Bay Management Area.

Rationale: The determination of a harvest rate is discussed previously in detail. This rate is set using data from surveys and commercial fisheries. It is set to zero when the population of female crab, estimated by survey, is below threshold or other conditions exist which indicate a fishery is not warranted. The threshold policy is further described in Appendix A. The most current data available is used in conjunction with other pertinent information in determining if a population is above threshold, and determining the population estimate to which a harvest rate is applied. The preseason guideline harvest level forecast is revised, when inseason fishery data can be used to improve accuracy of the population estimate. See Appendix B and the harvest rate section for further rationale on the harvest rate estimate.

VI. Closed Areas

The Bristol Bay Management Area has no areas closed to pot fishing for red king crab, other than those established by normal season openings and closures.

Rationale: The red king crab fishery in the Bristol Bay Management Area has not resulted in excessive sorting of nonlegal or molting crabs during the regular season that would require closed areas. Also, there are no areas that conflict with other fisheries that warrant special closure areas for red king crab fishing. Areas have been closed to bottom trawling and restrictions have been made on the season dates for other species to reduce bycatch mortality on red king crab.

VII. Gear types

Pot and ring nets only are allowed for the taking of red king crab as defined under 5 AAC 34.425.

Rationale: Red king crab harvests in Bristol Bay can be completed efficiently, with minimal mortality to sorted nonlegal crab by use of pot gear. This gear is cost effective when compared with other gear types capable of catching crab and minimizes wastage. Wastage is further reduced by requiring biodegradable panels to insure lost pots do not ghost fish.

VIII. In-season adjustments

In-season adjustments are made in accordance with emergency order authority, as established in 5 AAC 34.035.

Rationale: In-season emergency order authority provides ADF&G with flexibility to close fisheries based on a variety of foreseen and unforeseen circumstances. In general, adjustments made to the fishing season in-season are based upon attainment of the guideline harvest level. If in-season data indicate that the preseason estimate of the guideline harvest level is in error, then the fishery is prolonged or shortened, to allow attainment of the revised guideline harvest level. Exceptions to this are made when extenuating circumstances arise. Examples of such exceptions are the presence of a significant number of molting animals, high bycatch of nontarget animals (sublegals,

females, or other species), large scale misreporting of catch by the fleet, high rates of gear loss due to the presence of ice, etc. This latitude in issuing closures allows ADF&G to immediately compensate for conditions that develop in-season. The closure of fisheries because of high degrees of wastage allows surplus animals to be harvested at a later date. This provision also allows ADF&G to remove surplus animals based on the most current information available on the status of stocks (in-season fishery performance).

IX. Other measures

To provide for an orderly fishery, the Board of Fisheries has adopted additional regulations, such as tank inspections, check out procedures, pot storage areas, etc. The Board has recently enacted a mandatory observer program for all at-sea processors. This requires those vessels operating at sea to comply with the sex and size restrictions established for the management area as well as other regulations. These measures are specified in subsections under 5 AAC 34.0, 5 AAC 34.4 and 5 AAC 39.

Pribilof Islands Management District(Area Q) Blue King Crab

The management measures identified in the proposed policy statement are addressed in this management plan for blue king crab in the Pribilof management district. The measures identified in the plan are operable with the assumption that periodic surveys of the stock will be completed and will provide sufficient information to estimate the required parameters.

I. Harvest Rates

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 120 millimeters in carapace length. If this exploitation rate results in a harvest rate of legal males, greater than 60%, the harvest rate is set at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%. Threshold values are listed in Appendix A.

Rationale:

A technical report describing the ramifications of this harvest strategy is included in Appendix C. This report also provides the logic for use of 120 millimeters as the minimum size of maturity. This method is considered superior to previous methods for the reasons established under the rationale section of the Kodiak management plan. As with the Kodiak stocks, the harvest rate of legal crab provides values similar to the midpoint of the harvest rate values previously used. The long term average harvest rate of legal males would be 26%. Note that this value is significantly below the Bristol Bay red king crab rate, reflecting very low recent recruitment, a shorter time series of data, and perhaps different growth rates of the adult male crab, despite identical legal size limits.

II. Size Limits

The minimum size limit established by regulation for blue and red king crab in the Pribilof District Management Area is 6.5 inches in carapace width (including spines).

Rationale:

Historically, the six and one-half inch size limit was established to provide for several years of breeding potential after reaching sexual maturity. The legal size limit of six and one-half inches is approximately 138 mm in carapace length which is the measurement used in research studies.

Previous industry comments to the Board of Fisheries indicated a desire to have large crab (current legal size), which have a premium market value. Appendix B, provides analysis of variable size limits on long term yield from the Kodiak area. These analyses indicate yield changes relatively little over a wide range of size limits. Given the size of maturity of female blue crab from the Pribilof Islands is much closer to the female size of maturity from Kodiak, the size limit of male animals for the Pribilof could be larger if comparable biological size limits are desirable among management areas. Size limits can be most appropriately established using economic data, such as the effect of size on price per pound, coupled with yield per recruit data specific for this species and this area.

III. Sex restrictions

Harvest of blue or red king crab in the Pribilof District Management Area is limited to males only.

Rationale:

Sex restrictions have been standard practice in crab management for decades. Historically, they were established to provide maximum female reproductive capacity to insure conservation of the resource. When crab were abundant, industry was resistant to harvesting females because of market value. During periods of low numbers, females were not harvested to preserve the maximum reproductive potential of the depressed crab stock.

Other than market considerations, there is little justification for not exploiting female blue or red king crabs, when females numbers are in excess of reproduction requirements. Harvesting females also provides the only management tool available with the potential to stabilize recruitment of crab to the sexually mature population. Harvesting females would stabilize recruitment if the recruitment of young crab is dependent upon the density of adult females producing eggs. Excess egg and larval production could potentially depress recruitment because of density dependent interactions. Competition for food, spread of disease, and cannibalism are some of the density dependent mechanisms which could influence recruitment. In the Pribilof Management District, the prohibition of female harvest should be repealed in the future, when stocks recover sufficiently to allow a directed harvest. When this occurs, a revised management plan supplement regulating harvests of females will occur.

IV. Fishing Seasons

The Pribilof District Management Area fishing season for red or blue king crab begins September 25th, 12:00 Noon through April 15th. The season normally is closed by emergency order, in accordance with 5 AAC 34.410.

Rationale:

The biologically acceptable fishing season for Pribilof blue and red king crab is established during a period that minimizes handling mortality of newly molted crab. Maintaining a harvest within this period decreases wastage of legal animals due to deadloss, and decreases undocumented fishing mortality on sublegal and female crab. Molting season in the Pribilof Islands area is poorly established but is assumed to primarily occur after the 15th of April. In addition to biological concerns for wastage, optimal product quality may occur when carapaces are well hardened and crab have had an opportunity to fill the shell. Input from the processing industry in determining this period has resulted in fishery opening dates later than the period where handling mortality would be unacceptable. In addition, the current season opening date addresses allocative concerns, and conflicts with the opening date of other fisheries. Common opening dates among areas, limits effort in any particular area. Opening dates in late winter may adversely affect small boat owners who are less able to fish later in the year because of weather.

V. Guideline Harvest Levels

The guideline harvest level for the Pribilof Islands District Management Area is determined by multiplying the harvest rate times the best estimate of the legal population of blue king crab available for the Pribilof Management District.

Rationale: The determination of a harvest rate is discussed previously in detail. This rate is set using data from surveys and commercial fisheries. It is set to zero when the population of female crab, estimated by survey, is below threshold or other conditions exist which indicate a fishery is not warranted. The threshold policy is further described in Appendix A. The most current data available is used in conjunction with other pertinent information in determining if a population is above threshold, and determining the population estimate to which a harvest rate is applied. The preseason guideline harvest level forecast is revised, when inseason fishery data can be used to improve accuracy of the population estimate. See Appendix B and the harvest rate section for further rationale on the harvest rate estimate.

VI. Closed Areas

The Pribilof Islands District Management Area has no areas closed to pot fishing for red or blue king crabs, other than those established by normal season openings and closures.

Rationale: The blue king crab fishery in the Pribilof Management District has not resulted in excessive sorting of nonlegal or molting crabs during the regular season that would require closed areas. Also, there are no areas that conflict with other fisheries that warrant special closure areas for red and blue king crab fishing.

VII. Gear types

Pot and ring nets only are allowed for the taking of blue and red king crab as defined under 5 AAC 34.425.

Rationale: Blue and red king crab harvests in the Pribilof area can be completed efficiently, with minimal mortality to sorted nonlegal crab by use of pot gear. This gear is cost effective when compared with other gear types capable of catching crab and minimizes wastage. Wastage is further reduced by requiring biodegradable panels to insure lost pots do not ghost fish.

VIII. In-season adjustments

In-season adjustments are made in accordance with emergency order authority, as established in 5 AAC 34.035.

Rationale: In-season emergency order authority provides ADF&G with flexibility to close fisheries based on a variety of foreseen and unforeseen circumstances. In general, adjustments made to the fishing season in-season are based upon attainment of the guideline harvest level. If in-season data indicate that the preseason estimate of the guideline harvest level is in error, then the fishery is prolonged or shortened, to allow attainment of the revised guideline harvest level. Exceptions to this are made when extenuating circumstances arise. Examples of such exceptions are the presence of a significant number of molting animals, high bycatch of nontarget animals (sublegals, females, or other species), large scale misreporting of catch by the fleet, high rates of gear loss due to the presence of ice, etc. This latitude in issuing closures allows ADF&G to immediately compensate for conditions that develop in-season. The closure of fisheries because of high degrees of wastage allows surplus animals to be harvested at a later date. This provision also allows ADF&G to remove surplus animals based on the most current information available on the status of stocks (in-season fishery performance).

IX. Other measures

To provide for an orderly fishery, the Board of Fisheries has adopted additional regulations, such as tank inspections, check out procedures, pot storage areas, etc. The Board has recently enacted a mandatory observer program for all at-sea processors. This requires those vessels operating at sea to comply with the sex and size restrictions established for the management area as well as other regulations. These measures are specified in subsections under 5 AAC 34.0, 5 AAC 34.4 and 5 AAC 39.

St. Matthew Management Section, Northern District (Area Q) Blue King Crab.

The management measures identified in the proposed policy statement are addressed in this management plan for blue king crab in the St. Matthew Section of the Bering Sea (Area Q) management area. The measures identified in the plan are operable with the assumption that periodic surveys of the stock will be completed and will provide sufficient information to estimate the required parameters.

I. Harvest Rates

A harvest rate is based on an exploitation rate of 20%, applied to the estimated mature male population. Mature males are defined as all male crab greater or equal to 105 millimeters in carapace length. If this exploitation rate results in a harvest rate of legal males, greater than 60%, the harvest rate is set at 60% of the legal males. When the population estimate of mature females is below threshold or other conditions exist as outlined in Appendix A, the harvest rate is set at 0%. Threshold values are listed in Appendix A.

Rationale:

A technical report describing the ramifications of this harvest strategy is included in Appendix C. This report also provides the logic for use of 105 millimeters as the minimum size of maturity. This method is considered superior to previous methods for

the reasons established under the rationale section of the Kodiak management plan. As with the Kodiak stocks, the harvest rate of legal crab provides values similar to the midpoint of the harvest rate values previously used. The long term average harvest rate would be 36%. Note that this value is similar to the harvest rates projected for Bristol Bay red king crab.

II. Size Limits

The minimum size limit established by regulation for blue king crab in the St. Matthew Section is 5.5 inches in carapace width (including spines).

Rationale:

Historically, the five and one-half inch size limit was established to provide for several years of breeding potential after reaching sexual maturity. The legal size limit of five and one-half inches is approximately 120 mm in carapace length which is the measurement used in research studies.

Size limits can be most appropriately established using economic data, such as the effect of size on price per pound, coupled with yield per recruit data. Given the lower growth rates of St. Matthew Blue King crab, the size limit appears to be biologically comparable to the red king crab size limit established in Bristol Bay.

III. Sex restrictions

Harvest of blue king crab in the St. Matthew Section is limited to males only.

Rationale:

Sex restrictions have been standard practice in crab management for decades. Historically, they were established to provide maximum female reproductive capacity to insure conservation of the resource. When crab were abundant, industry was resistant to harvesting females because of market value. During periods of low numbers, females were not harvested to preserve the maximum reproductive potential of the depressed crab stock.

Other than market considerations, there is little justification for not exploiting female red king crabs, when females numbers are in excess of reproduction requirements. Harvesting females also provides the only management tool available with the potential to stabilize recruitment of crab to the sexually mature population. Harvesting females would stabilize recruitment if the recruitment of young crab is dependent upon the density of adult females producing eggs. Excess egg and larval production could potentially depress recruitment because of density dependent interactions. Competition for food, spread of disease, and cannibalism are some of the density dependent mechanisms which could influence recruitment. In the Kodiak Management Area, the prohibition of female harvest should be repealed in the future, when stocks recover sufficiently to allow a directed harvest. When this occurs, a revised management plan supplement regulating harvests of females will occur.

IV. Fishing Seasons

The St. Matthew fishing season for red or blue king crab begins September 1st, 12:00 Noon, and is closed September 22nd. This fishery normally is closed by emergency order, in accordance with 5 AAC 34.410.

Rationale:

The biologically acceptable fishing season for blue king crab is established during a period that minimizes handling mortality of newly molted crab. Maintaining a harvest within this period decreases wastage of legal animals due to deadloss, and decreases undocumented fishing mortality on sublegal and female crab. For blue king crab from this area, little data are available documenting time of molting. This appear to occur in the spring or early summer so the current season is well within the biologically acceptable season. In addition to biological concerns for wastage, optimal product quality may occur when carapaces are well hardened and crab have had an opportunity to fill the shell. Input from the processing industry in determining this period has resulted in fishery opening dates later than the period where handling mortality would be unacceptable. In addition, the current season opening date addresses allocative concerns, and conflicts with the opening date of other fisheries. Common opening dates among areas, limits effort in any particular area. Opening dates in late winter may adversely affect small boat owners who are less able to fish later in the year because of weather.

V. Guideline Harvest Levels

The guideline harvest level for the St. Matthew section is determined by multiplying the harvest rate times the best estimate of the legal population of blue king crab available for the St. Matthew section.

Rationale: The determination of a harvest rate is discussed previously in detail. This rate is set using data from surveys and commercial fisheries. It is set to zero when the population of female crab, estimated by survey, is below threshold or other conditions exist which indicate a fishery is not warranted. The threshold policy is further described in Appendix A. The most current data available is used in conjunction with other pertinent information in determining if a population is above threshold, and determining the population estimate to which a harvest rate is applied. The preseason guideline harvest level forecast is revised, when inseason fishery data can be used to improve accuracy of the population estimate. See Appendix B and the harvest rate section for further rationale on the harvest rate estimate.

VI. Closed Areas

The St. Matthew section has no areas closed to pot fishing for red or blue king crabs, other than those established by normal season openings and closures.

Rationale: The blue king crab fishery in the St. Matthew section has not resulted in excessive sorting of nonlegal or molting crabs during the regular season that would require closed areas. Also, there are no areas that conflict with other fisheries that warrant special closure areas for red and blue king crab fishing.

VII. Gear types

Pot and ring nets only are allowed for the taking of blue and red king crab as defined under 5 AAC 34.425.

Rationale: Blue king crab harvests in the St. Matthew section can be completed efficiently, with minimal mortality to sorted nonlegal crab by use of pot gear. This gear is cost effective when compared with other gear types capable of catching crab and minimizes wastage. Wastage is further reduced by requiring biodegradable panels to insure lost pots do not ghost fish.

VIII. In-season adjustments

In-season adjustments are made in accordance with emergency order authority, as established in 5 AAC 34.035.

Rationale: In-season emergency order authority provides ADF&G with flexibility to close fisheries based on a variety of foreseen and unforeseen circumstances. In general, adjustments made to the fishing season in-season are based upon attainment of the guideline harvest level. If in-season data indicate that the preseason estimate of the guideline harvest level is in error, then the fishery is prolonged or shortened, to allow attainment of the revised guideline harvest level. Exceptions to this are made when extenuating circumstances arise. Examples of such exceptions are the presence of a significant number of molting animals, high bycatch of nontarget animals (sublegals, females, or other species), large scale misreporting of catch by the fleet, high rates of gear loss due to the presence of ice, etc. This latitude in issuing closures allows ADF&G to immediately compensate for conditions that develop in-season. The closure of fisheries because of high degrees of wastage allows surplus animals to be harvested at a later date. This provision also allows ADF&G to remove surplus animals based on the most current information available on the status of stocks (in-season fishery performance).

IX. Other measures

To provide for an orderly fishery, the Board of Fisheries has adopted additional regulations, such as tank inspections, check out procedures, pot storage areas, etc. The Board has recently enacted a mandatory observer program for all at-sea processors. This requires those vessels operating at sea to comply with the sex and size restrictions established for the management area as well as other regulations. These measures are specified in subsections under 5 AAC 34.0, 5 AAC 34.4 and 5 AAC 39.

