KING AND TANNER CRAB RESEARCH IN ALASKA:

ANNUAL REPORT FOR

JULY 1, 1995 THROUGH JUNE 3O, 1996

Submitted Under Cooperative Agreement NA37FL0333 To

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
P.O. Box 21668
Juneau, Alaska 99802

Edited By

Gordon H. Kruse
ADF&G Project Coordinator

Regional Information Report No. 5J96-11
Alaska Department of Fish & Game
Commercial Fisheries Management and Development Division
P.O. Box 25526
Juneau, Alaska 99802-5526

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[1]The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or 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 Commercial Fisheries Management and Development Division.

OVERVIEW OF KING AND TANNER CRAB RESEARCH

Dr. Gordon H. Kruse, ADF&G Project Coordinator

Alaska Department of Fish & Game, Commercial Fisheries Management and Development Division
P.O. Box 25526, Juneau, Alaska 99802-5526

Introduction

A federal budget initiative for crab research was funded by the United States Congress in 1992 to address pivotal biological and fishery research questions associated with the determination of optimal management strategies for the king *(Paralithodes, Lithodes)*, Tanner *(Chionoecetes bairdi)* and snow crab *(C. opilio)* fisheries off Alaska. This initiative, funded through the National Marine Fisheries Service (NMFS), was developed by staffs of the Alaska Department of Fish and Game (ADF&G) and NMFS. It reflects their shared responsibilities for crab research and fishery management. It funds cooperative investigations conducted by researchers with state and federal agencies and universities. ADF&G was awarded a cooperative agreement for $237,500 for the third year of work during the period July 1, 1995 through June 30, 1996. In this report, fiscal years are denoted according to protocol used by the state of Alaska. For example, FY 96 corresponds to July 1, 1995 to June 30, 1996.

This document reports on work performed under Cooperative Agreement NA37FL0333 during FY 96. Previously-published quarterly (Kruse 1995b) and semiannual reports (Kruse 1996a) documented interim project progress during this contractual year. This annual report covers: (1) synopsis of long-term research strategy for king, Tanner, and snow crabs; (2) the overall plan for third year research that includes four projects; (3) project by project summary; and (4) plans for fourth year research. Sections of this report were authored by individual project leaders as noted.

Long-term Research Strategy

The Gulf of Alaska (GOA), Aleutian Islands area (AI), and Bering Sea (BS) support large commercial fisheries for king, Tanner and snow crabs. Many crab stocks crashed in the 1980s, and a dozen crab fisheries remain closed due to low abundance. Poor success in maintaining productive fisheries over the long-term prompted the need for a re-evaluation of management strategies (Kruse 1993). However, research is needed so that optimal management strategies can be developed.

Planning of a long-term crab research strategy has been an active, ongoing process involving many agency and university staff. These research plans are formally discussed at annual meetings of agency and university staff and annual meetings with members of the crab industry and general public. These collective planning efforts have helped to guide crab research including studies funded under this cooperative agreement.

An original draft research plan was reviewed at the first interagency meeting in August 1993 and subsequently published (Kruse 1994b). The plan reflects the accumulated contributions of many ADF&G and NMFS staff including results of a questionnaire of opinions of crab researchers conducted by Murphy et al. (1994). Following an extensive research review at the third interagency in October 1995, the long-term plan was revised to reflect progress and new ideas (Kruse 1996b).

The long-term crab research strategy is based on the idea that wise management of any fishery can only be accomplished by providing answers to four basic questions: (1) what are the stocks?, (2) how abundant are they?, (3) what features drive their productivity?, and (4) how should this productivity be best harvested? Although previous crab research provided insights, many uncertainties exist that prevent a critical and thorough evaluation of alternative management strategies. Investigations are planned into four broad areas to provide answers to these pivotal questions.

(1) **Stock Structure.** Fisheries cannot be managed successfully without understanding the underlying stock structure. In general, crab management units have been established to reflect the geographical distribution of king and Tanner crabs. Although the geographic distribution of some crabs is discrete (e.g., Norton Sound red king crabs), questions remain about the structure of some BS/AI crab stocks. Some of the most important questions concern the Tanner and snow crab species complex and golden king crabs *(Lithodes aequispinus)*, although some uncertainties exist concerning stock boundaries for some red king crabs *(Paralithodes camtschaticus)*, as well. Answers to these questions will be used to improve the alignment of fishery management units with genetic stocks so that individual stocks can be managed based on their own productivity features.

(2) **Stock Assessment.** Good stock assessment programs exist for many stocks in the BS and GOA, and for some stocks in the AI. Yet, for some other stocks, such as BS blue king crabs *(Paralithodes platypus)*, precision is low; for yet others (e.g., Adak red king crabs) assessments are too costly to conduct annually; and for still others (e.g., all golden king crab stocks) no assessments are conducted due to fiscal constraints. Thus, population models are needed that integrate multiple years of diverse and sometimes conflicting information from survey and fishery data into more precise estimates of abundance under a variety of situations. The goal is to make optimal use of fishery and survey information so that true population changes can be distinguished from survey measurement errors.

(3) **Stock Productivity.** Unlike most groundfish, herring and salmonids, we lack critical biological information about parameters that regulate productivity of many crab species. For example, good natural mortality estimates are lacking for most stocks. Growth of Tanner and snow crabs (including terminal molt of males) is poorly understood. Questions exist about size of maturity of snow crabs, and little is known about most life history traits of golden king crabs. Knowledge of these parameters

that drive stock productivity is imperative so that harvest rates can be specified to reflect the underlying biological productivity of each species and stock.

