KING AND TANNER CRAB RESEARCH IN ALASKA:

ANNUAL REPORT FOR

July 1, 1996 THROUGH June 30, 1997

Submitted Under Cooperative Agreement NA67FM0212 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. 5J97-12
Alaska Department of Fish & Game
Commercial Fisheries Management and Development Division
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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
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Introduction

A budget initiative for crab research was funded by the U.S. 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. The funds support cooperative investigations conducted by researchers with state and federal agencies and universities. Under Cooperative Agreement NA67FM0212, ADF&G was awarded $237,500 for a fourth year of work during state fiscal year FY 97 which spans July 1, 1996 through June 30, 1997.

This annual report describes work performed under Cooperative Agreement NA67FM0212 during FY 97. Previously-published quarterly (Kruse 1996b) and semiannual reports (Kruse 1997a) 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 fourth-year research; (3) individual project summaries; and (4) plans for fifth year research. Sections of this report were authored by individual project leaders as noted.

Long-term Research Strategy

Background, justification, and a long-term strategy for crab research were provided in the original statement of work (Kruse 1993a) and long-term work plans (Kruse 1994, 1996a). In overview, 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 more than a dozen crab fisheries remain closed due to low abundance. Poor success in maintaining productive fisheries over the long-term prompted a general re-evaluation of management strategies (Kruse 1993b). However, research is needed so that optimal management strategies can be specified.

Planning of a long-term crab research strategy has been an active, ongoing process involving many agency and university scientists, managers, and members of the public. Research plans are formally discussed at annual meetings of agency and university staff, annual interagency crab research meetings, and annual meetings with the crab industry.

These collective 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 1994). 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 1996a).

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 partial answers, many uncertainties remain 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 fishery and survey 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 stock productivity parameters is imperative to specify harvest rates that 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, historically 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 including 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 density-dependent and environmental effects. Laboratory, field and computer simulation studies are needed to evaluate the implications of these productivity features on harvest strategies.

Overall Project Plan For Fourth Year

This fourth year of research continues progress on the long-term work plan by conducting four studies: (1) recruitment dynamics of Tanner crabs; (2) crab handling mortality and bycatch reduction; (3) genetic stock identification; and (4) crab management strategies. With respect to the long-term research plan (Kruse 1996a), project 1 is directed toward the question "what features drive crab stock productivity?" Projects 2 and 4 provide insights into "how should this productivity be harvested?" Project 3 attempts to answer the general question "what are the stocks?" Project descriptions and progress follow.

A fifth project, on breeding success of legal-size male red king crabs, was funded in FY 96 but was not completed last year due to difficulties collecting experimental animals. ADF&G sought and NMFS approved funding extension to FY 97 to allow completion of this project this year. Since then, this fifth project has been successfully completed, and an annual completion report was published separately under Cooperative Agreement NA37FI0333 (Kruse 1997b).

PROJECT 1: RECRUITMENT DYNAMICS OF TANNER CRABS

Dr. Albert V. Tyler, Principal Investigator

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

Background and Need

The Japanese tangle net fishery for Tanner crabs in the eastern Bering Sea began in the 1960s. Minor landings were taken incidental to the U.S. domestic pot fishery for king crabs during 1968 to 1974. Since then, Tanner crabs have been the focus of a valuable but volatile fishery. Periods of large harvests have been followed by population declines leading to low harvests and limited fishing seasons.

The eastern Bering Sea stock of Tanner crabs is currently in a depressed condition which has been attributed to senescence of strong year classes in 1983 and 1984. Presumably, occasional periods of high productivity are the source of the biomass which drives the fishery. Factors contributing to this production are unknown.

Project Description

This project is being conducted through a Reimbursable Services Agreement (RSA) between the University of Alaska Fairbanks (UAF) and ADF&G. RSAs are administrative agreements between ADF&G and other state agencies for the performance of a service that involves the receipt or expenditure of funds. The RSA funds research-related expenses for Dr. Albert V. Tyler and a graduate student (Gregg Rosenkranz) who is working on a masters degree in fisheries under the direction of Dr. Tyler of UAF. Mr. Rosenkranz is a Rasmuson Fisheries Fellow and brings his tuition and stipend to the project. The project is a two-year study.

The overall research goal is to understand the causes of bursts of increased, fishery-sustaining production. 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. Step-by-step evaluation of possible effects of oceanographic variables on each stage in the species' life history will lead to formation of hypotheses that can be expressed as mathematical functions and will serve as the basis for a conceptual model. 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 provide inputs to a computer model which implements the hypothesized relationships to calculate theoretical Tanner crab year-class strength. Statistical comparison of these results with population estimates from ADF&G will provide an indication of the relative importance of explanatory variables and validity of hypotheses.