Summary

This management plan is provided to assist the public in understanding the management process used by the Alaska Department of Fish and Game in the management of selected red and blue king crab fisheries of the westward region. Although regulations sections are cited, this document does not have regulatory force. Consult the current regulation book for legal requirements pertaining to these fisheries.

Appendix A

Westward Region King Crab Threshold Criteria

Threshold criteria have been developed for king crab stocks in the westward region that have sufficient historical survey data to develop these criteria.

The definition of threshold to be used in these plans is adopted from the "Fishery Management Plan for the Commercial King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands". This definition is as follows:

"Threshold is the minimum size of a stock that allows sufficient recruitment so that the stock can eventually reach a level that produces MSY (Maximum Sustained Yield). Implicit in this definition are rebuilding schedules. They have not been explicitly specified since the selection of a schedule is a part of the OY determination process. Interest instead is on the identification of a stock level below which the ability to rebuild is uncertain. When a stock is at or below threshold, the fishery will be closed entirely, because further removals from the spawning stock will further jeopardize the already uncertain ability of the stock to recover. The estimate given should reflect use of the best scientific information available...".

Thresholds are designed to provide fixed criteria to be used to determine if sufficient biological surplus of adult king crab exists to warrant a commercial fishery on the stocks. These thresholds will be revised when ever research and survey data warrant changes. Thresholds of relative abundance indices of king crab for each of the Westward region stocks where sufficient data are available, have been developed.

These thresholds are developed for the Kodiak Districts by examination of the relationship of historic fertilized female abundance in a given year to abundances of male animals of a size class from predominantly the parent year of the females. For each stock within the Kodiak area, the threshold value is listed as "fertilized females per pot" and for expanded trawl surveys as "total fertilized female crab" for each district.

Bristol Bay red king crab threshold is developed from examination of the stock-recruitment data for that area. St. Matthew and Pribilof Blue King crab have been determined from the stock recruit relationship for Bristol Bay red king crab.

These abundance levels for each fishing district which approximates the stocks for which they are calculated as follows:

AREA	DISTRICT OR AREA DESCRIPTION	FERTILIZED FEMALES/POT*	TOTAL FERTILIZED FEMALES **
K	**Northeast District**	3.3	(1.93 Million)
K	**Southeast District**	3.3	(.72 Million)
K	**Southwest District**	7.1	(2.28 Million)
K	**Shelikof District**	.5	(.19 Million)
T	**Bristol Bay Red King Crab**	(To be developed prior to the 1990 season)	
Q	**Pribilof District Blue King Crab**		"
Q	**St. Matthew Blue King District Crab**		"

*Relative abundance of adult fertilized females in survey (CPUE)

**Total numbers reflect equivalent catch per pot data. Fertilized females/Pot applied to pot survey data, adult total females applied to expanded trawl survey data.

If the survey reveals the abundance indices are below these values, the district or management area is closed to fishing for that season. This is to insure that handling mortality on the females remains insignificant and accidental over harvest of male animals during the season does not have major affects on the reproductive potential of the stock. (In the unlikely event that a large surplus of males, beyond that which is necessary for reproduction is indicated by the survey, even if the females are below threshold, the data will be re-examined to determine if a season is warranted under these unusual conditions. Alternatively, if the mature male population is below the minimum number necessary to fertilize the threshold level of females, the season would also be closed). If the survey indicates numbers of females are above threshold a guideline harvest level of legal male animals is established for that district or area in accordance with the established management plan.

If the guideline harvest level is a number of sufficient magnitude to have a controlled harvest, the season progresses as scheduled. The minimum harvest considered controllable depends on the number of pots expected to be deployed in the fishery. The season is closed upon reaching this harvest guideline, or if other closure criteria established in an areas management plan or under emergency order authority provided in the current Board of Fisheries Regulation, are met in-season.

Appendix B

Investigations on an Alternative Harvest Strategy for Red King Crab (Paralithodes camtschatica) in Alaska

Dana Schmidt

Douglas Pengilly

Alaska Department of Fish and Game

Kodiak, AK 99615

(Presented at the 1989 International Crab Symposium, Anchorage, Alaska)

ABSTRACT

The red king crab (Paralithodes camtschatica) harvest strategy that is presently used in Alaska applies varying harvest rates to legal crabs depending on the size and age structure of the population. That strategy, however, suffers from ambiguity in application and is apparently less effective in stabilizing annual landings in the face of variable recruitment than is a fixed harvest rate on legal crabs. We present an alternative harvest strategy that is intended to help stabilize landings under variable recruitment while providing a low fixed rate of exploitation on breeding males. The properties and utility of the proposed harvest strategy are studied using computer simulations applied to a growth and mortality model developed for Kodiak Area red king crabs. Our results indicate that, compared to fixed harvest rates on legal crabs, the proposed strategy offers more protection to breeding males and, under highly variable recruitment, greater stability in yearly landings while producing the same average yield per recruit.

INTRODUCTION

The Alaska Board of Fisheries (ABOF) identified three goals of red king crab (Paralithodes camtschatica) management that apply to commercial harvest strategies (ADF&G, 1988; Otto, 1985). These goals are as follows: (1) to establish stability in landings, (2) to produce long-term optimum yield, and (3) to the protect reproductive potential of the stocks. Otto (1985) reviewed these management goals relative to the history of instability and dependence upon fluctuating annual recruitment that has characterized the Alaska king crab fishery. In its policy statement, the ABOF acknowledges that "maximum physical yield will not necessarily produce the long-term optimum yield" (ADF&G, 1988). Thus, optimum yield is a compromise between maximum yield and stability in landings. Overall, the ABOF red king crab management policy indicates that a conservative harvest strategy should be applied to Alaska's red king crab stocks -- a strategy that emphasizes stability more than maximum yield and insures adequate protection of breeding males.

The harvest strategy that is presently applied to Alaska's red king crab stocks is given in Table 1. This harvest strategy prescribes a harvest rate on legal crabs which varies with population size, the status of sublegal-sized males, and the relative abundance of males that have previously recruited to the fishery. The maximum harvest rate allowed in this strategy is 60% while, in some circumstances, the harvest rate prescribed may be 20% or less.

Table 1. Current harvest strategy for red king crab in Alaska (from ADF&G, 1986). Approximate harvest rates of legal crab at given levels of postrecruits.

Population Size	Prerecruit Abundance	Low*	Moderate**	High***
Depressed	Declining	Less than 20	Less than 25	Less than 25
	Stable	30	30	35
	Increasing	30	30	35
Average	Declining	40	40	40
	Stable	40	45	45
	Increasing	40	50	50
Peak	Declining	40	45	50
	Stable	50	55	60
	Increasing	60	60	60

*Low=less than 1/3 of total population (lbs).
**Moderate=1/3 - 2/3 of total population.
***High=2/3 of total population.
Prerecruits - those crab which will not reach legal size for one to two molts.
Recruits - those crab which have attached legal size for the first time.
Postrecruits - those crab which have been legal size for one or more years.

This current harvest strategy presents two problems to managers of Alaska's red king crab stocks. The first is that it cannot be operationally applied because the terms used to describe most of the stock conditions which set the harvest rate ("depressed," "average," "peak," "declining," "stable," and "increasing") are ambiguous and are not defined in either relative or absolute terms. Differences in interpretation of these terms as they are applied to a given stock of crabs can lead to enormous differences in the exploitation of that stock.

The other problem with the current harvest strategy is that it may be ineffective in establishing stability in landings over time. Otto (1985) used computer simulation studies to compare the performance of the current harvest strategy table with that of a harvest strategy which prescribed a fixed harvest rate of 40% on legal crabs. His results indicate that the two strategies would show little difference in average yearly landings, but that the current strategy would produce more variability in yearly landings than the constant 40% harvest rate. This result is not surprising since the current harvest strategy prescribes the highest harvest rates when stock size is high and the lowest harvest rates when stocks are depressed. In terms of landings, such a strategy would serve to amplify the effects of variable recruitment into the fishery.

We present here a revision to the current harvest strategy for red king crabs in Alaska. The revision was designed to accommodate the goals of the ABOF red king crab management policy statement without the ambiguity of the current harvest strategy table. That is, this proposed alternative to the current harvest strategy attempts to (1) provide stability in landings in the face of variable recruitment into the fishery, (2) provide adequate protection to breeding male crabs, and (3) provide a reasonable balance between yield-per-recruit and the goals of stability and protection of breeding males.

In this paper, we investigate the properties and utility of the proposed harvest strategy as it would apply to red king crabs in the Kodiak area by using a growth model and an operational definition for breeding males that were both developed from data on Kodiak area red king crabs. Preliminary to the investigation of the proposed harvest strategy, we assess the effects that changing the current minimum legal size of 7 inches in carapace width for Kodiak area red king crabs and changing the current maximum harvest rate of 60% would have on yield per recruit.

RESULTS AND DISCUSSION

An Alternative Harvest Strategy

The following proposed harvest strategy is the basic component of our analysis. Note that we use the term "exploitation rate" when referring to the percentage of breeding males that are to be harvested, while we use "harvest rate" when referring to the percentage of legal crabs that are to be harvested. The proposed harvest strategy sets a constant exploitation rate, E, on breeding males. The number of crabs removed by the harvest will be applied to the legal component of the population as currently set by minimum size limits. That is, the harvest rate applied to legal crabs is,

$$H = \min\{E(N_b/N_l),0.6\}, \quad (1)$$

where min{x,y} denotes the minimum of x and y, H is the harvest rate applied to legal crabs, N_b is the number of breeding males, and N_l is the number of legal-sized males. Note that, like the current harvest strategy, the maximum harvest rate that would be applied to legals is 60%. Because legal-sized males are a subset of the breeding males, equation (1) becomes,

$$H = \min\{E + E(N_b - N_l)/N_l,0.6\}, \quad (2)$$

noting that $N_b - N_l$ is the number of nonlegal (i.e., sublegal-sized) breeding males. From equation (2) it is seen that E is both a constant exploitation rate on breeding males and a minimum harvest rate on legal crabs, a minimum that is attained only when all breeding males are legal-sized. We tentatively apply exploitation rates of E = 20% and E = 25%; these are at the low end of the harvest rates in the current harvest strategy.

To explore the behavior and utility of this revised harvest strategy, we required a growth and survivorship model for male red king crabs and an estimate of the minimum size of breeding males. A description of the growth model and the development of an estimate of minimum size for breeding males follow.

Growth and Survivorship Model for Male King Crabs

Our growth and survivorship model for Kodiak male red king crabs is summarized in Table 2. The model is designed to produce shell age and size distributions of male red king crabs in an unharvested population. The shell age and size distributions are intended to reflect those of the summer months that follow the spring breeding and molting period and precede the commercial fishery season of fall and winter. Shell condition identifies whether a crab has molted in the preceding spring: "newshell" crabs molted and grew, while "oldshell" (or, "skipmolt") crabs did not. The yearly changes in

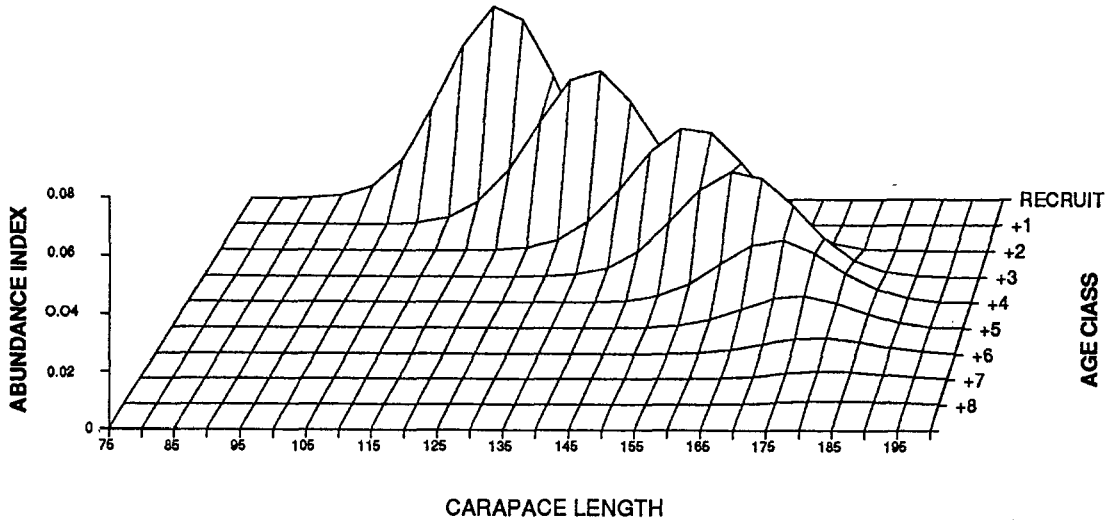

Figure 1. Modelled changes in size distribution and abundance for a cohort of male red king crab in the Kodiak area.

Table 2. Kodiak area male red king crab growth and survivorship model. Recruits to the model are probably six years old. Carapace lengths in the recruit age-class are normally distributed. Carapace length growth increments are normally distributed. Relative abundance is the probability that an individual in an unexploited population survives to an age class, given that it has attained the recruit age-class.

age-class	shell condition	carapace length (mm) mean (variance)	growth (mm) to next age-class mean (variance)	annual survivorship	relative abundance
recruit	all*	116.3 (81.18)	17.3 (6.52)	0.75	1.000
+1	all*	133.6 (87.70)	18.2 (7.85)	0.75	0.750
+2	all*	151.8 (95.55)	16.4 (8.00)**	0.75	0.563
+3	new	164.2 (82.52)	16.4 (8.00)**	0.75	0.245
	old	157.3 (72.51)	12.6 (8.00)***	0.45	0.177
	all	161.3 (90.00)		0.62	0.422
+4	new	171.2 (81.56)	12.6 (8.00)**	0.45	0.120
	old	166.5 (67.58)	12.6 (8.00)***	0.45	0.143
	all	168.6 (79.47)		0.45	0.263
+5	new	176.8 (66.75)	12.6 (8.00)**	0.45	0.054
	old	172.2 (67.54)	12.6 (8.00)***	0.45	0.065
	all	174.3 (72.39)		0.45	0.118
+6	new	181.8 (63.14)	12.6 (8.00)**	0.45	0.019
	old	177.0 (60.72)	12.6 (8.00)***	0.45	0.035
	all	178.7 (66.89)		0.45	0.053
+7	new	186.1 (57.86)	12.6 (8.00)**	0.45	0.007
	old	180.9 (57.63)	12.6 (8.00)***	0.45	0.017
	all	182.5 (63.41)		0.45	0.024
+8	new	189.6 (54.76)	12.6 (8.00)**	0.00	0.003
	old	184.3 (55.79)	12.6 (8.00)***	0.00	0.008
	all	185.6 (60.79)		0.00	0.011

* Age class is composed entirely of newshells.
** Probability of molting given length (l) is,
exp(20.156-.130(l))/[1+exp(20.156-.130(l))].
*** Probability of molting given length (l) is,
exp(21.840-.125(l))/[1+exp(21.840-.125(l))].

size distribution and relative abundance for an unharvested cohort resulting from this model are illustrated in Figure 1. Removal from the population due to harvest can be applied to the growth and survivorship model to model the effects of harvest strategies.

Our approach differs from that of the growth model of McCaughran and Powell (1977). While McCaughran and Powell (1977) modelled the growth in carapace length of individual crabs, we modelled the carapace length frequency distribution of a population of crabs. Our approach allows us to study the effects of harvest strategies applied to a population represented by a model size distribution; McCaughran and Powell's (1977) approach, which provides no model for a size distribution beyond the mean and variance of carapace length at age, does not.

Our model is based largely on an analysis of carapace length frequency data obtained from the Alaska Department of Fish and Game (ADF&G) Kodiak area pot surveys conducted from 1972 through 1986 (Peterson et al., 1986). Yearly length frequencies of over 140,000 newshell male red king crabs from southwest Kodiak Island were fit as mixtures of individual normally distributed components representing age-classes by using the EM algorithm to obtain maximum-likelihood estimates of the mixture parameters (Titterington et al., 1985). The multi-year length frequency data were fit simultaneously to mixture densities under the assumption that component means and variances did not vary among years. Parameter estimation for the growth model was supplemented by data from the extensive tagging studies on red king crabs performed by ADF&G in the Kodiak area in 1961 and from 1974 through 1982. The tagging data gave information on growth per molt, differential growth per molt due to shell age, molting probabilities dependent upon carapace length and shell age, and differential survivorship between newshell and oldshell male crabs.