(4) **Harvest Strategy.** Crab harvest strategies may be seriously flawed. Unwittingly, size limits, sex restrictions, and current exploitation rates may adversely affect fishery productivity. In some instances, size limits are based on size of morphological maturity (i.e., males with a large claw) rather than functional maturity (i.e., males that actually participate in reproduction). Thus, high harvest rates may have eliminated breeding males from stocks managed by size-sex-season regulations. Further, gear designs may promote handling mortality that exacerbates stock declines. Also, changes in other components of the ecosystem and changes in oceanographic conditions can have profound effects on crab stock dynamics. Ideally, optimal management strategies should be developed to recognize species- and stock-specific biological characteristics such as growth, terminal molt phenomena, mortality, size of maturity, and recruitment dynamics as driven by stock and environmental effects. Statistical and simulation studies are needed to evaluate the implications of these productivity features on harvest strategies.

Overall Project Plan For Third Year

This third year of research continues progress on the long-term work by conducting four studies: (1) relative roles of fishing, predation, and environment on long-term dynamics of Alaskan crab stocks; (2) breeding success of legal-size male red king crabs; (3) genetic stock identification; and (4) population estimates and alternative crab harvest strategies. With respect to the long-term research plan (Kruse 1996b), project 3 attempts to answer the question: "what are the stocks?" Projects 1 and 2 are directed toward the question: "what features drive their productivity?" Project 4 attempts to provide insights into two questions: "how abundant are they?" and "how should this productivity be best harvested?"

Detailed descriptions of these four projects appear in the following sections. For completeness, we also include a description of a fifth project, *Handling Mortality of Red King Crabs,* that was funded by NOAA Cooperative Agreement during FY 94 and FY 95. Due to limited federal funds, the project was funded during its third and final year (FY 96) with state of Alaska funds.

A complete list of written products of projects funded NOAA Cooperative Agreement NA37FL0333 during the first three contractual years are listed in Appendix 1. Copies of manuscripts and final publications are filed annually with the NOAA Grants Officer. Additional copies may be obtained directly from the lead author of each publication. Authors request unpublished manuscripts not be cited until they are accepted for publication.

PROJECT 1: LONG-TERM DYNAMICS OF ALASKAN CRAB STOCKS

Dr. Albert V. Tyler, Principal Investigator

School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, Alaska 99775-7220

Background and Need

Three decades of catch histories and one to two decades of stock assessments reveal a wide range of crab population trends. To date, most stocks have crashed and not improved, some others have declined and recovered, and still a few others remain healthy. A number of causes of these dynamics have been proposed, including anthropogenic and natural causes. More specifically the main suggestions for stock demise are overfishing, handling mortality, predation, and oceanographic changes. Despite wide speculation about the relative roles of various factors on crab populations, the supporting evidence for the alternatives has never been objectively evaluated.

Project Description

The purpose of this multi-year project is to investigate relative effects of fishing (over-harvest and handling mortality) and natural changes (predation and oceanography) on the long-term dynamics of crab populations in Alaskan waters. This will be accomplished through five phases of research.

First, data bases will be compiled relevant to variables that would be implicated in possible causes of change, including crab spawning stock abundance and recruitment, oceanographic variables, and predator abundance.

Second, two workshops will be held with crab biologists and physical oceanographers to develop a conceptual model of causal mechanisms by which fishing, predation, and oceanography could act on the long-term dynamics of Alaskan crab populations.

Third, analyses will be conducted to characterize intrinsic features of the data sets, such as time intervals between successful crab year classes, periods of increased predator abundance, and years of favorable ocean conditions during crab larval stages.

Fourth, the causal mechanisms will be stated in terms of alternative hypotheses and tested with available data sets by a range of statistical methods where feasible.

Fifth, based on the above results, the most likely mechanisms will be selected for inclusion in a model to fully explore the relative roles of these competing factors on crab populations. The model will be used to identify possible confounding effects of several mechanisms that may interact in sequential and non-linear ways not amenable to standard statistical methods.

However, for red king crabs, because of the lack of quantitative information it is unlikely that a computerized version of the conceptual model will be valuable. In particular there is little on which to base the scaling of many of the graphs of the possible functional relationships. The ranges of parameters of these functions are too vague to set even hypothetically. Instead, a formalized conceptual model will be developed and used to give insight into the gaps in knowledge. All known and relevant information about red king crab recruitment will be set into the ordering format of a quantitative, computer oriented, conceptual model, but the final step of writing computer code will not be taken. We will still be able to use the model to elucidate the kinds of research programs that will lead to an evaluation of the mechanisms that influence year-class strength. Important processes include the influence of predation on survival of key developmental stages, effects of physical oceanographic factors on year-class strength, and the impact of relationships involving density dependent survival and productivity stemming from limited food supply.

Goals for FY 96

During the third year, the following milestones will be accomplished:

(1) Develop a report on the workshop on Tanner crab year-class strength held in May 1995. This report will be published in the Regional Information Report series of ADF&G during the new fiscal year.

(2) Conduct analyses to gain insights into the comparison of the historic variability in both king and Tanner crab year classes, the predators that may influence year-class strength, and the ocean environment.

(3) Develop a conceptual model of a simulation for the formation of year-class strength of Tanner crabs.

(4) Write a manuscript for primary publication on the model of the red king crabs produced under this contract. Present a talk based on this manuscript at the Lowell Wakefield Symposium in October 1995.

Progress During 1st Quarter

Tables and graphs were developed for the primary publication on formation of year-class strength of the red king crab stock in Bristol Bay. Audio tapes from the Tanner crab workshop were transcribed, and a first draft of the report was written.

Progress During 2nd and 3rd Quarters

(1) A second draft of the Tanner crab workshop was written and submitted for review by ADF&G.