Although this is a new project, preliminary research was completed by Dr. Tyler. His work suggested that there are significant statistical relationships between physical variables and Tanner crab population levels. In particular, there appears to be a correlation between May-June wind from the northeast and brood strength. Northeast winds flow parallel to the coast along the Bristol Bay side of the Alaska Peninsula. Physical oceanographic theory predicts that this wind would cause 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 organism productivity. There are likely other ocean factors as well that would change productivity and survival of Tanner crabs. A multivariate modeling approach will provide the means to further investigate these relationships.

Goals for FY 97

The following list outlines project milestones for FY 97 and approximate time allotment for each:

(1) July 1-September 1: Review the literature on Tanner crab life history, physical oceanographic variables, and modeling approaches.

(2) August 1-September 15: Statistically evaluate oceanographic time series and ADF&G estimates of Tanner crab population levels.

(3) August 15-November 1: Formulate hypotheses on the effects of physical variables on each stage of Tanner crab life history.

(4) September 15-December 1: Develop the conceptual model that integrates hypotheses and leads to logical flow.

(5) December 1-June 30: Implement and test a computer model derived from the conceptual model. Testing will include step-wise multivariate linear modeling and multivariate second-order curvilinear modeling.

Progress During 1st Quarter

Relevant literature were reviewed, and hypotheses were formulated. Data series were compiled to investigate each hypothesis in a statistical model. These hypotheses are expressed here in order of their life history occurrence.

Hypothesis 1. Year-class strength of Tanner crabs is limited by food availability during the period from hatching to settlement (pelagic phase). At least two forces, wind-driven turbulent mixing and Ekman upwelling, transport nutrients into the euphotic zone, increasing primary production. Favorable sea surface temperatures combined with

heightened primary production increase the abundance of copepod nauplii, the primary prey of Tanner crab zoeae.

Hypothesis 2. Advection during the pelagic phase takes Tanner crab to unfavorable habitat in inner Bristol Bay in some years. Unfavorable transport could result from net northeasterly flow along the north shore of the Alaska Peninsula that is in part determined by the intensity of the Alaska Coastal Current.

Hypothesis 3. Large numbers of out-migrating Bristol Bay sockeye salmon prey on larval Tanner crabs. Abundance of Bristol Bay sockeye smolts varies interannually.

Hypothesis 4. Tanner crab survival rate is reduced by settlement into bottom waters colder than 2° C. Extent of the annual mid-shelf cold pool is a function of ice cover and intensity of the previous winter.

Hypothesis 5. Predation on benthic juveniles by cod and sole decreases numbers of age 0 to age 2 Tanner crabs. Fluctuations in biomass of these groundfish species are estimated by the NMFS trawl survey.

Hypothesis 6. Anthropogenic disturbances of the Tanner crab breeding population reduce total fecundity and lower year-class strength. Bottom trawling and pot-fishing effort vary both by year and by area.

Progress During 2nd and 3rd Quarters

The conceptual framework for this study of the Bering Sea Tanner crab population was developed using the time-events method described by Tyler (1992). A review of basic research provided information about Tanner crab life history and the timing of the reproductive cycle. Plankton sampling from the PROBES investigation (Incze 1983) and NMFS trawl surveys (e.g., Stevens et al. 1996) helped identify probable geographical locations of the population during larval, pre-recruit, and adult stages. A review of literature on the physical and biological oceanography of the Bering Sea shelf supplied a description of the environment and aided the understanding of mechanisms that could affect Tanner crab productivity and survival during various life-history stages. Life history and oceanographic information was integrated in the construction of the series of hypotheses about factors affecting Tanner crab year-class strength.

Length-based modeling by ADF&G (Zheng et al. 1997) produced a time series of year-class strength estimates that reflect Tanner crab reproduction and survival to maturity. Hypotheses about factors affecting Tanner crab recruitment are tested by applying correlation and regression methods to time series of candidate variables and year-class strength estimates. If there is a significant relationship between an explanatory variable and the Tanner crab time series in the univariate setting, the variable will be considered for inclusion in a multivariate model. Of particular interest is the identification of

environmental conditions which lead to periods of above-average reproduction that provide sufficient biomass to support the Tanner crab fishery. The final model will include the two or three variables which best explain the variation in the Tanner crab year-class strength estimates. Note that the statistical techniques in use cannot prove causation; rather, this work will identify factors which seem important and warrant further investigation while eliminating others. In some cases, time series of explanatory variables hypothesized to be important have not been collected or do not exist for all years (1968-1986) of the Tanner crab time series. The possibility of estimating these variables from related data will be investigated as work progresses:

The fitting of a theoretical stock-recruit model to the Bering Sea Tanner crab population does not seem practical at present because the respective time series of spawning biomass and recruitment overlap for only 13 years. However, possible relationships between spawning stock abundance and recruitment were investigated qualitatively by stratification and reexamination of the NMFS trawl survey data. This analysis was also undertaken to become familiar with data which provide input for the length-based model and hence the year-class strength estimates. Tanner crab catches from the survey were stratified according to Bering Sea oceanographic regions. Three areas selected for study were the outer shelf, mid-shelf, and a coastal region comprised of a strip adjacent to the Alaska Peninsula from Unimak Pass to Port Heiden. Separate series of length-frequency and catch per trawl plots for males and females in each region were constructed and examined.

Analysis of the NMFS survey data and comparison to the year class estimates revealed key features of Bering Sea Tanner crab population dynamics over the past 20 years. Relatively large populations which produced poor year classes were found in all regions of the eastern Bering Sea shelf from 1975 to 1979. Strong year classes were produced by a moderate spawning stock in the early 1980s. This was followed by a drastic drop in abundance between 1984 and 1985 which was most noticeable in the outer shelf region, where female CPUE fell from about 50 to 5 crabs per tow. The population then rebounded, peaking again in 1990, but has since declined and is presently at very low levels. Incze (1983) found high densities of newly hatched Tanner crab larvae in the outer shelf area during plankton sampling, and the stratified CPUE provides evidence that female abundance in this region is important for the production of new recruits. The sharp drop in Tanner numbers there in 1985 marked the end of a period which produced above average year classes. Yet, moderately high abundance levels in this area from 1975 to 1979 failed to produce good recruitment, suggesting that environmental variables play a crucial role.

We collected data and initiated statistical analysis of the many time series suggested by our hypotheses. The relationship between wind direction and recruitment which was uncovered in preliminary work on the project has been investigated in more detail. Expressing average May-June winds measured at St. Paul Island in vector-component form made it possible to perform a series of linear regressions with wind intensity from a

given direction as the explanatory variable and estimated recruitment as the response. A separate regression was performed for each 15 degree increment from 5° to 170°, effectively covering all points of the compass (note 5° is equivalent to 185° with a change of sign). Hypothesis testing to determine which of these regressions are significant shows there is a relationship between wind intensity and Tanner crab recruitment when winds are from 5° to 80° and no relationship for winds from 95° to 170°. The strongest relationship occurs when the time series of wind intensity is taken from 65°, which produces a regression correlation coefficient r^2=0.34 and shows good overall agreement with the trend of the estimated year class abundance. Noting that May-June coincides with the pelagic phase of newly hatched Tanner crab, this finding provides evidence for both the first and second hypotheses. Ekman transport is caused by alongshore winds moving south in the Northern Hemisphere and promotes upwelling of nutrient-rich bottom water leading to increases in phytoplankton abundance. Winds from 5° to 80° are long-shore relative to the Alaska Peninsula and hence this finding suggests that Tanner crabs may benefit from increased primary production associated with upwelling. However, the relationship between northeast winds and good Tanner crab year classes may also be explained by the second hypothesis. Northeast winds affect the net movement of Bering Sea surface water and may prevent zoeae from being advected to the inner reaches of Bristol Bay, where habitat is known to be more suitable for king crab. Additional work will be necessary to determine if one or both of these mechanisms is at work.

Preliminary analyses were also performed on time series of predator abundance and Bering Sea bottom water temperature. Estimates of Pacific cod relative abundance in the study region from NMFS trawl surveys appear to be uncorrelated with Tanner crab recruitment, although cod estimates are not available for all years of the Tanner crab time series and measurement error due to changes in survey techniques may be a factor as well (Gary Walters, NMFS Seattle, personal communication). Similarly, work with time series on abundance of out-migrating and returning Bristol Bay sockeye salmon obtained from ADF&G has shown no relationship to Tanner crab recruitment. Regression of the Tanner crab time series against June bottom temperatures measured over the Southeastern Bering Sea shelf by the Japanese research vessel Oshoro Maru (Ohtani and Azumaya 1995) reveals a significant relationship when recruitment is expressed by year of fertilization rather than year of hatching. This indicates that the intensity or extent of the cold pool affects Tanner crab reproduction, possibly by delaying brood development. Laboratory studies on the effects of temperature on Tanner crab reproduction are lacking, but conceivably, persistent cold waters may inhibit development of the oocyte and embryo clutch and disrupt timing of the reproductive cycle. Analyses of related time series (such as sea ice cover and sea surface temperature) should help clarify the relationship between water temperatures at various life-history stages and year-class strength formation.