"Recruits" to this model are a group of newshell crabs having a normally distributed carapace length frequency with a mean of 116.3 mm and a variance of 81.2. We believe that the model recruits are 6 years old. Individuals can remain in the model for up to 8 years after recruiting to the model. Age-classes following the recruit class in the model are denoted as + 1, + 2, up to + 8. Yearly growth decreases markedly after the + 2 age-class is attained. This is due to a higher incidence of skip-molting by larger crabs and a reduction in growth per molt in individuals that have skip molted. In terms of recruitment to the fishery, the Kodiak area minimum legal size limit of 7 inches in carapace width corresponds to a carapace length of roughly 147 mm (B. A. Johnson, ADF&G, Kodiak, personal communication). Thus, the + 2 age class is the first age-class to be largely exposed to the commercial harvest (Figure 1).

We assume that annual survivorship for the model recruit class is 75%. This value is not inconsistent with year-to-year trends in catch per unit effort observed in the pot survey data. Because tagging studies have indicated an increased natural mortality in skip-molt males, the annual survivorship of oldshell males in the +3 age-class and all individuals in age-classes from +4 and above is reduced by a factor of 60% to an annual survivorship of 45%. This differential survivorship between younger and older age classes results in a survivorship at length relationship which is similar to that modelled by Balsiger (1974) for Bering Sea red king crabs.

To obtain the available yield in weight from carapace length, we applied the following weight at length equation from Blau (1986):

$$W = 4.45174(L^{3.11937})(10^{-7}), \quad (3)$$

where W is weight in kilograms (kg) and L is length in millimeters(mm).

Determination of Breeding Males

Powell et al. (1973) indicated that male red king crabs from the Kodiak area are sexually mature at sizes as small as 85 mm in carapace length. Our interest is not, however, with the size at which males attain physiological sexual maturity, but rather with the size at which males become important components of breeding pairs under natural conditions. That minimum size could then be applied to length frequency and abundance data from preseason surveys to estimate the abundance of breeding males in a population. To our knowledge there is only one data set that would allow an estimation of this size for any stock of Alaska red king crabs. This is the carapace length frequency data collected from mating pairs of red king crabs by Guy Powell in the east side of Kodiak I. during the springs of 1964 through 1971 (Powell et al., 1972; Eldridge, 1975). Although Powell et al. (1973, 1974) and Eldridge (1975) have referred to or presented some of these data, a graphical summary of the size frequencies within this data is presented for the first time in this paper. These data were collected by SCUBA divers and, hence, are probably not a random sample from the population of king crabs in the area. However, the data do reflect certain trends that are not obvious in experimental breeding studies conducted with caged animals (e.g., Powell et al., 1973).

The entire data set is composed of over 3400 mating pairs. Because the data were collected during the molting period for both male and female crabs, inclusion of all shell ages would forgo any comparison with survey length frequency data collected during the summer after the molting period. Consequently, the data set was reduced to include only those 1800 pairs in which the crabs had shell ages of approximately 12-months. Newly molted males grasping females with 12-month old shells comprised most of the mating pairs not included from the larger data set.

Length frequencies for the subset of grasping males and females with 12-month old shells are plotted in Figure 2. A plot for the full data set of all grasping pairs is similar (Figure 3). The exclusion or inclusion of the animals of different shell age had little effect on the conclusions drawn from this data set. Further subdividing the data by year or area did not change the major features depicted in Figure 2. These length frequency data from grasping pairs allow a comparison of the size at which females enter into mating pairs with the minimum size at which females extrude eggs. From data collected in population surveys, the minimum size for egg extrusion in the Kodiak area is known to be approximately 100 mm in carapace length (ADF&G unpublished data; Powell et al., 1973). In support of using the grasping pair data to determine minimum size for breeding, the lower size bound for females in the mating pair data (Figure 2) agrees well with the minimum size for egg extrusion.

The length frequency distribution for males in this data indicates that males with carapace lengths less than 130 mm play an insignificant role in breeding under natural conditions. Note that the nature of the commercial fishery during the period that these data were collected -- largely unregulated except for size and sex restrictions -- should have tended to remove larger males from the stocks and, consequently, increase the proportional representation of smaller males in mating pairs. Males with carapace lengths greater than 163 mm are well represented in the mating pair data; growth per

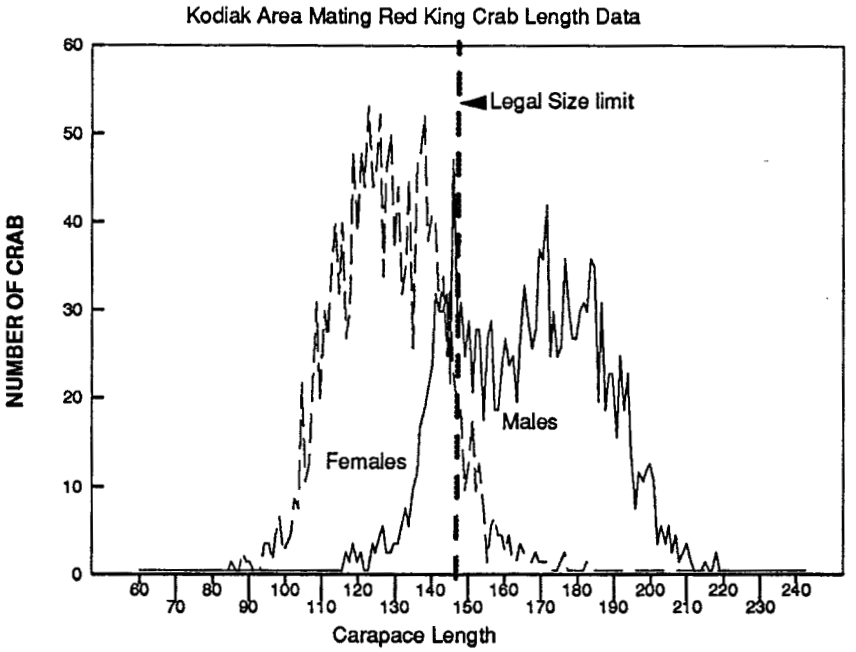

Figure 2. Length frequencies of male and female red king crab collected from the Kodiak area, 1964 through 1971. Only pairs in which both the male and female had shell ages of approximately 12-months are included.

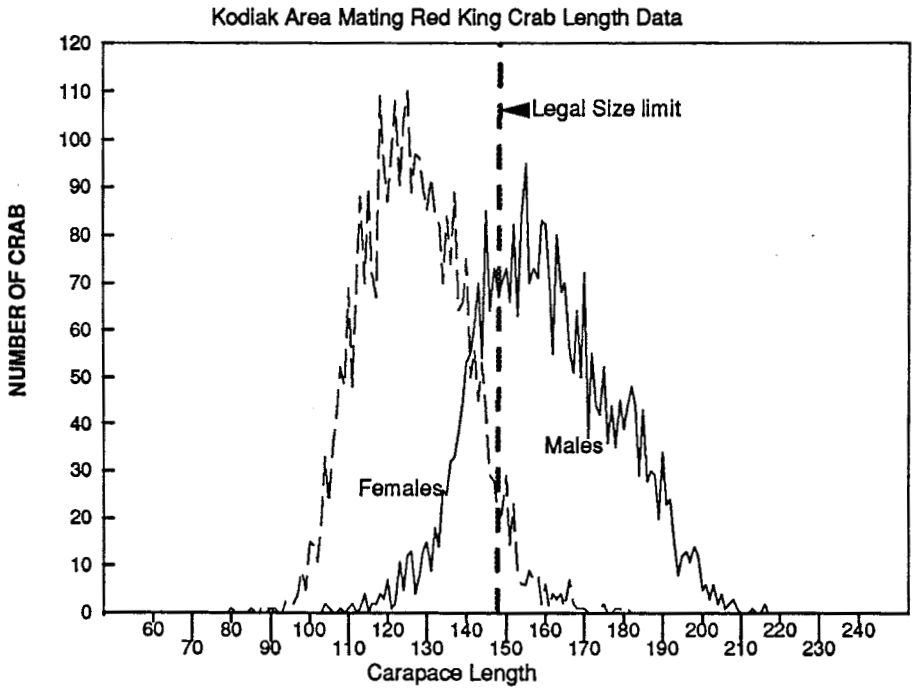

Figure 3. Length frequencies of male and fimale red king crab mating pairs collected from the Kodiak area, 1964 through 1971. Pairs of all shell ages are included.

molt data from tagging studies in the Kodiak area indicate that males in that size range have been legal-sized for at least one fishery season. Overall, these data strongly suggest that the breeding population of males is dominated by legal-sized crabs, including those that have been legal-sized for over a year.

The grasping pair data indicate that breeding males are substantially larger than the minimum size to maturity cited in earlier publications (Powell et al., 1973) and we

concluded that a carapace length of 130 mm is a generously low minimum size to delineate breeding males in length frequency data. We shall consider all males with carapace lengths greater than or equal to 130 mm as breeding males in our application of equations (1) and (2).

Effects of Size Limits and Harvest Rate on Yield per Recruit

Under the assumptions of the growth model outlined above, we can assess the effects of varying minimum legal size limits and harvest rates on yield per recruit. A "recruit" in this instance is, again, the first age class to recruit to the growth model. Yield is measured in weight (kg) and there is no attempt to attach an economic value to our yield per recruit analyses. Our results are for yield per recruit under the conditions of a fixed annual natural mortality function and a fixed harvest rate applied to legal-sized males. We assume that the period of exploitation is of short duration and that natural mortality is negligible during the harvest season. We also assume that all legal-sized crabs have an equal chance of being harvested.

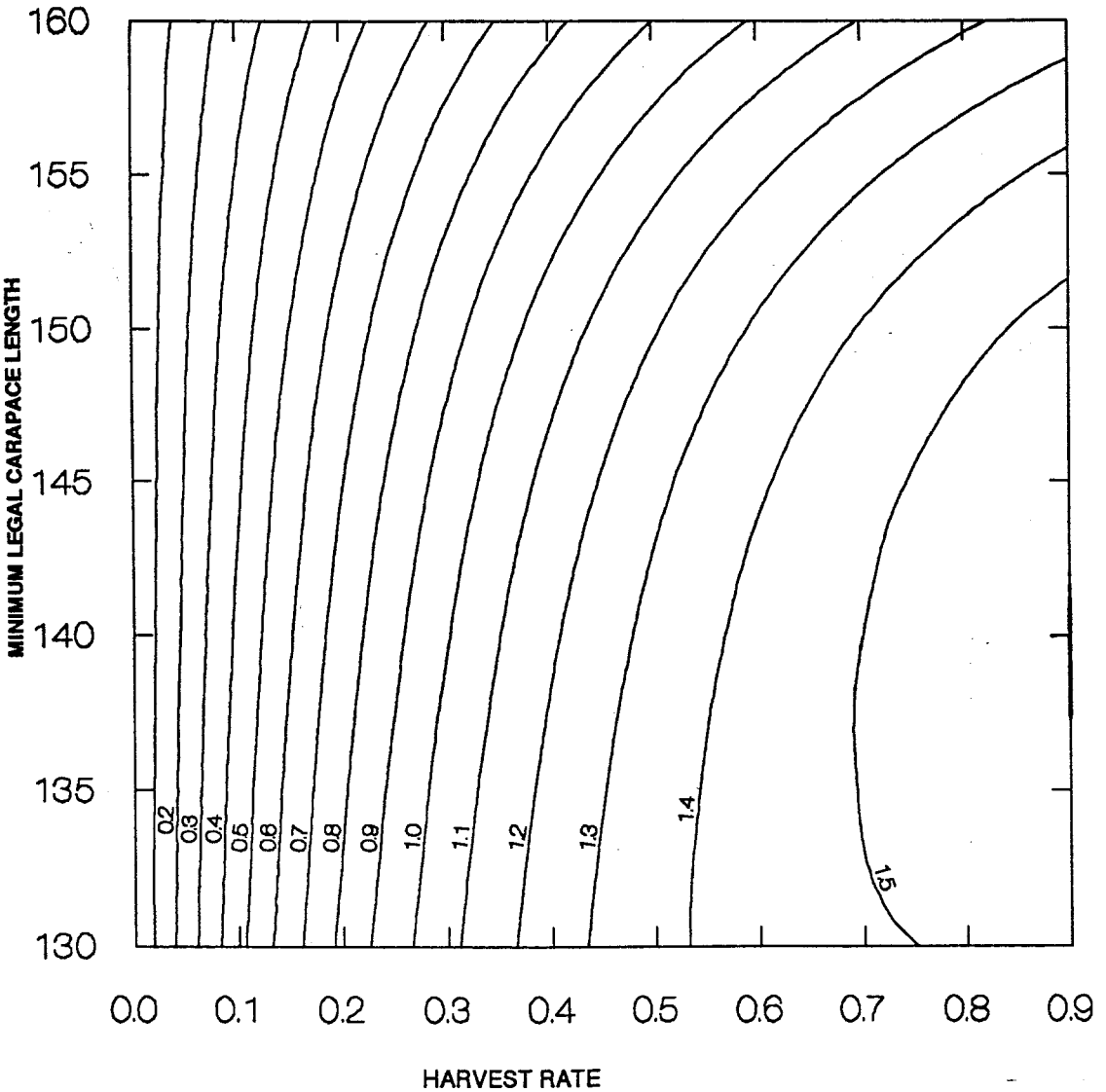

Figure 4. Yield per recruit contours based on the growth and mortality model for Kodiak area male red king crab. Yield is in kilograms.

Yield per recruit contours for minimum size limits ranging from 130 mm to 160 mm in carapace length and harvest rates of up to 90% are shown in Figure 4. Under the assumptions of our model there is little indication that a gain in yield would result by changing the current minimum size limit of 7 inches in carapace width (roughly 147 mm in carapace length). For fixed harvest rates of 60% or less, reducing the minimum size to 130 mm in carapace length, the minimum size of breeding males, will give only slight gains in yield; for higher harvest rates, reducing the minimum size would produce no gain or a slight loss in yield. Increasing the minimum size limit would reduce yield under all rates of harvest, with the reduction becoming more pronounced under the higher rates. Eldridge's (1975) yield per recruit analysis, which used an early form of the McCaughran and Powell (1977) red king crab growth model, also supported the 7 inch carapace width minimum size limit.

Our model for growth and mortality also indicates that there would be little to be gained from harvest rates greater than the current maximum rate of 60%. Under the assumptions of our model and the current minimum size of 7 inches in carapace width, a fixed yearly harvest rate of 60% would secure approximately 1.4 kg per recruit (Figure 4). This is more than 85% of the maximum yield (approximately 1.6 kg) that could possibly be derived from a cohort under any fixed harvest rate applied to legal-sized crabs with the current minimum legal size of 7 inches in carapace width.

Investigations on the Proposed Harvest Strategy

We investigated the behavior and utility of the proposed harvest strategy using the assumptions on growth, mortality, and size at maturity that have been stated or developed above. The values of E applied to equations (1) and (2) were 20% and 25%. Using a 130 mm carapace length as minimum size for breeding males and 147 mm as a minimum size for a legal crabs, we can restate the equation (2) representation of the proposed harvest strategy as,

$$H = \min\{E + E(N_p/N_l), 0.6\}, \qquad (4)$$

where E is the exploitation rate applied to breeding males, H is the harvest rate applied to legal-sized crabs, N_l is the number of legal males, and N_p is the number of sublegal males with carapace lengths greater than or equal to 130 mm. Notationally, we use N_p in equation (4) rather than $(N_b - N_l)$ as in equation (2) because sublegal males greater than or equal to 130 mm in carapace length correspond well with "prerecruit-ones" -- males one year from recruiting to the fishery. The notation N_p here indicates that this is roughly the number of prerecruit-ones. Using the proposed harvest strategy the harvest rate applied to legal crabs is linearly dependent on the ratio of prerecruit-one abundance to legal crab abundance and may range from a minimum of E to a maximum of 60%.

We will investigate this proposed harvest strategy by considering the following: (1) the steady state harvest rate on legals that would be attained under constant recruitment, (2) the behavior of the harvest strategy in the situation of a single recruitment event, and (3) the long-term behavior of the strategy through simulation studies of random recruitment. We use "recruitment" to mean recruitment to the recruit age-class in the growth model. All results reported here are from computer simulations of the proposed harvest strategy applied to the growth and survivorship model described earlier.

Steady state harvest rates on legal crabs. Under conditions of constant annual recruitment, the harvest rate applied to legal crabs prescribed by the proposed harvest strategy will converge to a fixed annual harvest rate. In the case when the minimum harvest rate, E, is set at 20%, the steady state harvest rate on legal crabs converges to 36%. Yield per recruit at a fixed annual harvest rate of 36% on legals is 1.05 kg, or 77% of that attained by a fixed harvest rate of 60%. If E is increased to 25%, the steady state harvest rate on legals converges to 47%. At a fixed harvest rate of 47%, yield per recruit is 1.23 kg, or 89% of that attained by a harvest rate fixed at 60%. The 36% steady state harvest rate is at the high end of the rates prescribed by the current harvest strategy when population sizes are "depressed"; the 47% steady state harvest rate is at the center of the rates prescribed by the current harvest strategy when population size is "average" (Table 1).