(2) Analyses of the historic variability in both king and Tanner crab year classes were carried out. The ocean factors examined for their influence on year-class strength were developed during the crab recruitment workshops. For red king crabs, historical recruitment data from 1966 to 1986, as back-calculated by Zheng et al. (1995a, 1995b) included a period of brood strength increase and a long period of decrease that began sometime between 1971 and 1976. Tanner crabs were distinct from red king crabs and showed a decrease from 1968 to 1977, then an increase to 1983, followed by a decrease. Both stocks have remained low to the present. Two statistically significant relationships were found. The brood strength of red king crabs was related to the general climate change of the late 1970s, and showed a significant positive correlation with barometric pressure anomalies. Barometric pressure of the Aleutian Low intensified during the late 1970s and this change was associated with decreased brood strength. For Tanner crabs, the distinctive pattern of the brood strength time series was positively correlated with winds from the northeast. These winds flow parallel to the coast along the Bristol Bay side of the Alaskan Peninsula. Physical oceanographic theory predicts that this wind would bring about Ekman transport in the form of upwelling. It is well known that moderate upwelling enhances the concentration of nutrients that bring about increased phytoplankton production, and later a general increase in secondary production.

(3) A conceptual model of the formation of year-class strength of Tanner crabs was begun. This model is based on the results of the Tanner crab workshop.

(4) A primary publication (Tyler and Kruse 1996a) on formation of year-class strength of the red king crab stock in Bristol Bay was submitted for publication.

Progress During 4th Quarter

All goals for FY 96 were met. In addition to those goals met earlier in the year, the following goals were met during the last quarter:

(1) The report of the Tanner crab workshop was finalized and submitted for publication by ADF&G (Tyler and Kruse 1996b).

(2) A conceptual model of the formation of year-class strength of Tanner crab was completed and submitted for publication as a section in the Regional Information Report of ADF&G (#1 above) on the Tanner crab workshop. This publication will become available for distribution in August 1996.

Plans for FY 97

This project has been completed. However, the products of this research have led to the development of a new project, titled *Recruitment Dynamics of Tanner Crabs*, that will begin in FY 97. A detailed project description appears in the project proposal for next year (Kruse

1996c). In sum, a Reimbursable Services Agreement will fund research-related expenses for Dr. Albert V. Tyler and a graduate student (Gregg Rosenkranz) who will work on a masters degree in Fisheries at UAF. The project is conceived as a two-year study with an overall research goal to understand the causes of bursts of increased, fishery-sustaining production of eastern Bering Sea Tanner crabs. The primary objective is to develop a statistical model to study the relationships between physical and biological factors affecting population levels of Tanner crabs in the Eastern Bering Sea. Existing time series of sea water temperature, prevailing winds, ice cover, and barometric pressure, as well as information from stock assessment work by NMFS and ADF&G will be gathered for statistical analysis. Results will provide an indication of the relative importance of explanatory oceanographic factors on Tanner crab recruitment.

Benefits of Project

Results from this project have helped provide a framework for systematic planning of future research in areas of greatest consequence to crab management. It has also led to the development of conceptual models about factors affecting red king and Tanner crab recruitment. The new project to begin in FY 97 will provide statistical evidence of the causative factors of strong year classes of Tanner crabs. Because recruitment to the fishery occurs 7 years after hatching, knowledge about key factors that operate during early life history will yield vital information to fishery management. During long periods of poor recruitment, harvest rates should be lowered so that spawning stocks are not reduced to levels so low that the stock cannot recover. During periods of strong recruitment, increased harvests may be taken. Results from this project will be directly incorporated into analyses of alternative harvest strategies by Project 4, *Crab Management Strategies.* Besides benefiting managers of the Tanner crab fishery, the modeling approach may provide insight into the population dynamics of other species in the ecosystem.

PROJECT 2: BREEDING SUCCESS OF LEGAL SIZE MALE RED KING CRABS *PARALITHODES CAMTSCHATICUS* (DECAPODA, LITHODIDAE)

Dr. A.J. Paul, Principal Investigator

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Background and Need

Male red king crabs previously supported an important commercial fishery in Alaska. Currently several fishing areas have very restricted harvest quotas because of low crab abundance. The reasons for the large scale population decreases are poorly understood, but their occurrence has increased the desire to understand the reproductive biology of the species. For Kodiak red king crabs, the fishery is restricted to males larger than 145 mm carapace length (CL), and a decrease in the number of large males in the population due to fishing mortality is to be expected. In nature males

in grasping pairs are typically larger than 120 mm. Thus, it appears that the larger males are those that mate. The removal of large males by the fishery may affect the reproductive potential of the species. Experiments are proposed in which legal size males will have access to several ovulating females. The experiments will determine how many females legal size males can fertilize. This information will be useful in reviewing regulations concerning the number of males that can be harvested and still maintain full reproductive potential of the population.

In a previous study of sublegal male reproductive potential, red king crab males of 80-89 mm CL were successful in inducing ovulation with 75, 38, 12 and 12% of their 1st, 2nd, 3rd and 4th potential mates respectively. An average of 68% of the eggs initiated division in clutches of their first mate. Corresponding values for their 2nd, 3rd and 4th consecutive mates were 18, 12 and 12%, respectively. As male size increased so did the ability to mate with successive females. Males in the 130-139 mm group induced an average of 88, 78, 100 and 44% of their four successive potential mates to ovulate. Clutches of the first through fourth females bred by 130-139 mm males had 87, 76, 95, and 38% of the eggs initiate division on the average. Thus, these sublegal males often fertilize only part of an egg clutch.

Several older observations exist for multiple matings with king crabs. In an early report (Paul and Paul 1990) 11 new shell males, 120-144 mm, bred 51 females that all extruded full clutches. Males near legal size have been reported to mate as many as 13 successive times, but their mating ability decreased after the sixth or seventh mating (Powell et al. 1974). None of those reports quantified egg viability and it is possible that the reproductive capacity of those red king crab males was overestimated. During this study mating experiments with legal size males will be redone with egg viability monitored to verify or discount the existing observations.