Progress During 4th Quarter

Uncertainty about time lag from hatching to recruitment for Tanner crabs is a problem that cannot be resolved given the information currently available. A simple carapace-width regression on age developed from experiments conducted near Kodiak (Donaldson et al. 1980) suggested that recruitment of males to the modeled stock of Zheng et al. (1997) would be 6 years of age, whereas unpublished work for the Bering Sea (B. Stevens NMFS, Kodiak, personal communication) suggested that slower growth and a longer recruitment lag. Correlation between 65° vector (northwesterly, NW) winds measured at St. Paul Island and recruitment in our model is significant for males at lags of 5, 6, and 7 years and for females (which recruit a year sooner than males) at lags of 4, 6, and 7 years. The strongest correlations are at 7 years for males ($P = 0.0087$) and 6 years for females ($P=0.011$).

Sea surface temperature (SST) is another factor hypothesized to affect larval stage Tanner crabs. The seven years of lowest female recruitment correspond with SST values near the mean for the 1947-1994 period, but simultaneously, this period happens to include years of the strongest SW winds. Male recruitment estimates exhibit a similar although less distinct pattern. Correlation coefficients between model recruitment and SST reveal significant relationships at lags of 6, 7, 8, and 9 years when the low recruit observations are excluded from the analysis. The strongest correlations occur at lag 6 years for females ($P=0.003$) and at lag 7 years for males ($P=0.0142$). One interpretation of these results is that wind-driven advection plays a key role in larval survival and hence the formation of year class strength. Alongshore winds in the region are highly correlated with surface currents (Brower et al. 1988). It is possible that SST is an important factor only in years when advection is favorable (NE winds) but has no effect when wind-driven currents carry Tanner larvae to unsuitable habitat (SW winds).

Plans for FY 98

This project is planned for completion during it's second year of funding (FY 98). The following list outlines project milestones planned for July 1, 1997 through June 30, 1998 and an approximate time line for each:

July 1, 1997 - October 31, 1997: Continue collection and analysis of biotic and abiotic data suggested by the hypotheses on Tanner crab year class strength.

July1, 1997 - December 31, 1997: Evaluate missing data. Not all variables hypothesized to influence Tanner crab recruitment have been measured in all years of the response variable time series. The possibility of estimating these factors from related data will be investigated.

November 15, 1997 - February 28, 1998: Formate a regression model and analyze combinations of variables to best explain variation in the time series of year-class strength estimates.

January 1 - June 30, 1998: Compilation of results and writing of thesis.

Benefits of Project

This project will provide insights about factors that cause strong year classes of Tanner crabs. Because recruitment drives the fishery, 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: CRAB HANDLING MORTALITY AND BYCATCH REDUCTION

Dr. Shijie Zhou, Principal Investigator

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Background and Need

Pots capture male and female crabs of a range of sizes and carapace conditions. Yet, all Alaskan crab fisheries are regulated by size and sex restrictions. As a result, females and small males are discarded. Concern exists regarding handling mortality of crabs returned to the sea. A previously-funded project under this NOAA Cooperative Agreement found that repeated handling of red king crabs caused increased injury rate but had no effect on feeding, growth, righting response or mortality (Zhou and Shirley 1995). On the other hand, exposure to extremely cold temperatures can have severe adverse effects (Carls and O'Clair 1990, 1995). Conceivably, handled crabs might experience increased mortality from other factors such as habitat displacement or predation (Murphy and Kruse 1995), but such potential effects have not yet been studied in Alaska.

Another approach to the handling problem is to minimize bycatch of female and sublegal male crabs through gear modifications. In FY 96, ADF&G funded a study of red king crab behavior near crab pots. An outcome of this research was a new experimental pot design that significantly reduced bycatch while maintaining catches of legal crabs. Although this

new gear is quite promising from laboratory studies, it must be tested in field trials before recommendations can be made about potential gear changes by the fleet.

Project Description

This project funded a non-permanent fishery biologist II for 11 months. The project approached the handling problem in two ways. The first approach was to attempt to estimate handling mortality during historical commercial crab fisheries. The second approach was to attempt to minimize the capture of nonlegal king crabs by the current commercial fishery with gear modifications. Several studies involved these two approaches.

In the first study relationships between mortality rates of Bristol Bay red king crabs, fishery discard rates, and weather conditions were investigated. Input data are historical records of daily commercial catches, catch rates, observed discard rates, natural mortality rates, and Pribilof Island air temperature and wind speed. Functional relationships are mortality from cold air exposure as determined from laboratory studies (Carls and O'Clair 1990, 1995) and time of exposure as affected by number of crabs per pot from field observations (Zhou and Shirley 1996). Reconstructed mortality rates were compared to historical records from the fishery.