We used these steady state harvest rates and the 60% harvest rate as benchmarks for comparison in our studies of the behavior of the proposed harvest strategy.

Behavior of the proposed harvest strategy when applied to a single recruitment event. Here we consider the behavior of the proposed harvest strategy when it is applied through the life span of a single cohort recruited to the growth model. This allows for a detailed examination of the responses of the proposed harvest strategy to changes in the size distribution and abundance of a stock. This should also give an idea of how the proposed harvest strategy will respond through time when a stock is dominated by a single cohort.

In the first year of recruitment, the number of breeding males will be small and the number of legal crabs will be negligible relative to the size of the recruiting cohort (Table 3). In the second year, breeding males will be dominated by sublegals and the

Table 3. Simulation results for yearly harvest rate on legal crab in a population composed of a single cohort of males. Year 1 is year that the cohort recruits to the growth model. "Breeding" denotes the number per recruit of males with carapace lengths greater than or equal to 130 mm. "Legal" denotes the number per recruit of legal-sized crab. "Rate" is the harvest rate applied to legal crab.

EXPLOITATION RATE, E, ON BREEDING MALES = 20%									
Year	1	2	3	4	5	6	7	8	9
Breeding	0.07	0.50	0.53	0.32	0.13	0.05	0.02	0.01	0.00
Legal	0.00	0.06	0.37	0.30	0.13	0.05	0.02	0.01	0.00
Rate	-	60%	29%	22%	20%	20%	20%	20%	20%
EXPLOITATION RATE, E, ON BREEDING MALES = 25%									
Year	1	2	3	4	5	6	7	8	9
Breeding	0.07	0.50	0.53	0.30	0.12	0.04	0.01	0.00	0.00
Legal	0.00	0.06	0.37	0.28	0.12	0.04	0.01	0.00	0.00
Rate	-	60%	36%	27%	25%	25%	25%	25%	25%

harvest rate on legals will be at the maximum value of 60%. Two years after recruitment, the harvest rate decreases to a value below the corresponding steady state harvest rate. In that year, the breeding males are dominated by legal crabs and the reduction in harvest rate is in response to the relatively low abundance of sublegal breeding males. By the third and following years after recruitment, the harvest rate is near or at the minimum.

The yearly and total yield per recruit obtained using the proposed harvest strategy is compared to those obtained using harvest rates fixed at the steady state values and at 60% in Table 4. Using the proposed harvest strategy, the yield from the cohort will be lower than those obtained using the fixed harvest rates. This relative reduction in yield is most apparent during the second and third years after recruitment, when the cohort is in the + 2 and + 3 age-classes. In those years and in the subsequent years of the cohort's lifetime, the proposed harvest strategy serves more to protect the breeding males than to maximize yield (Table 5).

Simulation studies on the long-term behavior of the proposed harvest strategy. We investigated the long-term behavior of the proposed harvest strategy through computer

Table 4. Simulation results for yield (kg) per recruit from stock composed of a single cohort of males. Year 1 is the year that the cohort recruits to the growth model.

Year	Proposed Harvest Strategy with:		Fixed Exploitation Rate on Legal Crab of :		
	E=20%	E=25%	36%	47%	60%
1	0.00	0.00	0.00	0.00	0.00
2	0.10	0.10	0.06	0.08	0.10
3	0.33	0.41	0.42	0.54	0.68
4	0.22	0.26	0.35	0.40	0.43
5	0.10	0.11	0.15	0.14	0.13
6	0.04	0.04	0.05	0.04	0.03
7	0.02	0.02	0.01	0.01	0.01
8	0.01	0.01	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00
Total	0.82	0.95	1.05	1.23	1.37

simulations of recruitment, growth, mortality, and exploitation. We modelled the yearly magnitude of recruitment into the growth model as being a lognormally distributed "white noise" process (i.e., the magnitude of recruitment to the growth model is random and uncorrelated among years). We investigated the behavior of the proposed harvest strategy under two random recruitment models. One is a "low variability" model, in which the yearly magnitude of recruitment has a coefficient of variation equal to 25%; the other is a "high variability" model with a coefficient of variation of 100%. In both models, the median of the recruitment abundance index is 1. Simulation results reported here are all based on 1,000 simulated years of recruitment.

Under random recruitment, the harvest rates applied to legal crabs prescribed by the proposed harvest strategy will be centered about the steady state harvest rates of 36% for E = 20% and 47% for E = 25% (Table 6). Not surprisingly, yearly variability in the harvest rates on legal-sized crabs increases with variability in recruitment. Lower values of E will also tend to give lower yearly variability in harvest rates for a fixed level

Table 5. Simulation results for number per recruit of crab with carapace lengths greater than or equal to 130 mm that escape harvest. Results are for a stock composed of a single cohort of males. Year 1 is year that the cohort recruits to the growth model.

	Sublegal	Legal					
		Proposed Harvest Strategy with:			Fixed Exploitation Rate on Legal Crab of:		
Year	No Harvest	No Harvest	E=20%	E=25%	36%	47%	60%
1	0.071	0.000	0.000	0.000	0.000	0.000	0.000
2	0.439	0.063	0.025	0.025	0.040	0.033	0.025
3	0.159	0.397	0.263	0.237	0.243	0.199	0.148
4	0.025	0.397	0.233	0.202	0.181	0.132	0.084
5	0.001	0.209	0.104	0.086	0.067	0.042	0.022
6	0.000	0.095	0.038	0.029	0.019	0.010	0.004
7	0.000	0.043	0.014	0.010	0.006	0.003	0.001
8	0.000	0.019	0.005	0.003	0.002	0.001	0.000
9	0.000	0.009	0.002	0.002	0.001	0.000	0.000

of variability in annual recruitment. Due to the maximum harvest rate cap of 60%, however, there is a point where variability in harvest rates will decrease with increasing values of E or variability in recruitment. Variability in harvest rate will decrease as a higher proportion of the yearly harvest rates attain the 60% maximum (e.g., compare the results for E = 20% with that of E = 25% in the "high variability" recruitment model simulations).

Table 6. Simulation results for yearly harvest rate on legal crab using the proposed harvest strategy in a randomly recruiting population. CV is the coefficient of variation of the yearly harvest rates. Q1 - Q3 are the first and third quartiles of the yearly harvest rates.

EXPLOITATION RATE, E, ON BREEDING MALES = 20%		
RECRUITMENT MODEL		HARVEST RATE ON LEGALS
Low Variability	Mean:	36.1%
	CV:	7.9%
	Median:	35.7%
	Q1 - Q3:	34.2% - 37.7%
High Variability	Mean:	37.1%
	CV:	25.2%
	Median:	34.2%
	Q1 - Q3:	30.3% - 41.2%
EXPLOITATION RATE, E, ON BREEDING MALES = 25%		
RECRUITMENT MODEL		HARVEST RATE ON LEGALS
Low Variability	Mean:	47.1%
	CV:	8.2%
	Median:	46.7%
	Q1 - Q3:	44.5% - 49.4%
High Variability	Mean:	46.3%
	CV:	19.4%
	Median:	44.4%
	Q1 - Q3:	39.0% - 54.1%

Yield per recruit for random recruitment under the proposed harvest strategy also tends towards the steady state results for constant annual recruitment -- 1.06 kg for E = 20% and 1.23 kg for E = 25% (Table 7). These central values of yield per recruit compare with a yield per recruit value of 1.38 kg attained under a fixed annual harvest rate on legals of 60%. Variability in yield per recruit among the recruiting cohorts is low, with coefficients of variation from the simulation studies ranging from 2.6% to 6.1%. Variability in yield per recruit under this harvest strategy increases with variability in annual recruitment.

Finally, we consider stability in the weight (kg) of yearly landings under the proposed harvest strategy and compare it with that of fixed yearly harvest rates. We compare stability in yearly landings using two measures, the coefficient of variation of yearly landings and the correlation between landings in adjacent years (i.e., the autocorrelation of yearly landings at a one year lag). The coefficient of variation measures the variability of yearly landings relative to the mean of annual landings. The adjacent year correlation measures the smoothness and year-to-year predictability of annual landings.

The results of our simulation studies on stability of landings are presented in Table 8. Variability in yearly landings under any harvest strategy will obviously be determined by the level of variability in recruitment. Our results indicate that the proposed harvest strategy will, under random recruitment, yield yearly landings that are at least as stable as, and probably more stable than, those produced by harvest rates fixed at the steady state values of 36% and 47%. Landings under the proposed harvest strategy would certainly be more stable than those under a fixed harvest rate of 60%.

Table 7. Simulation results for yield (kg) per recruit using the proposed harvest strategy in a randomly recruiting population. CV is coefficient of variation. Q1-Q3 are the first and third quartiles.

EXPLOITATION RATE ON BREEDING MALES = 20%		
RECRUITMENT MODEL		YIELD PER RECRUIT
Low Variability	Mean:	1.055
	CV:	2.6%
	Median:	1.055
	Q1 - Q3:	1.035 - 1.073
High Variability	Mean:	1.072
	CV:	8.5%
	Median:	1.065
	Q1 - Q3:	1.003 - 1.134
EXPLOITATION RATE ON BREEDING MALES = 25%		
RECRUITMENT MODEL	YIELD PER RECRUIT	
Low Variability	Mean:	1.228
	CV:	2.4%
	Median:	1.228
	Q1 - Q3:	1.207 - 1.247
High Variability	Mean:	1.216
	CV:	6.1%
	Median:	1.225
	Q1 - Q3:	1.160 - 1.270

Table 8. Simulation results on stability of yearly landings (kg) from a randomly recruiting population. CV is coefficient of variation. r(1) is autocorrelation of yearly landings at one year lag.

RANDOM RECRUITMENT MODEL	Proposed Harvest Strategy with:		Fixed Exploitation Rate on Legal Crab of:		
	E=20%	E=25%	36%	47%	60%
Low Variability					
CV:	11.6%	11.8%	11.8%	14.5%	15.2%
r(1):	0.78	0.77	0.71	0.67	0.62
High Variability					
CV:	43.7%	45.0%	54.9%	57.1%	60.0%
r(1):	0.80	0.76	0.71	0.67	0.62

SUMMARY AND CONCLUSIONS

The red king crab harvest strategy that we have proposed maintains harvest rates on legal crabs which fall within the range of those prescribed by the currently used harvest strategy. Compared to the current strategy, the proposed strategy has the desirable property of being unambiguous in application. This proposed strategy is conservative in that it sets a low fixed rate, E, of exploitation on breeding males. The harvest rate on legal crabs is adjusted from a minimum of E up to a maximum of 60% in response to the ratio of prerecruit breeding males to legal-sized males. Although our results are preliminary and dependent upon the assumptions of our growth and mortality model, the simulation studies indicate that the proposed harvest strategy is superior to a fixed harvest rate strategy in the degree of protection it affords to breeding males and in the relative stability of yearly landings it provides without forfeiting the long-term yield per recruit.

We have investigated the cases where E has values of 20% and 25%. The actual choice of E in the application of this harvest strategy would depend on how conservative management should be in protecting breeding males at the expense of reducing yearly landings. Determining the optimum balance between yield per recruit and protection of breeding males is presently impossible due to the poor understanding of the relationship between parental stock size and future recruitment to the fishery. On this point, however, we note that the grasping pair data presented in this paper, which indicate that breeding males are dominated by legal-sized crabs, suggests that protection of breeding males may require more conservative harvest strategies than was previously believed.

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APPENDIX C

Estimation of Bering Sea king crab size of maturity and the effect of the proposed harvest strategy on historic exploitation rates of legal male King Crab

I. Introduction

The Bering Sea populations that are addressed in this report are the Bristol Bay red king crab, the St. Matthew blue king crab , and the Pribilof blue king crab. This report examines the available data on size of maturity for these populations. Harvest rates from 1973 through 1989 are calculated to demonstrate the effect of the proposed changes by applying the guideline harvest level calculation to each years survey estimate of mature male crab. Application of the proposed harvest strategy to these populations requires size of maturity to be estimated with accuracy.

Given the absence of mating pair data for these populations, we assume that the minimum age that male crab become reproductively active in the Bering Sea blue and red king crab stocks, is of the same age cohort represented by the smallest mating pair males observed in studies from the Kodiak area. Size at which crab become reproductively active is estimated by using size at age data from the Bering Sea stocks, and comparing with the size at age model developed for the Kodiak stock in Appendix B. We considered the efforts of Somerton and McIntosh (1983) and Wallace (1949) in determining male maturity sizes for these populations by measuring the development rate of secondary sexual characteristics. These methods have been rejected because of the lack of significance of the fitted equations and/or wide confidence intervals in the parameters estimated (Johnson, 1990). Additionally, the size of maturity determined by these methods suggest a much smaller size of maturity than the size of observed breeding males collected in the field (Appendix B).

The use of size limits developed in this report will insure consistency in the application of an exploitation rate to mature male crab among stocks and between the species. Lacking actual mating pair data this method will provide a comparable estimate of the active reproductive population among all king crab stocks being considered in the westward region.

II. Methods

Use of assumptions identical to those used in the analysis of the Kodiak data requires that the growth parameters from Bering Sea crab populations be related to the Kodiak population.

Data available for the Bristol Bay red king crab include chela and merus growth data for females (Wallace, 1949; Somerton and MacIntosh, 1983), growth models (Otto, 1985; Balsiger, 1974). Takeshita et al. (1989) also provided initial descriptive information on the proportion of the population of red king crab in Bristol Bay that migrates seasonally with the females during the mating and molting period. Takeshita (personal communication,1989) also stated that size and shell age data suggests these animals begin this behavior at age 8.

Data for the blue king crab populations in the Pribilof and St. Matthew Districts are available from Somerton and MacIntosh (1983) and Otto and Cummiskey (1989).

From these data, we used the Bristol Bay red king crab size at age data of Balsiger (1974). These data were also used in the report by Otto (1985). We used the female size of maturity data from Otto et al. (1989) for all Bering Sea king crab stocks analyzed. Growth per molt data used for the blue king crab analysis were from Otto and Cummiskey (1989). Size of maturity from chela allometry studies listed above were not used but are included in the discussion of this report.

The age estimation method used in this report, is based on the use of female size of maturity as a common reference point. Actual age of the crab stocks may vary from the values reported because of unknown rates of growth prior to the time period when crab are assessed with trawl gear. We have a poor understanding of the annual growth of crab prior to the molt of females to sexual maturity. Therefore the age provided is relative and reflects the differences in numbers of molts assuming males and females were of the same size one molt prior to females reaching sexual maturity.

These data from the published reports provide common growth bench marks, to estimate size at age from these different species or stocks. The equivalent size at maturity for each stock (established at 130 mm for the Kodiak area in Appendix B) is estimated by linear interpolation between the sizes at age (expressed as carapace length). Male Kodiak red king crab reached a minimum size of maturity (CL = 130 mm) between estimated ages 6 and 7.

In the case of blue king crab, a growth model is poorly established. Otto and Cummiskey (1989) provide data suggesting similar growth per molt data for the Pribilof and St. Matthew blue crab populations. Survey length frequency data suggest these populations have decidedly different growth rates, despite similar growth per molt values obtained from tag recoveries of adult male crab. We assume this difference is caused by different molting probabilities as the crab reach sexual maturity. We assume that prior to sexual maturity, molting occurs annually in both of these populations. We also assume that male crab in these populations do not become reproductively active until reaching approximately two molts beyond the common molt at which females reach sexual maturity and male and female blue king crab have the same size one molt prior to females reaching sexual maturity. Further, we adjusted the size at age of the male crab to be identical with females at assumed age 4. We then applied the growth per molt data provided by Otto and Cummiskey (1989) to the size increments resulting from this common size at age. The estimated size of reproductive maturity of male king crab from all stocks is rounded to the nearest 5 mm carapace length increment.

III. Results

Table 1. depicts growth parameters for the four stocks considered. The age/length data for Kodiak and Bristol Bay red king crab are from Balsiger (1974) and Schmidt and Pengilly (1989). Female size of maturity for Kodiak is from Powell et al. (1973). Female size of maturity for Bering Sea stocks are from Otto et al.(1989). Growth per molt data for Bering Sea blue king crab are from Otto and Cummiskey (1989). The 130 mm size of reproductive maturity for Kodiak red king crab is from the Kodiak mating pair data presented in Appendix B.