Project Description

The reproductive potential of red king crab males 140-200 mm CL will be examined. Individual males will have access to four to ten females and breeding behavior, ovulation and percentage of dividing eggs in clutches will be recorded. The number of females a male has access to will be determined by the number of crabs collected by ADF&G. A mating will be considered successful if a male induces a female to ovulate and eggs initiate division. The results will provide information on the reproductive potential of large males which will be useful in refining the management program.

Goals For FY 96

The overall objective of this project is to provide information on the reproductive biology of legal size red king crabs to assist the regulatory agencies in the management of stocks of this species. Specifically the following aspects of the reproductive biology of red king crabs will be investigated:

(1) Ability of 140 mm CL and larger males to breed and successfully fertilize successive females.

(2) The percentage of developing eggs in clutches of females mated to different size males or males bred to several females.

Progress During 1st Quarter

No experiments were planned to take place during the first quarter because king crab reproduction takes place in late winter and spring.

Progress During 2nd and 3rd Quarters

Several unforeseen obstacles have been encountered in the collection of red king crabs for this study. We planned to use the ADF&G research vessel *Resolution* to collect red king crabs during late 1995 or early 1996 off Kodiak Island, Alaska. However, the vessel experienced major engine failure. Because extensive repairs were required, the vessel was unavailable for several months and it was not available for use in this study as planned. As a back-up, arrangements were made with a commercial fisherman to collect red king crabs off Kodiak. This fisherman deployed pots, but was unsuccessful in catching sufficient red king crabs for the experiments. Subsequently, the fisherman became unavailable due to his commitments to participate in the snow crab fishery in the Bering Sea. As another back-up plan, ADF&G made arrangements with a subsistence fisherman to collect the crabs in Kachemak Bay after thick ice in Homer harbor thawed. At present, the department is awaiting these collections.

Progress During 4th Quarter

Unfortunately, the subsistence fisherman in Kachemak Bay was unable to make the necessary collections, as well. Because female red king crabs molt and mate in April, it was biologically impossible to collect pre-molt crabs during the fourth quarter after this last attempt failed. To conduct this study, it is essential that that crabs are collected in late winter or early spring before female molting and mating occurs.

Plans for FY 97

For the reasons described above, it was not possible complete the study as planned during FY 96. However, ADF&G and UAF proposed a workable solution to NMFS, and we await authorization to implement this solution to this problem. ADF&G has requested permission to extend the deadline for deliverables from this project from June 30, 1996 to June 30, 1997 at no additional cost to NOAA. Crabs will be collected next year during late winter 1997, experiments will be conducted during spring 1997, and a manuscript of results will be available by June 30, 1997. The unfortunate major engine failure experienced by the *R/V Resolution* during FY 96 is highly unlikely to occur again next year. Therefore, this project has a very high probability of success, if the deadline is extended to June 30, 1997.

Benefits of Project

The results of the experiments will be published in a peer reviewed journal and appropriate management documents. The study will be useful to resource managers who rely on basic biological information, such as reproductive capacity which we will measure, to determine legal size limits and harvest quotas.

PROJECT 3: CRAB GENETICS

Sue Merkouris and Dr. Lisa Seeb, Principal Investigators

Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Genetics Laboratory, 333 Raspberry Road, Anchorage, AK 99518-1599

Background and Need

Fisheries cannot be managed successfully without understanding the underlying stock structure. Although we have made some progress (e.g., Seeb et al. 1990a,b) into genetic stock identification of red king crabs, several key questions remain about structure of Bering Sea and Aleutian Islands crab stocks. Some of the most important questions concern Tanner crabs and golden king crabs. Answers to these questions will be useful to improve alignment of management units with genetic stocks.

Project Description

In FY 95 this project funded a Fishery Biologist II for 7 months, and associated laboratory supplies to conduct studies into genetics of crab stocks. Specifically, this project concentrated on an allozyme analysis of Tanner and snow crab stocks in Alaska. Tissues were collected and analyzed in the laboratory. In the last quarter of FY 95, this project focused on analysis and report writing.

Following completion of this study, a small-scale pilot study of golden king crabs from the Bering Sea, Adak Island, and Southeast Alaska was initiated to determine the potential utility of allozymes for stock separation.

In FY 95 this project also provided partial funding for nuclear DNA-level marker development for red king crabs in Alaska, beginning April 15, 1995, with a report describing results due June 30, 1996.

In FY 96 this project is funding a Fisheries Biologist II for 6 months and associated laboratory supplies to conduct studies into genetics of crab stocks.

Goals for FY 96

Milestones for FY 96 include:

(1) Incorporation of editorial review comments and submission of manuscript on Tanner and snow crab stock identification based on allozyme analyses for publication in a professional journal.

(2) Initiation of a pilot study on golden king crab allozymes: collection of samples, screening of tissues and enzyme systems, and a draft report on findings. Results of allozyme analyses of a few blue king crab specimens will be compared to red and golden king crabs.

(3) Development of DNA-level markers, primarily microsatellites, for use in red king crab stock discrimination studies.

(4) Transfer of technology of mitochondrial DNA (mtDNA) methods developed by the University of Washington (UW) Marine Molecular Biotechnology Laboratory to the Alaska Department of Fish and Game Genetics Laboratory. These methods will be used in further investigation of hybridization between Tanner and snow crabs.