A second study on Tanner crabs parallels the first study on red king crabs. In this study, an attempt was made to reconstruct historical discard and handling mortality rates for the Tanner crab fishery in the eastern Bering Sea with appropriate temperature, wind, and catch data.

In a third study, a new red king crab pot, designed in the laboratory, was field tested under commercial fishing conditions in Bristol Bay. The fishery biologist developed the experimental design, implemented the field test, analyzed the results, and prepared a manuscript for publication. Aside from the biologist's salary, other costs of this project (e.g., gear purchase, vessel charters) were paid by ADF&G with state funding.

Goals for FY 97

Milestones of this project for FY 97 include:

(1) Prepare a manuscript on laboratory study of red king crab behavior around crab pots for publication in a professional fisheries journal.

(2) Design a field study of red king crab pot gear to reduce bycatch of females and sublegal males.

(3) Oversee experimental red king crab pot construction.

(4) Conduct gear experiments in Bristol Bay on red king crabs, analyze results, and prepare a manuscript for submission to a professional fisheries journal.

(5) Analyze air temperature, wind speed, and commercial catch data for Bristol Bay red king crabs and eastern Bering Sea Tanner crabs to reconstruct historical handling mortality from cold air exposure, and prepare a manuscript for publication.

(6) Help design, conduct, analyze, and report on results of a Tanner crab gear study conducted in Kodiak, Alaska.

Progress During 1st Quarter

The following progress was made during the first quarter:

(1) Eleven experimental pots were constructed. These pots were re-built from frames of standard king crab pots (210x210x87 cm) in Kodiak and shipped to Dutch Harbor before the field experiment.

(2) The field study was designed and conducted in the Bristol Bay coincidentally with two other gear studies that were designed to evaluate the escape of red king and Tanner crabs from pots rigged with escape rings. The experiments continued for one month. Six 4x4 sampling quadrats were used to compare the catchability of experimental and standard king crab pots.

(3) A manuscript on laboratory study of red king crab behavior around crab pots was revised in response to reviewer comments. This manuscript was accepted for publication in the Journal of Fisheries Research. Another manuscript comparing experimental and standard pot designs has been completed and submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

Progress During 2nd and 3rd Quarters

The project progressed as planned during the second and third quarters:

(1) The data from the Bristol Bay pot study were analyzed, and a manuscript titled "Catchability and size composition of red king crabs caught in two types of pots in the Bering Sea" was drafted for publication. This manuscript underwent internal ADF&G review.

(2) An analysis was completed of discarded Bristol Bay red king crabs from commercial fishery using air temperature, wind speed, commercial catch, and historical mortality. A first draft of a manuscript has been completed, and given to the coauthor for review prior to revision and internal ADF&G review.

(3) A companion analysis of the eastern Bering Sea Tanner crab fishery was initiated. Historical data on the commercial fishery, mortality, and weather were retrieved from computer archives.

(4) Ancillary data on red king crab feeding and growth rates, collected during a previously-funded project, were analyzed and a manuscript was completed. The manuscript was internally reviewed in advance of submission to the Journal of Crustacean Biology.

Progress During 4th Quarter

(1) Based on internal review comments, the manuscript titled "Feeding and growth of red king crabs (*Paralithodes camtschaticus*) under laboratory conditions" was revised and submitted to the *Journal of Crustacean Biology* for publication.

(2) Eastern Bering Sea Tanner crab fishery and weather data have been partially analyzed. Further analysis is pending development of a relationship between variable handling mortality estimates and the constant natural mortality estimates from the population model of Zheng et al. (1997).

(3) Deadloss data in the Tanner crab fishery were accessed. Analysis revealed that these data are questionable due to inconsistent reporting by fishermen. Further progress awaits determination of whether valid data can be extracted for meaningful analysis.

(4) Two experiments to be conducted next fiscal year under NOAA Cooperative Agreement have been designed. Two Project Operational Plans, "Modifications of cod pots to reduce Tanner crab bycatch" and "Effects of cold windchill on survival and activity of Tanner crabs," were written. Crabs were collected from the field, and the laboratory setup has been prepared for experiments.

Plans for FY 98

Two laboratory studies will be conducted during FY 98. In the first study, three to four different configurations of cod pot gear will be evaluated to reduce entry of Tanner crabs and increase their escape. An agency report on the results will be prepared for use in designing future field trials, and a manuscript will be prepared for publication. In the second study, the effects of cold wind chill on survival of Tanner crabs will be investigated. A manuscript on the results will be prepared for journal publication.