Table 1 also lists the size of maturity data for all three Bering Sea king crab stocks rounding to the nearest millimeter. The blue king crab size at age data from the Pribilof and St. Matthew areas are speculative, and are based on the assumption of common size at age of males and females one molt prior to maturity and the assumption that the age of females at maturity in the Kodiak area is identical to the age of maturity in the Bering

Table 1.Growth parameters used to estimate minimum size of reproductively active male king crab in the Bering Sea

Area	Minimum Size of Maturity Females	Growth Per Molt	Estimated Age (Molts) 4	5	6	7	8	9	Minimum Size of Maturity Males
Kodiak red king crab	100	(See Est. Age)	82	98	116	134	152	161	**130***
Bristol Bay red king crab	89	(See Est. Age)	82	96	111	125	136	145	**120**
Pribilof blue king crab	96	14 mm	82	96**	109	122	133	140	**120**
St. Matthew blue king crab	81	14 mm	67	81**	95	108	117	118	**105**

***From Appenidix B, Kodiak grasping pair data.**
****Assumes female C.L. = male C.L. at one molt below female C.L. at 50% maturity. Growth data from Otto et al. (1989)**

sea. The values for size of maturity parallel the differences among these fisheries in the current legal size limits.

An exploitation rate of 20% was applied to all male crab equal or greater in carapace width to the values in Table 1 for the estimated size of reproductive maturity. The harvest rates that would have occurred, given the survey results for the stocks listed in Table 1, are listed on Table 2. Note that the actual harvest rates may have been significantly different if this policy were in place during these years. The number of post recruit crab that survive into the next years fishery may have varied significantly under this policy.

IV. Discussion

This report provides justification to redefine the size of reproductively active male crab of the Bering Sea red and blue king crab species. In addition, the management plan proposed for this area, requiring an exploitation rate of 20% on sexually mature crab, is evaluated with respect to harvest rates that result from the survey data available from the recent past.

The size of maturity for male crab is much larger than the values previously published for these stocks of red and blue king crab (Balsiger, 1974; Somerton and MacIntosh, 1983). This is the result of using the Kodiak Management Area mating pair data as the basis for determining the minimum size of maturity of male crab. These types of data (grasping pairs) are difficult to obtain. However, the Kodiak grasping pair data are the only source of information that takes into account behavioral responses associated with sexual maturity of crabs in a natural environment. Although the mating pair data does not reflect what crab would mate if the large males were not present, our own observations of red king crab in the Kodiak area and the data presented by Takeshita (1989) for the Bristol Bay red king crab suggest that only a portion of the male crab population migrates with the females during the breeding period. These crab tend to be skip molts and larger than the crab which do not migrate. Such observations suggest that accommodation for commercial removal of larger males may be unlikely as the smaller or newly molted crab may not even be present at the appropriate time and area to successfully breed. Recent experimental studies of mating pair data by Paul and Paul (1989) suggests that males below 120 mm from Kachemak Bay and from Kodiak Island had a reduced reproductive success when compared with crab greater than 120 mm. Their ability to successfully mate multiple females was significantly reduced with occasional instances

Table 2. Harvest rates of legal males which result from application of the 20% exploitation rate on reproductive active males, with a maximum harvest rate of 60% on legal males allowed. Values are estimated using formula 4 from Appendix B. Mature males sizes are from Table 1. Legals males are from 135 mm and larger size classes for Bristol Bay red king crab and Pribilof blue king crab. Males 120 mm and larger are considered legal for the St. Matthew blue king crab.

	Fishery		
	Bristol Bay Red King Crab	Pribilof Blue King Crab	St. Matthew Blue King Crab
Year	Harvest Rate	Harvest Rate	Harvest Rate
1969	45%		
1970	39%		
1972	38%		
1973	49%		
1974	38%	40%	
1975	38%	33%	
1976	38%	26%	
1977	40%	23%	
1978	32%	36%	47%
1979	30%	24%	41%
1980	28%	24%	38%
1981	40%	24%	32%
1982	56%	24%	28%
1983	60%**	27%	29%
1984	56%	26%	28%
1985	60%	26%	26%
1986	45%	21%	41%
1987	40%	21%	40%
1988	32%	20%**	36%
1989	30%	25%**	33%
Avg.	42%	26%	35%

***Data from Stevens and MacIntosh, 1989. Estimates of 120 mm to 134 mm crab numbers for 1969-1982 Bristol Bay red and all years of the Pribilof blue king crab were estimated by taking .6 of the 110-134 mm size class.**
**** Fishery Closed**

of cannibalism when the small males were presented with multiple females. In addition, one instance of cannibalism was noted for a larger male when multiple matings were presented. Further, recent analysis of Bristol Bay red king crab spermatophores indicate full development has not occurred until male king crab reach a carapace width of 120 mm (Personal communication, R. Otto and A. J. Paul, 1990). Chela allometry, such as that produced by Somerton and MacIntosh (1983) provide data that is inconsistent with the observations of mating pairs of red king crab in the Kodiak area. For example, the size of maturity of females is presented as 80.6 mm, 3 mm larger than the size of maturity established for males in the population. The observations of Powell et al. (1972) indicated that females mating with males smaller than themselves is a very rare event, rather than the norm, as suggested by the St. Matthew estimations of similar size of maturity between the sexes. Without further data on the size, shell age, or real age of reproductively active crabs in these populations, the determination of size of maturity by the methods used in this report provide a conservative estimate of the sexually mature component of these stocks.

Because of the limitations in the published values for these species, the method presented here is considered preferable. This method reduces the risk of incorrectly classifying animals that do not actively participate in reproduction as "sexually mature". Conse-

quently the values presented for size at reproductive maturity will be used in the determination of the harvest rates for these stocks in the future.

The harvest rates that would have been applied to legal crab using historical survey data suggest the method would provide similar levels of harvest on the long term but individual years could vary significantly from the past. The adoption of this method should provide little change from the historical removal rate but should provide somewhat increased stability in landings.

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Appendix D

A Comparison of Alternative Harvest Rate Strategies

I. Introduction

Based on comments from the public and staff during the initial evaluation period of the management plans, a wider range of harvest rate strategies have been analyzed beyond those presented in Appendix B. The effects of these alternative harvest strategies have been presented in a less technical format to foster greater understanding of their implications to the fishing industry.

The alternatives explored include the following:

1. The current harvest table after defining the ambiguous terms.

2. A fixed harvest rate strategy on legal crabs ranging from 28% to 90%. The 90% is assumed to emulate a size, sex and season fishery with no limit on exploitation rate.

3. A fixed exploitation rate on sexually mature male crab using rates of 15%, 20%, 25%, and 30%.

We have projected the annual landings by weight, numbers of mature males remaining on the grounds after the fishery, and sex ratios for each of the above harvest strategies for about two decades. We projected the values using the recruitment pattern of young crab moving into the fishery observed in the southwest Kodiak district since the commercial fishery was developed. A fifteen year period (1970-1984) of this history is used to illustrate the effects of the alternative harvest strategies. To promote clarity, the last 9 years are provided in the Figures.

To illustrate the effects of different survival rates on landings, sex ratios, and abundance of sexually mature males, the survival schedule listed in Appendix B is compared to fixed survival rates of .9, .75, and .5. We have also produced one additional alternative mortality schedule. This reflects a constant survival rate of .75 during the increasing phase (years 1 through 8) of the time series with a .5 survival rate during the decreasing phase (years 9 through 15) of the time series. This is to approximate one possible explanation of the decline in harvests of Bristol Bay red crab during the past decade.

By allowing year by year comparisons, rather than presenting simulated long term averages, variances, and other statistical parameters, we are attempting to facilitate greater understanding of the implications of these harvest strategies.

II. Results

To compare the alternative harvest strategies with the current harvest table required definitions for the ambiguous terms in the table. We defined the term "Population" as all male crab 6 years or older. We defined a population as depressed when it was less than one standard deviation below the mean and peak when the population was greater than one standard deviation above the mean. We assumed all depressed populations had declining pre-recruits, all average populations had stable pre-recruits, and all peak populations had increasing pre-recruits. To simplify the simulation we did not adjust

harvest rates based on post-recruit abundances. This resulted in harvest exploitation rates of 20% on depressed populations, 40% on average populations, and 60% on peak populations. The mean and standard deviation estimations were updated annually during the simulations.

Figure 1 illustrates the differences in landings which would result from the current harvest table. Also illustrated in this figure are a fixed harvest rate on legal crab of 36%, a fixed harvest rate on legal crab of 90% (3-S management strategy), and a fixed exploitation rate of 20% on sexually mature crab. The survival rate used is identical to that used in Appendix B of this report. Note the nearly identical results between the proposed strategy and the current harvest table. Clearly the highest landings and the least stability in landings (i.e. more peaks and valleys) result with a 3-S management strategy. The average landings over the period simulated are listed in Table 1 along with the values plotted in Figure 1. Note the similarity for all of the policies with the exception of the 3-S policy.

Figure 2 illustrates sex ratio differences over time that result from the various harvest strategies. A cut line is provided to illustrate all of the years where the sex ratio is greater than four females to one male. Note that all of the harvest strategies with the exception of the 3-S harvest strategy, provide sex ratios within the four to one (females to males). The sex ratio are based on sexually mature males (greater than 130 mm) with all females greater than six years old. Equal natural mortality rates were applied to both sexes. These data are also contained in Table 1.

Figure 3 illustrates the number of mature males remaining on the grounds after the fishery is completed. Note that even with 3-S management, the relative number of reproductive male animals is highly variable.

Figures 4,5, and 6 illustrate the same concept as in Figure 1, 2, and 3 except the survival rate is set at a constant of .75. The values illustrated are also contained in Table 2. Note, the difference in average landings in Table 2 when 3-S management is compared with the other strategies. The landing differences are less than those listed in Table 1. The very high sex ratios are maintained, however. Also note the continued similarity between the 20% exploitation rate on mature males and the values generated by using the current harvest table.

Figures 7,8, and 9 illustrate the same simulation results with a survival rate of .50. The values are also listed in Table 3. Note that in this instance, the increased yield resulting in 3-S management is substantial but that the sex ratios still remain abnormally high when stocks are lowest. Again, the 20% harvest strategy provides very similar results when compared with the current harvest table.

Figures 10,11, and 12 illustrate the same simulations with a .90 survival rate. The values for this simulation are in Table 4. Note that in this case no significant yield is gained with 3-S management. The harvest table and the 20% exploitation rate on mature males again remain very similar.

Figures 13,14 and 15 illustrate the effects of an increase in natural mortality rates after a period of peak abundance. The values from the illustrations are listed in Table 5. An assumed .75 survival rate was initiated during the population expansion and a .5 survival rate was initiated during its decline. Again note the similarity between the harvest table and the proposed 20% exploitation rate. Also note the resulting sex ratios from 3-S management.

We have compared the simplified definition of the harvest strategy table with a more complex definition for a single survival scenario. This example is also provided to illustrate the complexity of the current table and the number of assumptions required. To compare the elaborate interpretation of the harvest table with the simplified version used in the previous simulations, a single run was completed using the following definitions for the various parameters in the harvest table. The term population was defined as the 6 year old and older males for both simulations (detailed versus simplified). The depressed category was defined as the above defined population being below one standard deviation from the mean with the mean and standard deviation updated annually. Average populations were defined as all abundance levels within one standard deviation of the mean and peak populations were greater than one standard deviation from the mean. Pre-recruits were defined using the size categories applied to survey size frequency data: male crabs with carapace lengths of 111 to 128 mm were considered to be two years from recruiting to the fishery, while those with carapace lengths of 129 to 146 mm were considered to be one year away from legal size. When pre-recruits one and two years prior to recruiting to the fishery showed an increase from the previous year the pre-recruits were classified as increasing. When both showed a decrease, they were classified as decreasing. When one showed an increase and the other a decrease they were classified as stable. The post-recruits were classified using standard length classifications traditionally interpreted from survey results: all old shell males of legal size (i.e., carapace lengths of 147 mm or greater) and all male crabs with carapace lengths of 163 mm or greater. Table 6 lists the comparative values for the simplified versus the complex interpretation of the harvest table. Note that there is very little difference in the results for any of the parameters over the simulation period.

We also have provided additional variations in the proposed fixed exploitation rate harvest strategy on mature males of 0% (No fishery), 15%, 20% (proposed), 25% (previously used in Appendix B), and 30%. Figures 16, 17 and 18 provide comparisons of landings, sex ratios, and mature males left on the grounds, when a fixed 75% survival rate was assumed. The values from these figures are contained in Table 7. Note the loss of yield from the 15% rate when compared with the 20 % rate and the sex ratios which result from the use of the 25% and the 30% rate.

III. Discussion

With the interpretation of the current harvest table used in these simulations, the result is equivalent to using a constant exploitation rate of approximately 20% applied to the mature male population. Any differences observed are well within our measurement error from either surveys or fishery performance data. In the actual application of estimating guideline harvest levels, use of a constant exploitation rate harvest strategy would be less sensitive to errors in preseason survey estimates of population size than the current harvest table.

Alternative policies such as a fixed exploitation rate resulting in equivalent yields applied to legal male animals only (similar to our current Tanner crab harvest strategy), provides no obvious benefits over the current harvest table or the proposed strategy. The 3-S management provides consistently unacceptable sex ratios but with gains in yield. These gains are most apparent when natural mortality is high. This however, is the same period when stocks have the highest risk to over fishing. The resultant highly skewed sex ratios on very low populations would be considered a significant conservation risk.

IV. Conclusions

The replacement of the harvest table with the fixed exploitation rate of 20% applied to mature male animals is a reasonable alternative to the current harvest table as it removes ambiguity, simplifies calculations, and provides essentially identical results with the current harvest table using the assumptions provided. Its adoption will primarily serve to simplify calculations and remove subjective interpretations of the current harvest table.

Table 1. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 75% with an accelerating mortality schedule with skip molt and older crab. Alternatives provided are a fixed 20% exploitation rate on mature male crab, a fixed harvest rate of 36% on legal male crab, a fixed harvest rate of 90% (3-S management), and the current harvest strategy table. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

LANDINGS

YEAR	PROPOSED E=20%	FIXED H=36%	FIXED H=90%	TABLE
1	1.12	0.67	0.98	0.71
2	0.97	1.23	2.37	1.33
3	1.02	1.04	1.23	1.10
4	1.12	0.96	1.43	1.02
5	1.06	1.17	1.93	0.62
6	0.89	1.09	1.49	0.67
7	0.75	0.80	0.94	1.08
8	0.87	0.65	0.88	0.76
9	1.23	0.89	1.57	1.47
10	1.35	1.43	2.59	1.40
11	1.07	1.51	2.21	0.78
12	0.65	0.95	0.89	0.60
13	0.33	0.43	0.24	0.32
14	0.17	0.18	0.11	0.15
15	0.11	0.10	0.09	0.08
Avg.	0.85	0.87	1.26	0.81

RATIO BREEDING FEMALES:BREEDING MALES (AFTER HARVEST)

YEAR	PROPOSED E=20%	FIXED H=36%	FIXED H=90%	TABLE
1	2.11	1.96	2.53	2.01
2	2.40	2.42	4.73	2.53
3	2.92	2.97	5.12	3.11
4	2.47	2.40	3.60	2.49
5	2.09	2.10	3.71	1.90
6	2.25	2.40	5.04	1.97
7	3.08	3.29	6.19	3.11
8	3.70	3.59	5.10	3.62
9	2.66	2.45	3.32	2.77
10	1.85	1.78	2.93	1.92
11	1.78	1.92	4.90	1.72
12	2.11	2.64	11.1	1.98
13	2.65	3.71	16.3	2.44
14	3.00	4.18	11.4	2.71
15	3.02	3.79	7.45	2.66

BREEDING MALES REMAINING AFTER HARVEST

YEAR	PROPOSED E=20%	FIXED H=36%	FIXED H=90%	TABLE
1	1.32	1.42	1.10	1.39
2	1.22	1.21	0.62	1.16
3	1.20	1.18	0.68	1.13
4	1.33	1.37	0.91	1.32
5	1.30	1.29	0.73	1.42
6	1.05	0.98	0.47	1.20
7	0.85	0.80	0.42	0.85
8	1.01	1.04	0.73	1.03
9	1.52	1.65	1.22	1.46
10	1.70	1.77	1.07	1.64
11	1.28	1.18	0.46	1.33
12	0.72	0.58	0.13	0.77
13	0.34	0.24	0.05	0.37
14	0.17	0.12	0.04	0.19
15	0.11	0.09	0.04	0.13
Avg.	1.01	1.00	0.58	1.03

Table 2. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 75% assuming a constant value with all crab. Alternatives provided are a fixed 20% exploitation rate on mature male crab, a fixed harvest rate of 36% on legal male crab, a fixed harvest rate of 90% (3-S management), and the current harvest strategy table. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

ANNUAL LANDINGS

YEAR	PROPOSED E=20%	FLAT H=36%	FLAT H=90%	TABLE
1	1.40	0.93	1.01	0.47
2	1.15	1.43	2.39	1.67
3	1.15	1.18	1.24	1.31
4	1.31	1.19	1.48	1.28
5	1.23	1.37	1.95	0.73
6	1.04	1.29	1.52	0.80
7	0.93	1.04	0.98	1.46
8	1.09	0.89	0.91	1.10
9	1.42	1.07	1.59	1.81
10	1.49	1.58	2.60	1.51
11	1.18	1.68	2.24	0.84
12	0.82	1.20	0.94	0.74
13	0.56	0.72	0.29	0.54
14	0.39	0.42	0.12	0.37
15	0.28	0.25	0.10	0.26
Avg.	1.03	1.08	1.29	0.99