Progress During 1st Quarter

(1) Analysis of Tanner and snow crab allozyme data are complete. A draft manuscript, "Biochemical genetic variation of highly exploited Tanner crabs, *Chionoecetes bairdi* and snow crabs, *C. opilio,* in Alaska" was reviewed internally. Following the review process, this manuscript will be submitted to a professional journal for publication. These data indicate that regional differentiation exists among populations of the Bering Sea, the Gulf of Alaska, and Southeast Alaska. Unfortunately, the number of allozyme marker loci available for the two *Chionoecetes* species is limited, and additional genetic markers are desirable to more accurately delineate population subdivision.

(2) One collection of 100 golden king crabs was obtained from the Adak fishery. An additional collection of 100 golden king crabs from the Dutch Harbor fishery was scheduled for early October. This collection has become feasible by the newly adopted regulation which places observers onboard all vessels participating in the Dutch Harbor Area fishery. Collection efforts in the Bering Sea, Southeast Alaska, and an alternative collection site, British Columbia, were not successful this quarter due to low harvests, low fishing effort, and the lack of population assessment programs in these areas. Opportunistic efforts to sample golden king crabs caught incidentally during the Bering Sea *Chionoecetes tanneri* fishery will continue, however past efforts have been thwarted by very low incidental catches of golden king crabs during this fishery.

(3) Over the last year, with state of Alaska funds under contract to UW, we began a new line of research to develop mtDNA and nuclear DNA markers for identification studies of Alaskan crab stocks. Both mitochondrial and nuclear markers have the potential of providing additional variability which can be used for stock discrimination. Further, mtDNA can be extremely useful in hybrid studies. When combined with allozyme data or other nuclear genetic data, the data sets can establish the direction of hybridization and the extent of introgression between *Chionoecetes* crab species.

The initial DNA crab study focused on extraction, amplification, primer and marker methods development for *Chionoecetes* and red king crabs. Muscle tissue was recommended for both genera (non-lethal, easy to work with, high yields). Several DNA extraction methods were compared with desirable results achieved in at least two methods for each genera. Several primers for DNA amplification were utilized with variable results.

The best results for red king crabs were obtained for the 16S mtDNA gene, however sequencing revealed no variation in sequences of all individuals examined. Red king crabs are difficult to work with in that several primers, including some "universal" primers, did not yield polymerase chain reaction product. Further experimentation is required to ascertain the utility of other mtDNA genes in red king crabs.

Suitable primers identified for *Chionoecetes* crabs included 16S mtDNA, cytochrome oxidase, and nuclear ribosomal primers III, IX. Sequencing of 16S revealed several differences between the two species, some of which were fixed. In a preliminary assay of nuclear ribosomal III, IX, seven restriction enzymes yielded clear species-specific differences. Additional preliminary results indicate bi-directional species hybridization between Tanner and snow crabs in the Bering Sea. A total of 192 restriction enzyme assays were performed on *Chionoecetes* crabs.

(4) Utilizing $7 K from FY 95 Federal Shellfish Research moneys, together with $15 K from existing state funding sources, a $22 K contract for continuation of DNA methods development, primarily microsatellites, for red king crabs was awarded. Additionally, DNA methods developed for use in red king crabs may also be applied in the future to golden king crab stock identification questions. This study is on-going.

Progress During 2nd and 3rd Quarters

(1) Internal reviews of a draft manuscript "Genetic variation of highly exploited Tanner crabs, *Chionoecetes bairdi* and snow crabs, *C. opilio* in Alaska" are complete. This manuscript will be submitted by the end of quarter 3 to *Fishery Bulletin* for publication.

(2) Two additional collections of golden king crabs were obtained. One collection (N=100) was obtained from the Dutch Harbor registration area in October 1995. These crabs were obtained by an observer from the ADF&G mandatory observer program during the fall 1995 Dutch Harbor golden king crab fishery. A second collection (N=110) was obtained from Frederick Sound and Chatham Strait in Southeast Alaska in March 1996. This collection was obtained through the cooperative efforts of a Southeast Alaska fisherman under a special scientific collection permit issued by the State of Alaska.

(3) During November 1995, the Fisheries Biologist II funded by this project completed one week of training in the UW Marine Molecular Biotechnology Laboratory. The purpose of this trip was to begin technology transfer of the mtDNA methods developed by UW under contract to ADF&G. A final report detailing these methods was completed (Bentzen and Jensen 1996).

Progress During 4th Quarter

(1) A manuscript entitled "Genetic variation of highly exploited Tanner crabs, *Chionoecetes bairdi* and snow crabs, *C. opilio* in Alaska" was submitted to the journal, *Fishery Bulletin*, for publication. This manuscript has been accepted for publication, though some minor revisions are required.

(2) An additional collection of golden king crabs was obtained from Bering Sea this quarter. Currently, we have four population collections (Adak, Dutch Harbor, Bering Sea, and Frederick Sound/Chatham Strait in Southeast Alaska) of golden king crabs to initiate an allozyme pilot study.

(3) Final collections of red king crabs for allozymes are currently being analyzed (Bristol Bay, Seymour Canal, and Pribilof Island). Concurrent with these analyses, a few blue and golden king crabs are being included to begin establishing allozyme protocols for these two species.

The ADF&G crab genetics program is not fully funded by NOAA Cooperative Agreement. Other (non-federal) funds are used to support a collaborative project with the University of Washington (UW) Marine Molecular Biotechnology Laboratory to develop DNA-level markers, primarily microsatellites, for stock discrimination among populations of red king crabs in Alaska. Because federal- and state-funded genetics projects share common goals, for completeness we report on progress on this collaborative project here.

Efforts by UW to clone microsatellites using library enrichment techniques were unsuccessful. This approach was abandoned in favor of the classic cloning technique which did prove successful. Isolated red king crab genomic DNA fragments of ~300-800 base pairs were inserted into plasmid vectors. The recombinant plasmids were used to transform *E. coli* cells containing plasmid, and grown on selective medium.