Based on reviews by journal referees and editors, prepare previously-submitted manuscripts for final publication, including: (1) red king crab gear experiments in Bristol Bay, (2) analysis of air temperature, wind, and commercial catch data for Bristol Bay red king crabs, and (3) feeding and growth of red king crab.

Benefits of Project

This project relates to the long-term research plan in two ways. First, by analyzing historical exposure of red king and Tanner crabs to cold air and wind exposure during the history of the fishery, this project will help further our understanding of one potential cause of crab stock declines. It will also help us evaluate the merits of current fishing seasons. Second, modifications of cod pots may help minimize the number of crabs that get handled and discarded during commercial fisheries.

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

Management of commercial fisheries relies on an understanding of the underlying stock structure. Although we made previous progress (e.g., Seeb et al. 1990a,b) into genetic stock identification of red king crabs, several key questions remain about the structure of the *Chionoecetes* species complex and as well as golden king crabs.

We recently completed the analysis of allozyme data for stock discrimination among *Chionoecetes,* and results have been accepted for publication. These data indicate that differentiation exists among populations ranging from the Gulf of Alaska to the Bering Sea, and heterogeneity exists in populations within the Bering Sea. However the number of allozyme marker loci within each species is limited.

Over the last two years a new line of research was begun to develop mitochondrial (mtDNA) and nuclear DNA markers for identification of Alaskan crab stocks. This work was done in collaboration with other laboratories. Nuclear markers have the potential of providing additional variability that can be used in 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.

Project Description

This project funds an ADF&G Fishery Biologist II for 6 MM and associated laboratory supplies to conduct studies into genetics of crab stocks. Specifically, the project will concentrate on the 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. Further, a small-scale pilot study of golden king crabs from Southeast Alaska, Adak Island, and the Dutch Harbor and Bering Sea areas will be performed to determine potential utility of allozymes for stock separation. These allozyme projects were proposed in FY 95 and FY 96, but adequate samples for analysis were not obtained until 1996. A few blue king crab *(Paralithodes platypus)* samples will be examined for comparison. If nuclear DNA-level markers currently being developed in collaboration with other laboratories prove promising, a study will be initiated late in FY 97 to further examine population structure of red king crab stocks in Alaska.

Goals for FY 97

Fourth-year work continues to achieve long-term research goals for crab genetics:

(1) Analyze mtDNA markers in *Chionoecetes opilio* and *C. bairdi* to determine the extent and direction of hybridization within the Bering Sea, and prepare a report for publication.

(2) Complete a pilot study on golden king crab allozymes: collection of samples, screening of gels, and report preparation. Results of allozyme analyses of a few blue king crab specimens will be compared to red and golden king crabs.

(3) Initiate a study late in FY 97 using DNA-level markers, primarily microsatellites, for stock discrimination among red king crab populations. These markers were developed under contract to Jensen and Bentzen of the University of Washington (UW) and may also be useful in future analyses of *Lithodes* stock structure.

Progress During 1st Quarter

(1) Allozyme analysis of remaining red king crab samples (N=250) was nearly completed. A few samples of golden and blue king crab were included for comparison to begin protocol development for these species.

(2) Microsatellite development continued under contract with the UW Marine Molecular Biotechnology Laboratory. Primers were developed and all 150 crabs representing three geographic populations (Bristol Bay, Uganik Passage, Deadmans Reach) were run at least once for six microsatellite loci. Optimization of these six loci continued. Preliminary analysis of data from one locus indicated significant heterogeneity among the three populations examined. Further data analyses progressed and final results of population screenings of all six loci were expected in the next quarter.

(3) A manuscript entitled "Genetic variation of highly exploited Tanner crabs, (*Chionoecetes bairdi*) and snow crabs (*C. opilio*) in Alaska" was accepted for publication in the journal, Fishery Bulletin, pending revisions.

Progress During 2nd and 3rd Quarters

(1) An analysis of hybridization of *Chionoecetes* species in Alaska utilizing mtDNA markers and a nuclear marker (ITS) was completed. This project utilized DNA markers developed under contract by UW. A total of N=50 of both parental species and N=170 putative hybrids were examined with these markers for this study.

(2) Microsatellite development under contract with UW Marine Molecular Biotechnology Laboratory was completed. Genetic data from 150 crabs representing three geographic populations (Bristol Bay, Uganik Passage, Deadmans Reach) were collected from six loci. Analysis of microsatellite data indicate significant heterogeneity among the three populations examined. Technology transfer to ADF&G was initiated in March 1997. One additional population collection (Barlow Cove) was analyzed during this transfer.