BREEDING MALE:FEMALE RATIO AFTER HARVEST

YEAR	PROPOSED E=20%	FLAT H=36%	FLAT H=90%	TABLE
1	2.28	2.26	3.14	2.16
2	2.57	2.72	5.64	2.74
3	3.01	3.16	5.70	3.27
4	2.51	2.53	4.08	2.64
5	2.20	2.29	4.30	2.07
6	2.37	2.62	5.98	2.13
7	3.09	3.48	7.34	3.20
8	3.65	3.77	5.86	3.75
9	2.71	2.60	3.69	2.96
10	1.99	1.96	3.34	2.13
11	1.94	2.13	5.74	1.93
12	2.21	2.83	13.9	2.14
13	2.60	3.90	24.5	2.48
14	3.03	5.07	23.7	2.84
15	3.41	5.87	18.6	3.11

BREEDING MALES AFTER HARVEST

YEAR	PROPOSED E=20%	FLAT H=36%	FLAT H=90%	TABLE
1	1.52	1.53	1.10	1.60
2	1.36	1.29	0.62	1.28
3	1.30	1.24	0.68	1.2
4	1.49	1.47	0.91	1.41
5	1.43	1.37	0.73	1.52
6	1.18	1.07	0.47	1.32
7	1.02	0.90	0.42	0.98
8	1.18	1.14	0.73	1.15
9	1.65	1.72	1.21	1.51
10	1.80	1.83	1.07	1.68
11	1.38	1.26	0.46	1.38
12	0.89	0.69	0.14	0.91
13	0.56	0.37	0.06	0.59
14	0.37	0.22	0.04	0.39
15	0.25	0.14	0.04	0.27
Avg.	1.16	1.08	0.58	1.15

Table 3. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 50% assuming a constant value with all crab. Alternatives provided are a fixed 20% exploitation rate on mature male crab, a fixed harvest rate of 48% on legal male crab, a fixed harvest rate of 90% (3-S management), and the current harvest strategy table. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

LANDINGS

YEAR	PROPOSED E=20%	FLAT H=48%	FLAT H=90%	TABLE
1	0.43	0.33	0.48	0.30
2	0.44	0.64	1.03	0.55
3	0.47	0.40	0.45	0.37
4	0.54	0.46	0.65	0.41
5	0.47	0.56	0.82	0.24
6	0.35	0.46	0.59	0.23
7	0.32	0.32	0.37	0.37
8	0.39	0.29	0.39	0.44
9	0.57	0.47	0.73	0.58
10	0.65	0.73	1.13	0.58
11	0.39	0.65	0.87	0.28
12	0.20	0.33	0.30	0.18
13	0.10	0.13	0.08	0.09
14	0.06	0.06	0.04	0.05
15	0.04	0.03	0.04	0.03
Avg.	0.36	0.39	0.53	0.31

BREEDING FEMALE:MALE RATIO AFTER HARVEST

YEAR	PROPOSED E=20%	FLAT H=48%	FLAT H=90%	TABLE
1	2.06	1.99	2.27	1.94
2	3.22	3.52	5.43	3.25
3	4.10	4.12	5.19	3.90
4	2.95	2.85	3.50	2.72
5	2.47	2.54	3.51	2.11
6	2.83	3.11	4.64	2.35
7	4.38	4.60	6.12	4.01
8	4.93	4.77	5.57	4.87
9	3.19	3.04	3.57	3.18
10	1.98	1.99	2.66	1.93
11	1.81	2.17	4.00	1.65
12	2.17	3.27	8.18	1.93
13	2.70	4.53	9.72	2.35
14	3.17	4.76	7.28	2.67
15	3.38	4.30	5.88	2.80

BREEDING MALES AFTER HARVEST

YEAR	PROPOSED E=20%	FLAT H=48%	FLAT H=90%	TABLE
1	0.78	0.81	0.71	0.83
2	0.57	0.52	0.33	0.56
3	0.57	0.56	0.45	0.60
4	0.68	0.71	0.58	0.74
5	0.59	0.58	0.42	0.70
6	0.43	0.39	0.26	0.52
7	0.38	0.36	0.27	0.42
8	0.57	0.59	0.51	0.58
9	0.88	0.93	0.79	0.88
10	0.83	0.83	0.62	0.86
11	0.48	0.40	0.22	0.53
12	0.23	0.15	0.06	0.26
13	0.11	0.06	0.03	0.13
14	0.06	0.04	0.02	0.08
15	0.04	0.03	0.02	0.05
Avg.	0.48	0.46	0.35	0.52

Table 4. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 90% assuming a constant value with all crab. Alternatives provided are a fixed 20% exploitation rate on mature male crab, a fixed harvest rate of 28% on legal male crab, a fixed harvest rate of 90% (3-S management), and the current harvest strategy table. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

LANDINGS

year	E=.20	H=.28	H=.90	Table
1	2.55	1.93	1.46	0.94
2	2.19	2.34	3.51	2.97
3	2.10	2.08	2.02	2.47
4	2.31	2.09	2.23	2.38
5	2.19	2.24	2.92	1.29
6	1.98	2.24	2.38	1.50
7	1.85	2.01	1.56	3.00
8	2.01	1.80	1.38	2.31
9	2.37	1.82	2.30	2.23
10	2.54	2.44	3.84	2.96
11	2.20	2.69	3.49	1.58
12	1.72	2.25	1.61	1.52
13	1.35	1.68	0.53	1.28
14	1.07	1.21	0.21	1.03
15	0.84	0.85	0.15	0.81
Avg.	1.95	1.98	1.97	1.88

BREEDING FEMALE:MALES AFTER HARVEST

Year	E=.20	H=.28	H=.90	Table
1	2.49	2.47	4.65	2.73
2	2.56	2.59	7.22	3.09
3	2.76	2.78	7.17	3.42
4	2.49	2.44	5.33	2.98
5	2.21	2.18	5.53	2.29
6	2.36	2.41	7.99	2.30
7	2.86	2.99	10.0	3.29
8	3.30	3.33	7.51	3.87
9	2.59	2.46	4.39	2.81
10	2.12	2.01	4.34	2.39
11	2.10	2.10	7.70	2.20
12	2.29	2.48	19.2	2.33
13	2.63	3.10	40.6	2.62
14	3.07	3.93	47.9	3.02
15	3.54	4.82	43.0	3.41

BREEDERS AFTER HARVEST

Year	E=.20	H=.28	H=.90	Table
1	2.53	2.55	1.35	2.30
2	2.39	2.36	0.84	1.98
3	2.23	2.22	0.86	1.80
4	2.46	2.50	1.15	2.05
5	2.41	2.44	0.96	2.32
6	2.13	2.09	0.63	2.19
7	1.90	1.82	0.54	1.65
8	2.03	2.01	0.89	1.73
9	2.55	2.68	1.50	2.35
10	2.87	3.02	1.40	2.55
11	2.45	2.45	0.67	2.34
12	1.81	1.67	0.21	1.78
13	1.31	1.11	0.08	1.32
14	0.97	0.76	0.06	0.99
15	0.72	0.53	0.05	0.75
Avg.	2.05	2.01	0.75	1.87

Table 5. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 75% assuming a constant value with all crab up until year 9. After year 9 a survivorship of 50% was assumed. Alternatives provided are a fixed 20% exploitation rate on mature male crab, a fixed harvest rate of 33%, 48% and 90%(3-S) on legal crab, and the current harvest strategy table. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

INDEX OF LANDINGS (WEIGHT)

YEAR	E=20%	H=33%	H=48%	H=90%	TABLE
1	1.40	0.92	0.96	1.01	0.47
2	1.15	1.36	1.66	2.39	1.67
3	1.15	1.14	1.30	1.24	1.31
4	1.31	1.15	1.31	1.48	1.28
5	1.23	1.31	1.56	1.95	0.73
6	1.04	1.24	1.42	1.52	0.80
7	0.93	1.02	1.08	0.98	1.46
8	1.09	0.87	0.92	0.91	1.10
9	1.42	1.03	1.21	1.59	1.81
10	0.99	1.00	1.25	1.73	0.50
11	0.54	0.71	0.86	1.00	0.43
12	0.26	0.36	0.39	0.31	0.25
13	0.13	0.16	0.15	0.08	0.12
14	0.07	0.07	0.06	0.04	0.06
15	0.05	0.04	0.03	0.04	0.03
Avg.	0.85	0.83	0.94	1.08	0.80

FEMALE:MALE RATIO

YEAR	E=20%	H=33%	H=48%	H=90%	TABLE
1	2.28	2.19	2.52	3.14	2.16
2	2.57	2.60	3.22	5.64	2.74
3	3.01	3.02	3.72	5.70	3.27
4	2.51	2.44	2.90	4.07	2.64
5	2.20	2.19	2.68	4.30	2.07
6	2.37	2.48	3.23	5.97	2.13
7	3.09	3.29	4.31	7.35	3.20
8	3.65	3.62	4.34	5.85	3.75
9	2.71	2.53	2.87	3.68	2.96
10	2.05	1.95	2.30	3.42	1.93
11	1.98	2.04	2.65	5.40	1.79
12	2.29	2.62	3.87	10.6	2.02
13	2.77	3.38	5.21	11.8	2.40
14	3.21	3.80	5.32	8.55	2.72
15	3.44	3.69	4.60	6.34	2.85

INDEX OF BREEDING (MATURE) MALES AFTER HARVEST

YEAR	E=20%	H=33%	H=48%	H=90%	TABLE
1	1.52	1.58	1.37	1.10	1.60
2	1.36	1.35	1.09	0.62	1.28
3	1.30	1.29	1.05	0.68	1.20
4	1.49	1.53	1.28	0.91	1.41
5	1.43	1.43	1.17	0.73	1.52
6	1.18	1.13	0.87	0.47	1.32
7	1.02	0.95	0.73	0.42	0.98
8	1.18	1.19	0.99	0.73	1.15
9	1.65	1.77	1.56	1.22	1.51
10	1.20	1.27	1.08	0.72	1.28
11	0.63	0.62	0.47	0.23	0.70
12	0.28	0.25	0.17	0.06	0.32
13	0.13	0.11	0.07	0.03	0.15
14	0.07	0.06	0.04	0.02	0.09
15	0.05	0.04	0.03	0.02	0.06
Avg.	0.97	0.97	0.80	0.53	0.97

Table 6. A comparison of a "complex" versus "simple" interpretation of the current harvest strategy table. Parameters compared are an index of landings by weight, sex ratios, and an index of numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 75% assuming a constant value with all crab. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

LANDINGS IN WEIGHT INDEX

YEAR	"SIMPLE" TABLE	"COMPLEX" TABLE
1	0.48	0.71
2	1.68	1.79
3	1.31	1.51
4	1.28	1.27
5	0.73	0.84
6	0.80	0.92
7	1.47	1.48
8	1.10	1.22
9	1.82	1.48
10	1.52	1.52
11	0.84	1.06
12	0.74	0.88
13	0.54	0.62
14	0.38	0.41
15	0.26	0.27
Avg.	1.00	1.07

BREEDING FEMALE:MALE RATIO

YEAR	"SIMPLE" TABLE	"COMPLEX" TABLE
1	2.16	2.26
2	2.75	2.96
3	3.28	3.66
4	2.64	2.84
5	2.07	2.23
6	2.13	2.34
7	3.20	3.55
8	3.75	4.15
9	2.97	2.95
10	2.14	2.13
11	1.93	2.02
12	2.14	2.36
13	2.48	2.87
14	2.84	3.41
15	3.11	3.83

INDEX OF BREEDING MALES AFTER HARVEST

YEAR	"SIMPLE" TABLE	"COMPLEX" TABLE
1	1.61	1.54
2	1.28	1.19
3	1.20	1.08
4	1.42	1.32
5	1.52	1.42
6	1.32	1.21
7	0.99	0.89
8	1.15	1.04
9	1.52	1.53
10	1.69	1.69
11	1.39	1.33
12	0.92	0.84
13	0.59	0.51
14	0.40	0.33
15	0.28	0.23
Avg.	1.15	1.08

Table 7. A comparison of alternative harvest strategies of landings by weight, sex ratios, and numbers of mature males remaining on the grounds after the fishery. The natural survivorship rate used was 75% assuming a constant value with all crab. Alternatives provided are a fixed 15%, 20%, 25% and 30% exploitation rate on mature male crab. Sex ratios and number of mature males in an unexploited population (E=0%) are also provided. The recruitment pattern of crab used is based on the southwest district of the Kodiak Management Area for the years 1970 through 1984.

LANDINGS

YEAR	E=15%	E=20%	E=25%	E=30%
1	1.18	1.40	1.49	1.20
2	0.98	1.15	1.28	1.49
3	0.97	1.15	1.30	1.46
4	1.09	1.31	1.47	1.55
5	1.03	1.23	1.37	1.52
6	0.89	1.04	1.15	1.23
7	0.81	0.93	1.02	1.07
8	0.93	1.09	1.20	1.14
9	1.17	1.42	1.56	1.40
10	1.23	1.49	1.70	2.01
11	1.00	1.18	1.31	1.46
12	0.72	0.82	0.87	0.91
13	0.52	0.56	0.57	0.57
14	0.37	0.39	0.38	0.37
15	0.27	0.28	0.27	0.25
Avg.	0.87	1.03	1.13	1.18

BREEDING FEMALE:MALE RATIO AFTER HARVEST

YEAR	E=0%	E=15%	E=20%	E=25%	E=30%
1	1.28	1.98	2.28	2.57	2.66
2	1.41	2.21	2.57	2.96	3.24
3	1.68	2.59	3.01	3.48	3.92
4	1.44	2.18	2.51	2.87	3.19
5	1.26	1.91	2.20	2.54	2.89
6	1.26	2.02	2.37	2.80	3.28
7	1.55	2.59	3.09	3.68	4.35
8	1.96	3.14	3.65	4.24	4.66
9	1.67	2.40	2.71	3.04	3.10
10	1.19	1.75	1.99	2.26	2.44
11	1.04	1.65	1.94	2.27	2.58
12	1.03	1.80	2.21	2.71	3.26
13	1.05	2.03	2.60	3.35	4.24
14	1.06	2.29	3.03	4.05	5.32
15	1.08	2.53	3.41	4.62	6.15

BREEDING MALES AFTER HARVEST

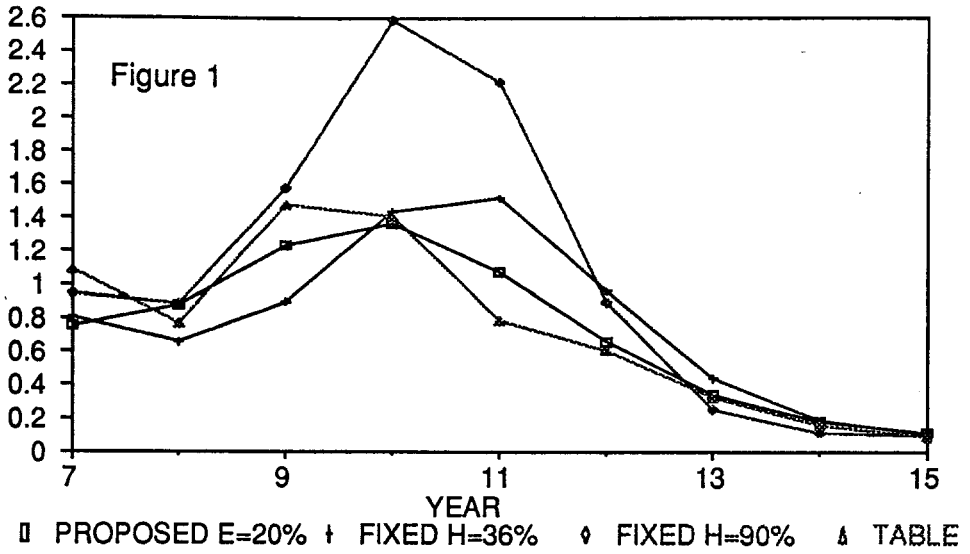
YEAR	E=0%	E=15%	E=20%	E=25%	E=30%
1	2.71	1.75	1.52	1.34	1.30
2	2.49	1.59	1.36	1.18	1.08
3	2.33	1.51	1.30	1.12	1.00
4	2.58	1.71	1.49	1.30	1.17
5	2.49	1.65	1.43	1.24	1.09
6	2.23	1.39	1.18	1.00	0.85
7	2.03	1.21	1.02	0.85	0.72
8	2.20	1.37	1.18	1.01	0.92
9	2.68	1.86	1.65	1.47	1.45
10	3.01	2.05	1.80	1.59	1.47
11	2.56	1.62	1.38	1.17	1.03
12	1.89	1.08	0.89	0.72	0.60
13	1.40	0.72	0.56	0.43	0.34
14	1.05	0.49	0.37	0.27	0.21
15	0.80	0.34	0.25	0.18	0.14
Avg.	2.16	1.36	1.16	0.99	0.89