Cells containing recombinant plasmid (plasmid and crab insert) are distinguished based on color. These colonies were lifted onto nylon membranes, cells lysed and the recombinant plasmid DNA fixed to the membranes. The membranes were exposed to a mixture of fluorescently labeled synthetic di- or trinucleotide repeats. Colonies containing inserts which hybridized to labeled probes were detected using a fluor-imager. Colonies identified in this manner were transferred to fresh agar plates and re-screened to eliminate false positives. Initially, 2,369 colonies were examined in the primary screen, and 288 taken through the second screen. Of the latter, 28 clones which demonstrated the full spectrum of weak to strong fluorescent signal were chosen for further analysis. These 28 clones were grown in liquid media and harvested for sequencing. Initially, all 28 clones were sequenced in one direction only.

All 28 clones had microsatellites of varying motifs and lengths, with some possessing multiple motifs and repeat arrays in the same clone. Primers have been designed for all 28 clones. In some cases, two sets of primers were designed for the same clone where multiple arrays were present.

All microsatellites have been organized by size and expected levels of polymorphisms (as predicted by array length and motif). Currently, both fluorescently labeled and unlabeled primers are being made for these loci on a DNA synthesizer. Primers and assigned colors for labeling have been designed to facilitate muliplexing on the ABI Gene Scanner.

Plans for FY 97

Additional work is planned on the collaborative project with UW using state of Alaska funds. The primers will be tested on genomic DNA from a red king crab specimen. Primer pairs which yield clean, reliable product bands in the expected size ranges will be optimized and used in polymerase chain reactions (PCRs) with the red king crab genomic DNA from 3 populations (Deadmans Reach, Uganik Passage, Bristol Bay) of 50 individuals each. Following these analyses, which is expected to require approximately one month, a final report on these methods will be completed and submitted to ADF&G.

This technology will be transferred to ADF&G and applied in a pilot study of 150 individuals beginning late in FY 97. Transfer of this technology will require a one-week onsite visit by the contractor. Success at this level of screening will likely result in future full population screenings of stocks of red king crabs in Alaska. These methods may also prove useful for stock identification of blue and golden king crabs in Alaska.

During FY 97, work funded by NOAA Cooperative Agreement will concentrate on development and application of DNA-level markers and completion of allozyme work previously initiated. A mtDNA analysis of hybridization of *Chionoecetes* species will be conducted and a manuscript submitted for journal publication. Further, a small-scale pilot study of golden king crabs from Southeast Alaska, Adak Island, and the Dutch Harbor area

will be performed to determine potential utility of allozymes for stock separation. A few blue king crab samples will be examined for comparison.

Benefits of Project

This project addresses questions related to stock structure that were described in the long-term research plan (Kruse 1996b). Studies of crab genetics may provide bases for revision of fishery management units to better match underlying population structure. For example, it is not known whether Tanner crabs in Bristol Bay and near the Pribilof Islands should be managed as separate stocks. Further, appropriate management units for golden king crabs are uncertain. Last, results of this project may aid enforcement of crab regulations by helping to provide forensic data for court cases that involve fishing in areas closed to protect depressed crab stocks.

PROJECT 4: CRAB MANAGEMENT STRATEGIES

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Background and Need

Sound management requires precise estimates of population abundance and objective, quantitative evaluations of alternative management strategies. In Alaska, many crab stocks are assessed annually by trawl or pot surveys, some are assessed irregularly, and some stocks lack assessments. Population estimation models are needed to make best use of multiple years of data on crab size, sex, and reproductive condition. Such models are necessary to evaluate measurement errors in annual surveys and to generate abundance estimates for stocks that are infrequently assessed.

Estimates of biological production parameters are needed to determine optimal management strategies and to calculate fishery yields for crab fisheries off the coast of Alaska. For most stocks, the common biological reference points, such as $F_{0.1}$, yield per recruit, optimum yield, and stock-recruit relationships have not been computed. The utility of fishery thresholds and alternative harvest rates have not been thoroughly evaluated either.

Project Description

This project funds an ADF&G Biometrician II to conduct quantitative analyses of abundance, biological, and fisheries data for crab stocks. Analyses focus on information germane to harvest policy: population estimation, optimal thresholds, biological reference points, natural and handling mortality, size limits, stock and recruitment relationships, effects of fishing on growth and reproductive success, sustainable yields, and molting seasonality as related to fishing seasons. Top priority was placed on development of

length-based population models that integrate multiple years of survey assessment and catch data, analyses of stock-recruit relationships, and evaluation of the utility of thresholds and harvest rates to optimize the trade-offs between high yield and low variability in yield.

Goals for FY 96

Third year work will advance new projects and finalize studies begun in the first two years:

(1) Revise the length-based model for Bristol Bay king crabs to reduce the number of parameters used to describe natural mortality and update the model to include annual survey data.

(2) Incorporate reviewer's comments in the three papers prepared and submitted to professional publications in FY 95 on optimal harvest strategies for Bristol Bay red king crabs, the catch-length analysis for crabs without survey information, and the length-based model for Bristol Bay Tanner crabs.

(3) Review documents for public education that summarize length-based population abundance estimation method and harvest strategies for Bristol Bay red king crabs.

(4) Continue the study of Bristol Bay red king crab stock rebuilding strategies. Investigate the sensitivity of the rebuilding strategies to parameter values and model specifications. This includes completion of simulations and draft manuscript.

(5) Estimate biological reference points for red king crab stocks in Alaska.

(6) Compare abundance estimation methods for red king crabs in Bristol Bay and Kodiak and prepare a draft manuscript.

(7) Conduct a catch-length analysis for the Adak red king crab population.

(8) Investigate the molting probabilities of mature male Tanner crabs in the eastern Bering Sea, focusing on the terminal molt problem.