(3) Allozyme analysis of remaining red king crab samples (N=250) was completed.

(4) A final report (Jensen and Bentzen 1997) was received on the development and application of microsatellite markers in red king crabs. This work was funded partly ($7,000) under NOAA Cooperative Agreement NA37FL0333 and partly ($15,000) with state funds during FY 95. A journal manuscript is planned.

Progress During 4th Quarter

(1) Final revisions of "Genetic variation of highly exploited Tanner crabs, (*Chionoecetes bairdi*) and snow crabs (*C. opilio*) in Alaska" by Merkouris and Seeb were completed and will be resubmitted soon for publication in Fishery Bulletin (U.S.).

(2) A manuscript "A genetic investigation of hybridization between *Chionoecetes bairdi* and *C. opilio*", based on previously collected allozyme data and recently collected mtDNA and nuclear (ITS) data is being prepared. This manuscript will be submitted for in-house review. Pending review, this manuscript will be submitted for publication in a professional journal. An additional manuscript describing development of mtDNA and nuclear (ITS) DNA *Chionoecetes* species markers is being prepared by UW (Jensen, Bentzen) and ADF&G (Merkouris).

(3) Transfer of microsatellite technology to ADF&G has been completed. An ADF&G pilot study of additional red king crab populations utilizing microsatellite loci was initiated late in FY 97. ADF&G has begun collecting microsatellite data on an additional population of red king crab from Barlow Cove in Southeast Alaska. A manuscript of the initial pilot study conducted by UW of four population collections will be prepared for submission to a professional journal by Jensen, Bentzen and

Seeb. A note describing microsatellite primer cloning, including red king crab, will be prepared by Jensen, Bentzen and Seeb.

Plans for FY 98

Fifth-year work will continue to achieve long-term research goals for crab genetics:

(1) Complete analysis and report preparation of mtDNA and nuclear (ITS) data for *Chionoecetes opilio*, C. *bairdi*, and *C. opilio* and *C. bairdi* hybrids to determine the extent and direction of hybridization within the Bering Sea.

(2) Complete analysis of red and golden king crab allozyme data and prepare a report.

(3) Continue a study initiated in FY 97 using DNA-level markers, primarily microsatellites, for stock discrimination among red king crab populations. In FY 98 this study will complete analysis of Barlow Cove samples, and will examine up to 50 individuals from four population collections currently archived in -80° C freezers. These markers may also be useful in future analyses of *Lithodes* stock structure.

Benefits of Project

This project addresses questions related to stock structure that were described in the long-term research plan (Kruse 1994, 1996a). Studies of crab genetics may provide bases for revision of fishery management units to better match underlying population structure. Additionally, results of this project may aid enforcement of crab regulations by helping to provide forensic data for court cases that involve fishing in closed areas.

PROJECT 4: CRAB MANAGEMENT STRATEGIES

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Background and Need

Sound management requires reliable estimates of population abundance and precision to quantitatively evaluate 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 the king, Tanner, and snow crab fisheries off the coast of Alaska. For most stocks, the common biological and 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 estimation 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 97

Milestones for fourth-year include:

(1) Update, according to reviewer comments, the two papers prepared and submitted to professional publications in FY 95 and FY 96 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 a catch-survey model for St. Matthew and Pribilof Islands 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.

Progress During 1st Quarter

The manuscript on optimal harvest strategies for Bristol Bay red king crabs was further revised and was accepted by the Canadian Journal of Fisheries and Aquatic Sciences for publication. The manuscript on rebuilding strategies for Bristol Bay red king crabs was revised based on reviewers' comments and was submitted to the Journal of Shellfish Research.

The 1996 Bering Sea crab survey data were analyzed, and an ADF&G regional information report on the stock status of Bristol Bay red king crabs in 1996 was prepared and published. Catch-survey models for St. Matthew and Pribilof Islands blue king crabs were constructed, and a manuscript containing the results was drafted. Pribilof Islands red king crab data were examined, and it was concluded that there are not enough data to conduct a catch-survey analysis at current time.

Stock-recruitment data of forage fish stocks were collected and updated. Also, preliminary computer simulations on optimal harvest strategies for crab populations with periodic recruitment, with an application to the eastern Bering Sea Tanner crab population, were conducted.

Progress During 2nd and 3rd Quarters

The manuscript on rebuilding strategies for Bristol Bay red king crabs was further revised based on reviewers' comments and was accepted by the Journal of Shellfish Research. Catch-survey analyses for St. Matthew and Pribilof Islands blue king crabs were refined and the manuscript was revised and submitted to the Alaska Fishery Research Bulletin. Examination of stock-recruitment data of forage fish stocks and comparison of their recruitment patterns were completed, and a manuscript was finished and submitted to the Alaska Sea Grant College Program for publication.