Fig. 1 *Comparison of landings by weight resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. A survival rate of 75 % is assumed with decreased survival of skip molts and older crab. Weights listed are indexed values.*

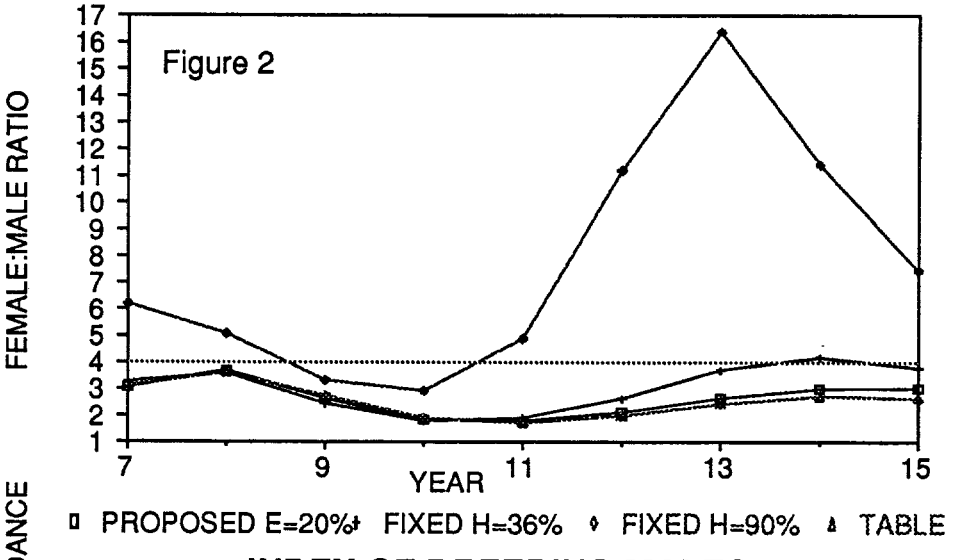
Fig. 2 *Comparison of sex ratios (Females:Mature Male) resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. A survival rate of 75 % is assumed with decreased survival of skip molts and older crab. Weights listed are indexed values.*

Fig. 3 *Comparison of numbers of mature males remaining after the harvest resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. A survival rate of 75 % is assumed with decreased survival of skip molts and older crab. Numbers listed are indexed values.*

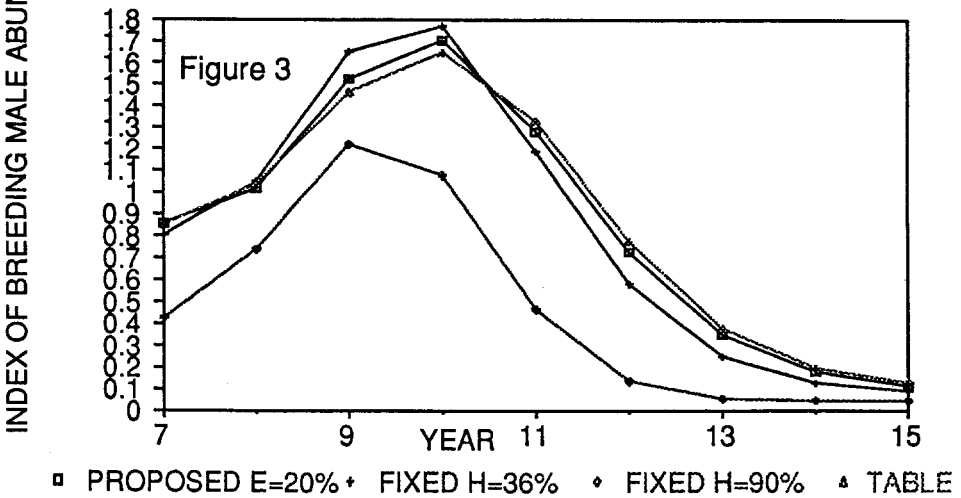
LANDINGS IN WEIGHT INDEX



BREEDING FEMALE:MALE RATIO



INDEX OF BREEDING MALES



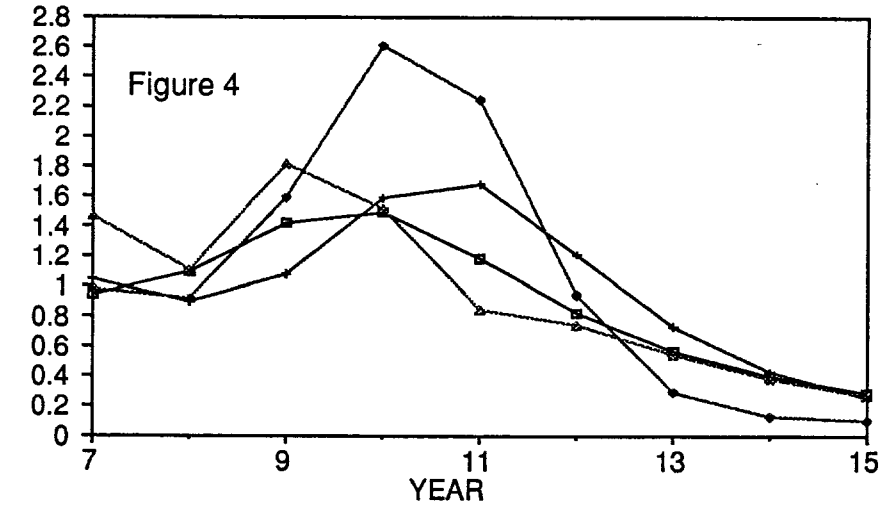
ACE 9122234

Fig. 4 *Comparison of landings by weight resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 75 % is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Weights listed are indexed values.*

Fig. 5 *Comparison of sex ratios (Females:Sexually Mature Male) resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 75 % is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area.*

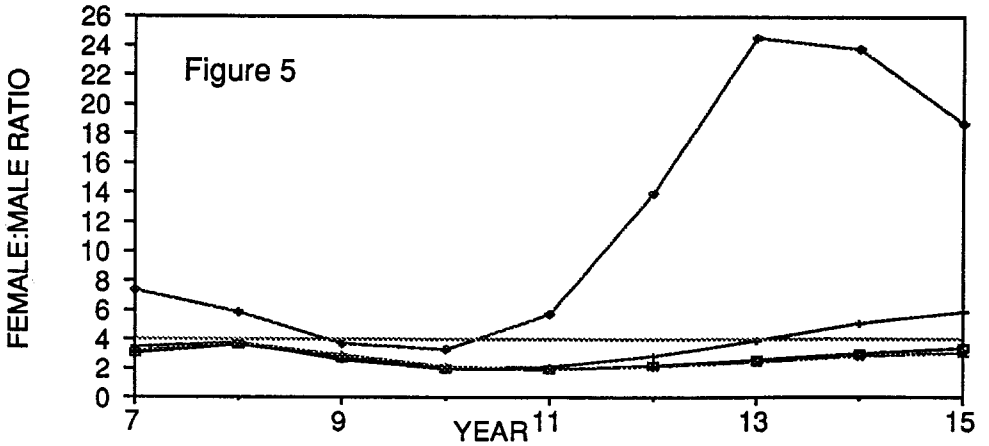
Fig. 6 *Comparison of numbers of mature males remaining after the harvest resulting from the current harvest strategy table, a fixed harvest rate of 36% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 75 % is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Numbers listed are indexed values.*

LANDINGS IN WEIGHT INDEX



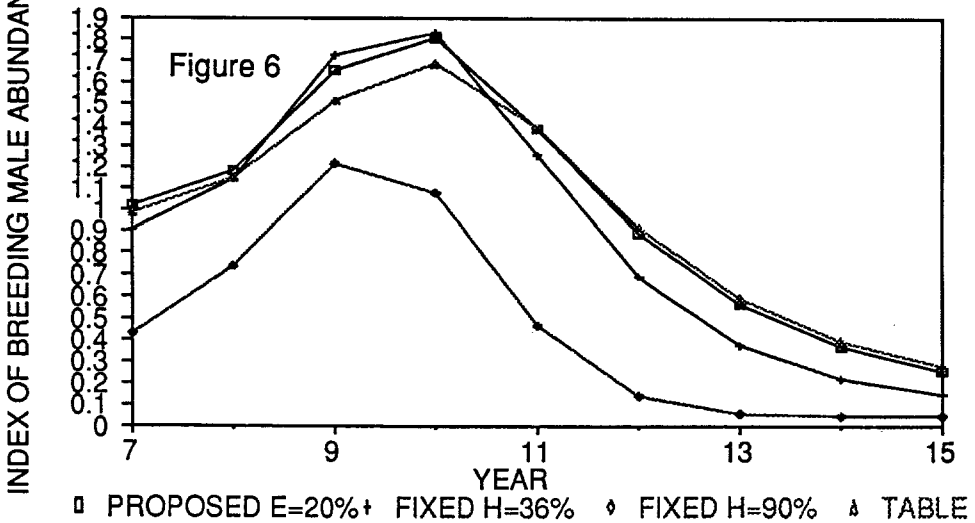
PROPOSED E=20% FIXED H=36% FIXED H=90% TABLE

BREEDING FEMALE:MALE RATIO



PROPOSED E=20% FIXED H=36% FIXED H=90% TABLE

INDEX OF BREEDING MALES



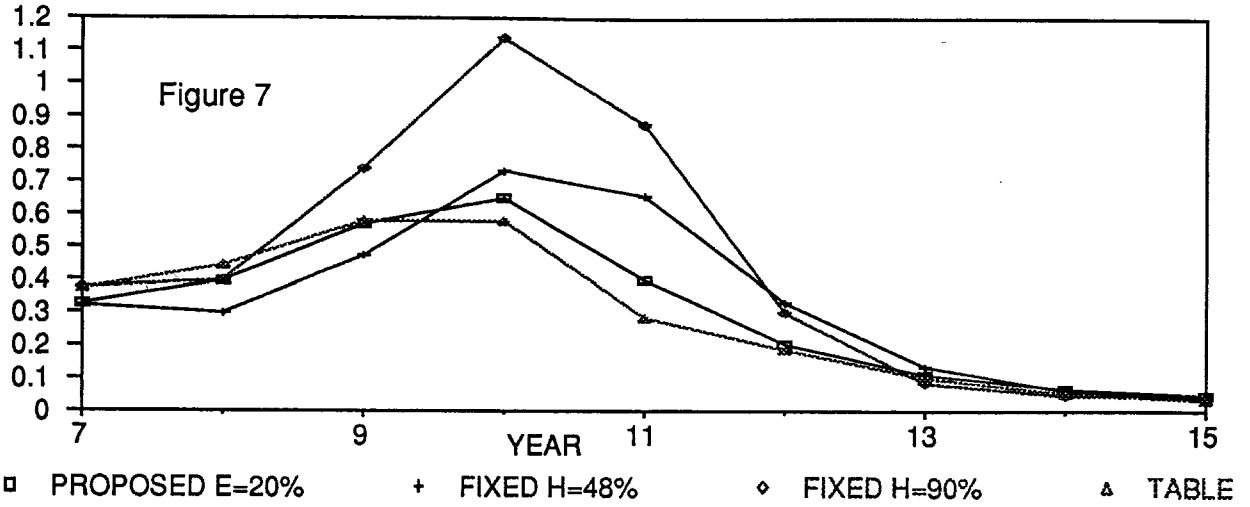
PROPOSED E=20% FIXED H=36% FIXED H=90% TABLE

Fig. 7 *Comparison of landings by weight resulting from the current harvest strategy table, a fixed harvest rate of 48% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management (90% fixed harvest rate of legal males). A survival rate of 50% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Weights listed are indexed values.*

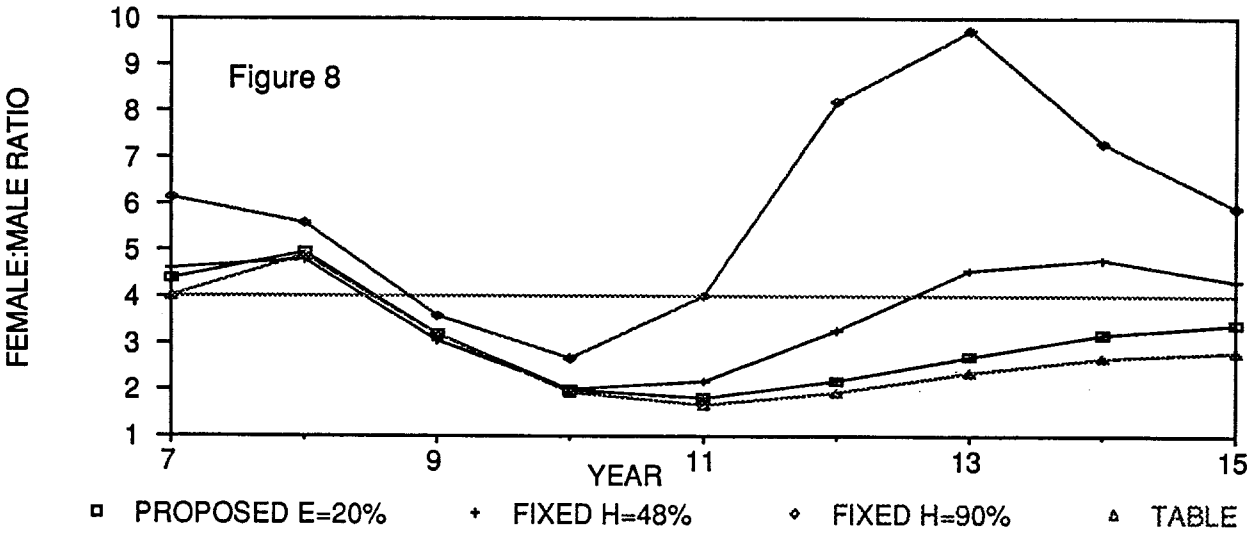
Fig. 8 *Comparison of sex ratios (Females:Sexually Mature Male) resulting from the current harvest strategy table, a fixed harvest rate of 48% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 50% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area.*

Fig. 9 *Comparison of numbers of mature males remaining after the harvest resulting from the current harvest strategy table, a fixed harvest rate of 48% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 50% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Numbers listed are indexed values.*

LANDINGS IN WEIGHT INDEX



BREEDING FEMALE:MALE RATIO



INDEX OF BREEDING MALES

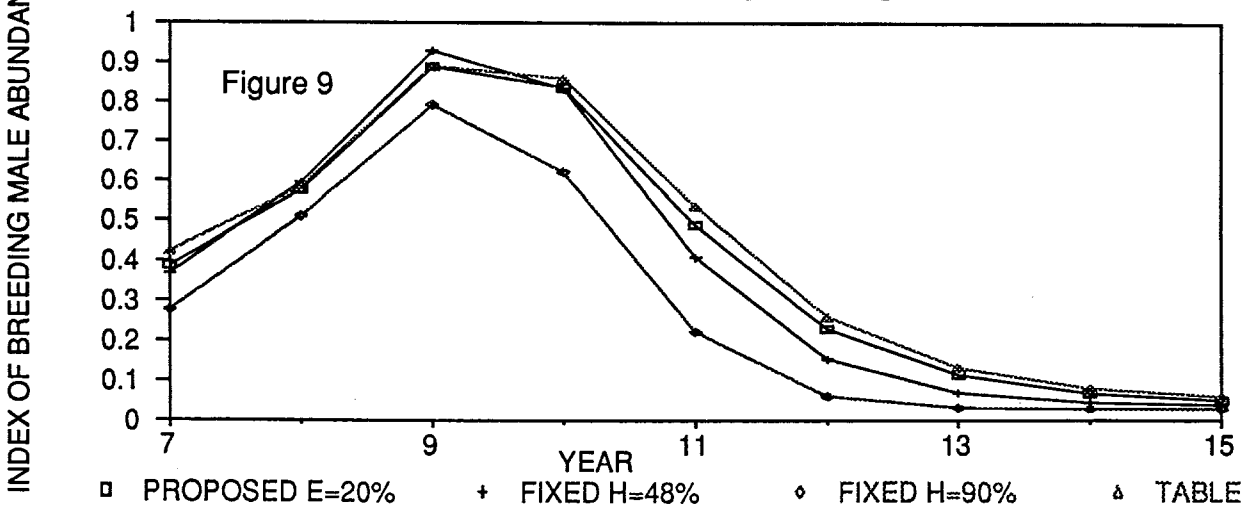
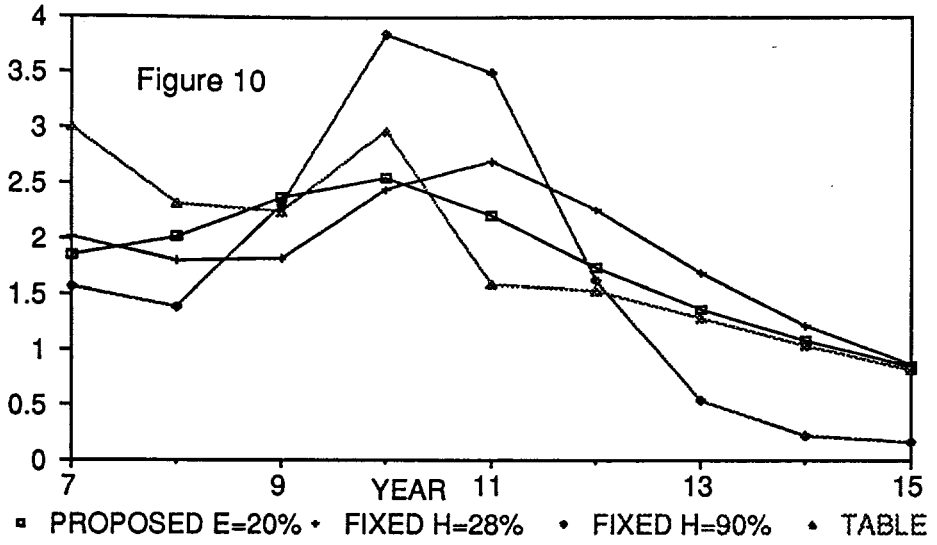