(9) Initiate work on optimal harvest strategies for crab populations with periodic recruitment, with an application to the eastern Bering Sea Tanner crab population.

(10) Initiate work on evaluation of minimum size reduction for the Bristol Bay red king crab fishery.

Project Progress

The length-based population estimation model for Bristol Bay red king crabs was revised and updated, and a second manuscript on these changes was completed and published by the Alaska Fishery Research Bulletin (Zheng et al. 1995b). The

manuscript on optimal harvest strategies for Bristol Bay red king crabs was further revised according to the comments we received from the editor and has been resubmitted to the Canadian Journal of Fisheries and Aquatic Sciences (Zheng et al. MSa). The manuscript on the catch-length analysis without survey data was revised, accepted, and published by Fishery Bulletin (Zheng et al. 1996b). The manuscript on the length-based model for Bristol Bay Tanner crabs was revised based on reviewers' comments and has been sent back to the Canadian Journal of Fisheries and Aquatic Sciences (Zheng et al. MSb). An overview of the length-based population abundance estimation method, long-term harvest strategies, and rebuilding strategies for Bristol Bay red king crabs was written and published for public distribution (Zheng et al. 1996a).

The simulation study of Bristol Bay red king crab stock rebuilding strategies has been completed, a presentation was given in the annual Alaska chapter meeting of the AFS, and a manuscript is being revised for submission to journal publication (Zheng et al. MSc). A presentation on comparison of abundance estimation methods for red king crabs in Bristol Bay and Kodiak was given in an International Symposium, and a manuscript has been submitted for publication in the proceedings (Zheng et al. 1996c). Biological reference points analysis was conducted, and a presentation was given and an extended abstract will be published in an International Symposium (Kruse et al. 1996).

Much effort was devoted to prepare staff reports for the meetings of the Alaska Board of fisheries in March 1996 and North Pacific Fishery Management Council in June 1996. The Alaska Board of Fisheries adopted our proposal for Bristol Bay red king crab harvest strategies. The North Pacific Fishery Management Council adopted a plan amendment to close portions of the Bering Sea to trawling and adjusted trawl bycatch caps for red king crabs.

Partial data used for the catch-length analysis for Adak red king crabs and molting probabilities of mature male Tanner crabs in the eastern Bering Sea have been collected and are being analyzed. These two projects will be continued in FY 97. Work on optimal harvest strategies for crab populations with periodic recruitment and evaluation of minimum size reduction for the Bristol Bay red king crab fishery is still in a planning stage and will be continued in FY 97.

Plans for FY 97

Fourth year work will advance new projects and finalize studies begun in the first three years:

(1) Update according to reviewer's comments the two papers prepared and submitted to professional journals on analysis of harvest strategies and rebuilding strategies for Bristol Bay red king crabs.

(2) Assist in completion of a manuscript on estimating biological reference points for red king crab stocks in Alaska.

(3) Continue to investigate the molting probabilities of mature male Tanner crabs in the eastern Bering Sea, focusing on the terminal molt problem. This includes completion of the project and preparation of a manuscript.

(4) Continue work on optimal harvest strategies for crab populations with periodic recruitment, with an application to the eastern Bering Sea Tanner crab population. This includes preparation of a manuscript.

(5) Continue to collect data and conduct a catch-length analysis for the Adak red king crab population.

(6) Construct catch-survey models for St. Matthew and Pribilof Island red and blue king crabs.

(7) Examine stock-recruitment data of forage fish stocks and compare their recruitment patterns. The results may be used to examine crab recruitment patterns.

(8) Improve the length-based model to deal with correlated error structure of survey data.

(9) Analyze potential size limit reductions for the Bristol Bay red king crab fishery.

Benefits of Project

This project relates to the long-term research plan in two ways. First, for all major crab stocks we intend to develop estimates of population abundance by modeling available data. For crab stocks with surveys, the models provide estimates of crab abundance that are relatively insensitive to survey measurement errors in any single year. For crab stocks with only fishery performance data, catch-length models provide abundance estimates which are currently not available. Second, because these models embody critical biological parameters specific to a species and stock, they provide a framework within which to evaluate optimal harvest strategies.

PAST PROJECT UPDATE: HANDLING MORTALITY OF RED KING CRABS

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Prologue

During FY 94 and FY 95, NOAA Cooperative Agreement NA37FL0333 funded a project on handling mortality of red king crabs. Due to limited federal funds, this project was funded for a third and final year (FY 96) with state of Alaska funds. Although federal funds were not involved during FY 96, we thought it prudent to describe the products of all three years in this final report as the research represented a single, integrated study.

Background and Need

Pots capture male and female crabs of a range of sizes and carapace conditions; however, all Alaskan crab fisheries are regulated by size and sex restrictions. As a result, females and small males are discarded. Several lethal and sublethal effects may result from the catching, handling and discarding processes. Handling mortality occurs during fisheries when crabs are killed due to crushing, desiccation, exposure to extreme temperatures, and other factors. Sublethal effects may include injuries, slower feeding and growth rates, and perhaps decreased competitiveness and reproductive potential. Although some crabs survive autotomy or amputation and regenerate lost limbs, severely injured crabs may experience reduced growth and initial molt inhibition, followed by a shortened intermolt period.

Project Description

This project approached the handling problem in two ways. The first approach, taken during FY 94, investigated the lethal and sublethal effects of handling by simulating the catching and discard processes in the laboratory. The second approach, taken in FY 95 and FY 96, examined ways to minimize handling of king crabs through modifications of commercial pot gear.