Computer simulations were conducted to evaluate minimum size reduction from 6.5 to 6.0 inch carapace width for the Bristol Bay red king crab fishery. A summary of results was written which will be included in a comprehensive, multiply-authored report on effects of size limit reduction that is being prepared by Kruse.

A great deal of effort has been spent to collect recruitment data for all major Alaskan crab stocks. These data are needed to study crab recruitment patterns in the next fiscal year. Survey, fisheries and tagging data for the Norton Sound red king crab stock were also collected for the study in the next quarter. Further computer simulations on optimal harvest strategies for crab populations with periodic recruitment were conducted.

Progress During 4th Quarter

Progress on the following three areas was made during the fourth quarter. First, the effect of correlated error structure of survey data on the length-based model was examined. At the current time, incorporating correlated error structure into the length-based model does not improve abundance estimates. Second, collection of crab recruitment data continued. These data will be used in a study next fiscal year. Third, a length-based stock synthesis model for the Norton Sound red king crab stock was constructed, and a manuscript has been drafted.

Plans for FY 98

Fifth-year work will advance new projects and finalize studies begun in the first four years:

(1) Based on reviewer comments, finalize for publication a manuscript on constructing a catch-survey model to estimate abundances of St. Matthew and Pribilof Islands blue 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 eastern Bering Sea Tanner crabs and prepare a manuscript for publication.

(5) If data are available, conduct a catch-length analysis for the Adak red king crab population, including preparation of a manuscript.

(6) Refine the length-based synthesis model for Norton Sound red king crabs, and submit a manuscript for internal review and subsequent publication.

(7) Initiate a study to compare year-class strengths of red king and Tanner crabs in Alaska. This includes data collection, analysis, and preparation of a manuscript.

(8) Assemble an electronic database of survey, catch sampling, and tagging data of Alaska Peninsula red king and Tanner crabs for future modeling.

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.

OVERALL RESEARCH PLANNING FOR FY 97

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Project progress and future plans were reviewed at the fourth annual interagency crab research meeting on December 18-19, 1996 in Anchorage, Alaska. A report on the minutes of this meeting will be forthcoming. Research was also discussed at the fourth annual crab industry meeting during October 3, 1996 in Kodiak, Alaska. These annual meetings continue to be informative for agency staff and industry alike and stimulate new ideas for promising crab research. The fifth annual interagency crab research meeting is tentatively scheduled for December 1997, and research will be discussed with members of the crab industry at a meeting to be held in the Seattle area during fall 1997.

A research proposal was submitted for FY 98 under NOAA Cooperative Agreement NA37FL0333 (Kruse 1997c). This proposal was approved by NMFS as Amendment #1 to Cooperative Agreement NA67FM0212. A total of $237,500 will be appropriated to ADF&G for July 1, 1997 to June 30, 1998. 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. See Kruse (1997c) for details on these projects.

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Appendix. Publications under NOAA Cooperative Agreements NA37FL033 and NA67FM0212.

Overview of Publications

Under NOAA Cooperative Agreements NA37FL033 and NA67FM0212, four years of federal funding for crab research to ADF&G have lead to a highly productive level of reporting on contemporary crab research findings: 14 journal publications, 4 journal manuscripts currently pending acceptance, 5 papers in international symposia, 19 agency reports, and one Ph.D. thesis. Copies of final reports and journal papers are routinely submitted to NOAA. Additional copies of these publications may be obtained from the lead author of the publication or from the ADF&G project leader. Reports and papers on crab research funded in whole or in part by NOAA Cooperative Agreement are shown below for FY 97 and previous years.

Submitted or Published in FY 97

Jensen, P.C., and P. Bentzen. 1997. Development and application of microsatellite markers in red king crab, *Paralithodes camtschaticus*. University of Washington, Final Report to Alaska Department of Fish and Game, Unpublished Report, Seattle.

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Merkouris, S.E., L.W. Seeb, and M.C. Murphy. MS. Genetic variation of highly exploited Tanner crabs *(Chionoecetes bairdi)* and snow crabs *(C. opilio)* in Alaska. Accepted by Fishery Bulletin pending revision.

Paul, A.J., and J.M. Paul. MS. Breeding success of large male red king crab *Paralithodes camtschaticus* (Tilesius 1815). Submitted to the Journal of Shellfish Research.

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Zhou, S., and T.C. Shirley. MS. Performance of two king crab pot designs. Submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

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