Fig. 10 *Comparison of landings by weight resulting from the current harvest strategy table, a fixed harvest rate of 28% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management (90% fixed harvest rate of legal males). A survival rate of 90% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Weights listed are indexed values.*

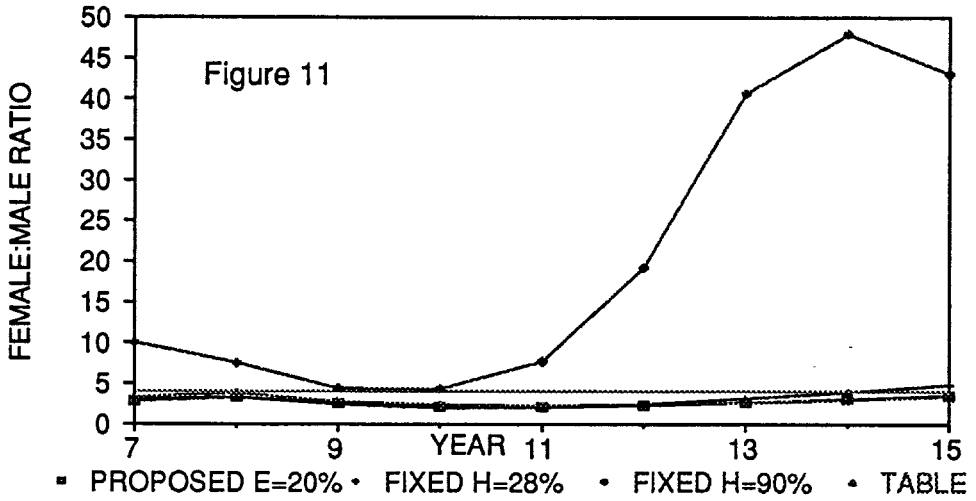
Fig. 11 *Comparison of sex ratios (Females:Sexually Mature Male) resulting from the current harvest strategy table, a fixed harvest rate of 28% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 90% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area.*

Fig. 12 *Comparison of numbers of mature males remaining after the harvest resulting from the current harvest strategy table, a fixed harvest rate of 28% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 90% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Numbers listed are indexed values.*

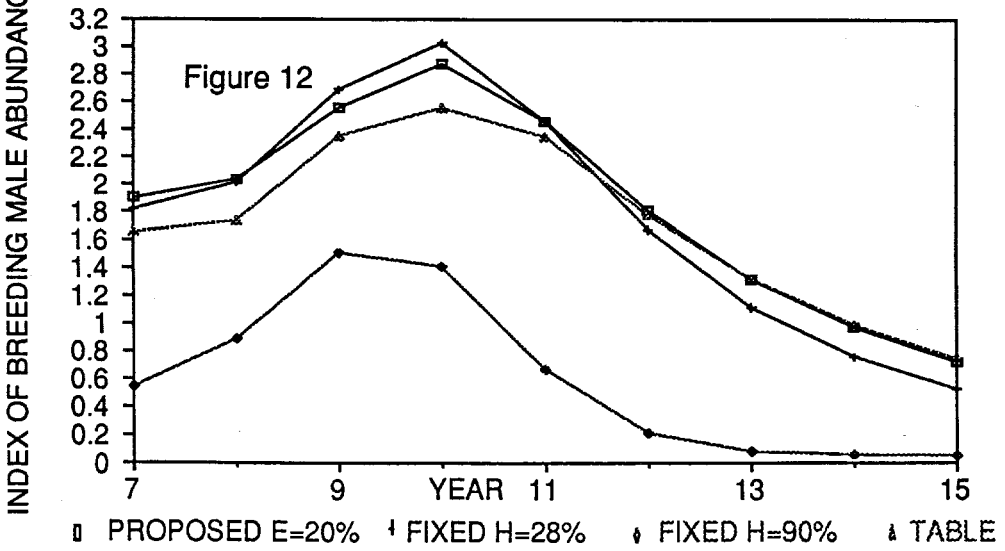
LANDINGS IN WEIGHT INDEX



BREEDING FEMALE:MALE RATIO



INDEX OF BREEDING MALES



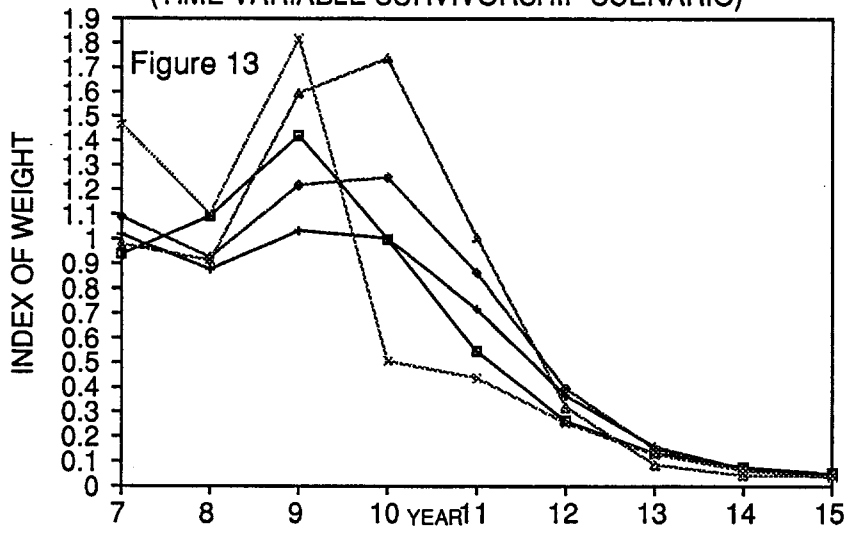
ACE 9122240

Fig. 13 *Comparison of landings by weight resulting from the current harvest strategy table, fixed harvest rates of 33% and 48% of the legal male population, a fixed exploitation rate of 20% of the mature male population, and 3-S management (90% fixed harvest rate of legal males). A survival rate of 75% is assumed for all aged crab through year 9 with a survival rate of 50% from year 10 through year 15. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Weights listed are indexed values.*

Fig. 14 *Comparison of sex ratios (Females:Sexually Mature Male) resulting from the current harvest strategy table, fixed harvest rates of 33% and 48% of the legal male population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 75% is assumed for all aged crab through year 9 with a survival rate of 50% from year 10 through year 15. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area.*

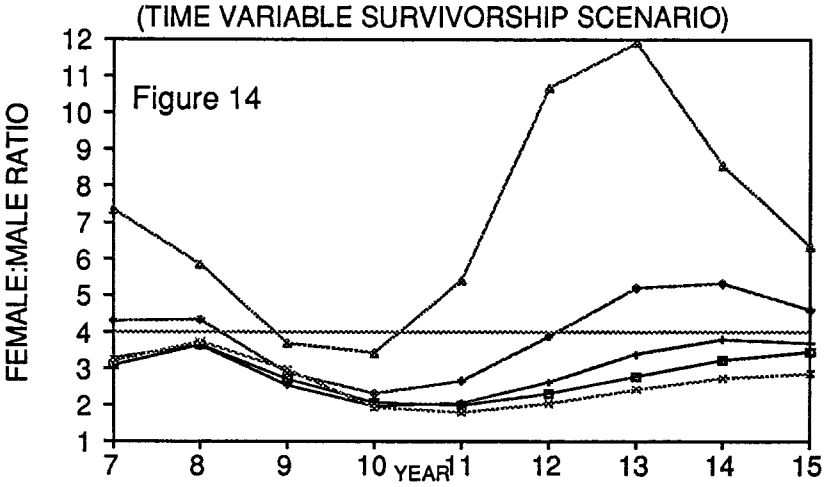
Fig. 15 *Comparison of numbers of mature males remaining after the harvest resulting from the current harvest strategy table, fixed harvest rates of 33% and 48% of the legal males population, a fixed exploitation rate of 20% of the mature male population, and 3-S management(90% fixed harvest rate of legal males). A survival rate of 75% is assumed for all aged crab through year 9 with a survival rate of 50% from year 10 through year 15. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Numbers listed are indexed values.*

INDEX OF WEIGHT OF LANDINGS
(TIME VARIABLE SURVIVORSHIP SCENARIO)



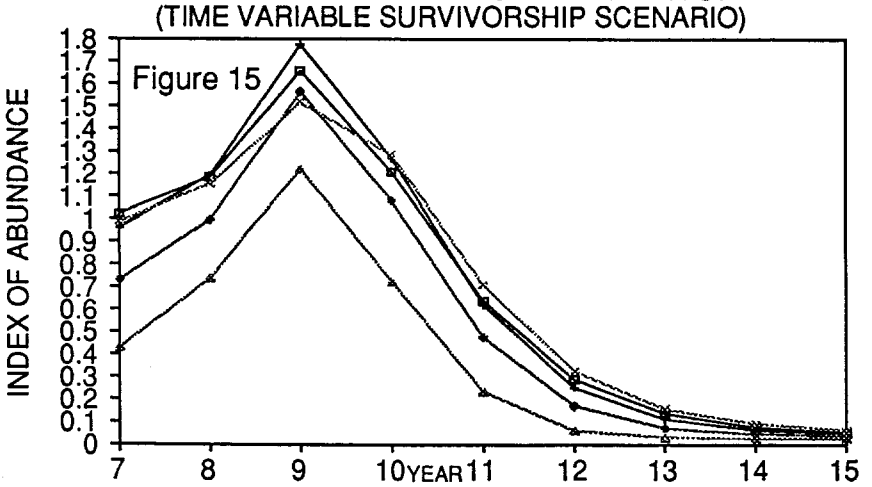
▫E=20% • fixed H=33% • fixed H=48% ▲ fixed H=90% × TABLE

MATURE FEMALE:MALE RATIO AFTER HARVEST
(TIME VARIABLE SURVIVORSHIP SCENARIO)



▫E=20% • fixed H=33% • fixed H=48% ▲ fixed H=90% × TABLE

INDEX OF MATURE MALES AFTER HARVEST
(TIME VARIABLE SURVIVORSHIP SCENARIO)



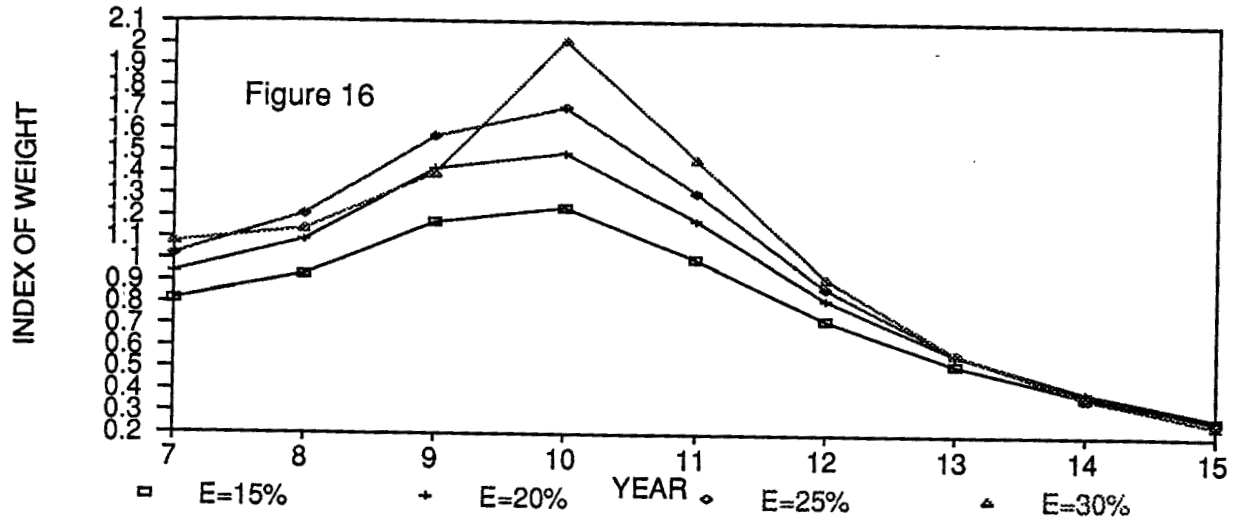
▫ E=20% • fixed H=33% • fixed H=48% ▲ fixed H=90% × TABLE

Fig. 16 *Comparison of landings by weight resulting from a fixed exploitation rate of 15%, 20%, 25%, and 30% of the mature male population with a maximum harvest rate of 60% of the legal males allowed. A survival rate of 75% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Weights listed are indexed values.*

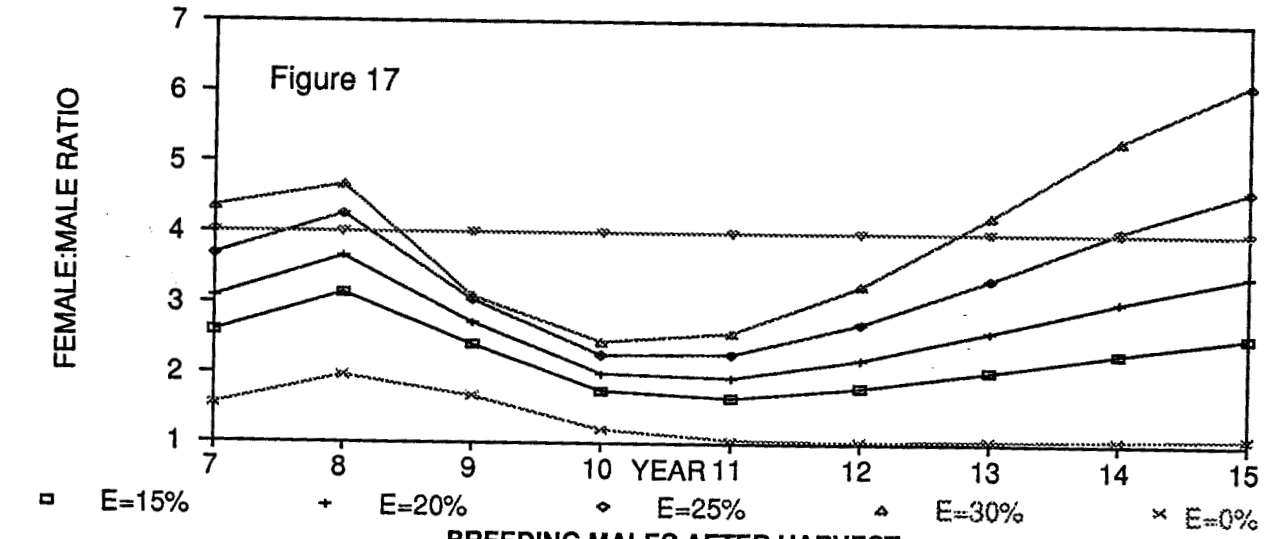
Fig. 17 *Comparison of sex ratios (Females:Sexually Mature Male) resulting from a fixed exploitation rate of 0% (no harvest), 15%, 20%, 25%, and 30% of the mature male population with a maximum harvest rate of 60% of the legal males allowed. A survival rate of 75% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area.*

Fig. 18 *Comparison of numbers of mature males remaining after the harvest resulting from a fixed exploitation rate of 0% (no harvest), 15%, 20%, 25%, and 30% of the mature male population with a maximum harvest rate of 60% of the legal males allowed. A survival rate of 75% is assumed for all aged crab. Recruitment period reflects the 1976 through 1984 data from the Southwest District of the Kodiak Management Area. Numbers listed are indexed values.*

LANDINGS IN WEIGHT INDEX



BREEDING FEMALE:MALE RATIO



BREEDING MALES AFTER HARVEST