The reason for the first approach is that handling mortality occurs during commercial fisheries when crabs are killed due to crushing, desiccation, exposure to extreme temperatures, and other factors. Handling mortality has been well documented in crustaceans. Death may be immediate or delayed. Stress from handling may reduce vigor and defense against predators. Sublethal effects of handling include injuries, reduced feeding and growth rates and may result in crabs in poorer physical and physiological condition. Appendage loss increases during the crabbing season, and may be a function of air temperature during severe weather. Although some crabs survive amputation and regenerate lost limbs, severely injured crabs may experience reduced growth and initial molt inhibition, followed by shortened intermolt period. In the

first stage of research, lethal and sublethal effects of handling on red king crabs were investigated.

Whatever the magnitude, it may be possible to reduce handling mortality by gear modifications. Little is known about red king crab behavior to fishing gear. Specifically, research was conducted on the behavior of red king crabs with respect to commercial crab pots, with the intent of formulating gear and/or deployment techniques that will decrease the catch of females and sublegal-sized males in the fishery. The reactions of king crabs to simulated commercial pots were recorded and analyzed by means of video cameras and computer-assisted quantitative techniques. An improved fishing method, which considers optimal soak time and modified crab pots, may facilitate the catch of legal male crabs but limit the catch of female and sublegal male red king crabs. Such a method was proposed and tested in a laboratory situation. These efforts may increase the catch efficiency of legal males with concomitant decreased catches of females and sublegal male king crabs.

Goals for FY 96

Project goals for FY 94 and FY 95 were reported in previous annual reports (Kruse 1994a, 1995a). For FY 96, primary goals were to: (1) complete analysis of king crab behavior on video tapes by means of computer-assisted quantitative techniques; (2) construct an ethogram of crab behavior around and inside crab pots; (3) study crab foraging behavior, and pot entering and exiting behavior; (4) analyze and compare the probabilities of crabs approaching, entering and exiting from two different crab pot designs with respect to size and sex of crabs; and (5) analyze observational data made during the commercial crab fishery and the crab observer program.

Progress During FY 96

Project progress during FY 94 and FY 95 was reported in previous annual reports (Kruse 1994a, 1995a). This project was completed during FY 96, and all goals have been successfully met. In summary, this project resulted in the completion of a doctoral dissertation (Zhou 1996), one paper on handling mortality published in a peer-reviewed journal (Zhou and Shirley 1995), another manuscript on handling mortality will be published in the proceedings of an international symposium (Zhou and Shirley 1996), four manuscripts on crab behavior in relation to pots that are currently in review in scientific journals (Zhou and Shirley MSa,b,c,d), an educational video on king crab mating behavior that is in final editing, an innovative crab pot design that is being readied for comprehensive field testing, and three talks given at scientific meetings.

A number of additional manuscripts are planned, including:

(1) Feeding and growth rates of red king crabs.

(2) Cannibalism and protective behavior of red king crabs during the mating season.

(3) An ethogram describing red king crab behavioral responses to crab pots.

Plans for FY 97

Although this project has been completed, it has led to the development of a new, one-year project titled *"Crab Handling Mortality and Bycatch Reduction"* that will be conducted in FY 97. A detailed project description appears in the project proposal for next year (Kruse 1996c). In sum, Dr. Shijie Zhou has been employed by ADF&G as a non-permanent fishery biologist to conduct one year of research into handling mortality and bycatch reduction through three studies.

In the first study, handling mortality rates will be simulated for Bristol Bay red king crabs and Eastern Bering Sea Tanner crabs from cold air exposure. Of all the handling factors studied so far, exposure to cold air seems to be the most consequential to handled crabs returned to the sea. Input data are historical records of daily commercial catches, catch rates, Pribilof Island air temperature, and Pribilof Island wind speed to calculate exposures to real and apparent temperatures from wind chill. Functional relationships are mortality from cold air exposure as determined from published laboratory studies and time of exposure as affected by number of crabs per pot from field observations.

In a second study, the new red king crab pot, designed in the laboratory, will be tested in the field under commercial fishing situations in Bristol Bay. Federal funding will cover the biologist's salary, and all other costs of this project (e.g., gear purchase, vessel charters) will be paid by ADF&G with state funding.

In a third study, the fishery biologist will design and conduct a gear study to evaluate rings and large-mesh panels as escape mechanisms for female and sublegal male Tanner crabs in Kodiak, Alaska, as a means to reduce bycatch and handling mortality. As with the other gear study, all costs other than the biologist's salary will be paid by ADF&G with state funds.

Benefits of Project

Acute and sublethal effects of handling of red king crabs during the commercial fishery have been quantified in controlled, laboratory experiments. The responses of red king crabs to bait and their behavior around and inside crab pots have been described and quantified. A new and innovative crab pot design that selectively retains legal-sized male crabs while permitting escape of juvenile and female crabs has been designed and tested in laboratory conditions. This has led to the design of a large scale, field test of the new crab pot to be conducted during FY 97. Should this design prove practical under commercial fishing operations, a major breakthrough in bycatch reduction could result. Based on findings from this study, ADF&G would be in a position to make appropriate fishery management recommendations concerning legal gear.

OVERALL RESEARCH PLANNING FOR FY 96

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A research proposal was submitted for FY 97 under NOAA Cooperative Agreement NA37FL0333 (Kruse 1996c). ADF&G awaits acceptance of the proposal by NMFS. We anticipate that $237,500 will be appropriated for July 1, 1996 to June 30, 1997. Four projects will be funded: (1) recruitment dynamics of Tanner crabs; (2) crab handling mortality and bycatch reduction; (3) crab genetics; and (4) crab management strategies.

Project progress and future planning will be reviewed at the fourth annual interagency crab research meeting tentatively scheduled during December 1996. Also, research will be discussed with members of the crab industry at a meeting to be held on Kodiak Island during fall 1996. These annual meetings have been very informative and stimulating for staff and industry alike.

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