AN INTERNSHIP AT NWAFC:

THE BERING SEA CRAB DATABASE

by

Michael K. McDowell

Internship Report

Submitted to

Marine Resource Management Program
College of Oceanography
Oregon State University
Corvallis, Oregon 97331

1985

in partial fulfillment of
the requirements for the
degree of

Master of Science

Commencement June 1986

Internship: U.S. Department of Commerce
National Oceanic and Atmospheric Administration
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INTRODUCTION

I served an internship with the National Marine Fisheries Service (NMFS), Northwest and Alaska Fisheries Center (NWAFC), Resource Assessment and Conservation Engineering (RACE) division in Seattle, Washington from June, 1983 to December, 1983. This experience proved to be very rewarding because of the techniques I learned, the job experience I gained and for the glimpse of what my future in marine fisheries management might hold for me. At the same time, I performed a valuable service for the RACE division.

The RACE division is primarily concerned with groundfish management in the Gulf of Alaska, the Bering Sea, and the Northeast Pacific. Yearly surveys in these areas are taken for the purpose of regulating fishing seasons and collecting scientific data. The groundfish data collected during the survey cruises are stored in RACEBASE, the RACE division's computerized database. RACEBASE contains data from approximately 30 years of research, representing over 20,000 trawls and 1.2 million groundfish records (Mintel and Smith, 1981). It is supported by an extensive and easily-used set of documented software.

The crab data collected during the survey cruises is stored on magnetic tape at the NWAFC and is maintained by the RACE division in Kodiak, Alaska. This database is not readily accessible to NWAFC researchers. Therefore, while RACEBASE has been used extensively by NWAFC scientists for their research, the crab database has been used only for yearly stock assessments and decisions concerning crab fishery management even though it contains a tremendous amount of other useful biological data. Under the direction of Dr. Murray Hayes, director of the RACE division at NWAFC, Dr. Lewis Incze and I began some of the first research using this crab database.

We were particularly interested in studying red king crab (*Paralithodes camtschatica*). During the years preceding 1981, the abundance of red king crab in the southeastern Bering Sea had supported one of the most successful fisheries in the world. After 1981, however, the population underwent a dramatic decline. Pressure from economic interests and the potential danger to the crab population prompted RACE to begin research into the causes of the population's decline. Because man's effect on this resource is minimal, we wanted to use the crab database to determine what environmental aspects could have played a role in the decline. My contribution to the investigation had two parts. First, to make the crab files compatible with the software for RACEBASE and secondly, to work with these new files to find the youngest crab reliably caught in the yearly surveys and to compute population abundance indices.

CONVERTING THE DATA BASE FROM KODIAK FORMAT TO RACE FORMAT

The crab database contains information on sampled and sub-sampled crab beginning in 1966 for red king crab and from 1975 for five other species of crab (see the attached Technical Memorandum). These files were compatible with software useful for the yearly stock assessment summaries, but were not compatible with the software written for RACEBASE which is useful for other types of biological investigations.

I obtained access to the crab files and was able to convert most of them into RACEBASE format; from 1970 for red king crab, and all files for the other crab (see attached technical memorandum for details). Actual conversion of the files was a fairly simple, though time consuming, process. I had the tape mounted, read the file from the tape to disk, and then ran the file through a special program (developed by R. Mintel at NWAFC) which performed the conversion. Since not all crabs were measured when sampled, I also had to apportion these unmeasured crabs among the measured crabs (i.e. the unmeasured crabs were assigned sizes based on the sizes of the measured crabs - please see the attached technical memorandum for details).

As we began to use the new files it became apparent that the data contained many errors. Cruise numbers, station numbers and vessel numbers often did not match between the crab files and RACEBASE. In a few cases, hauls were recorded to have been made on land (latitude/longitude errors). I compared dates and haul numbers between the crab and groundfish files to determine true ship locations. Most of these errors were resolved; however the red king crab data before 1970 were not useable.

USING THE DATABASE

Once the conversion was complete, we began a preliminary study using the data in the files. My role in this research was to use the new RACEBASE-compatible crab files to produce size-frequency histograms and calculate population estimates. Size frequency histograms (e.g. Fig. 1) for each year of the survey were produced and visually scanned for year class modes corresponding to the growth models of Weber (1967) and McCaughran and Powell (1977). These ranges and year classes are described in more detail in the attached paper (Incze et. al. 1985). When the size ranges for each year class were determined, I produced crab population estimates for the sample areas shown in Fig. 2 as described in the attached technical memorandum.

RESULTS

I accomplished three goals as a result of the work I did with the crab files:

1. The crab database is now relatively error-free, consistent with the existing database (RACEBASE), and ready for further analysis.
2. Size guidelines of consistently sampled crab have been determined.
3. Population estimates for each year class in each sample area have been made.

These items constitute a good starting point for crab database investigations. One such investigation is attached (Incze et. al. 1985).

FUTURE WORK ON THE BERING SEA RED KING CRAB

Our red king crab research (Incze et. al., attached) is only a preliminary to the work which can be done on the large crab data base now available. Lengthy time-series databases are rare, and this crab database offers a unique opportunity for an extensive investigation of crab population dynamics and ecology. A parallel database of weather and physical oceanographic conditions available at NWAFC could be used to compare crab abundances with weather and ocean conditions. Stomach content analyses of certain species of groundfish might show selection of crab as prey when crab reach a critical population density. Information which would be extremely useful to fisheries managers, and which might be collected in the future, are the density, population size and distribution of smaller, juvenile crab.

ACKNOWLEDGEMENTS

There are a number of people I would like to thank for their assistance with this project. First I would like to thank Dr. Robert Holton for his help in my obtaining this internship. Dr. Murray Hayes and Dr. Lewis Incze, with whom I worked closely at the NWAFC, were great people to work with and helped me immensely while I was in Seattle. Finally, I would like to thank Dr. Victor Neal and my fellow MRM students for their insistence that I finish my degree. Of course, I must also thank my wife, Dede, for her continual support and encouragement.

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Weber, D.D. 1967. Growth of the immature king crab Paralithodes camtschatica, (Tilesius). Bull. 21, Int. North Pac. Fish. Comm., p. 21-53.

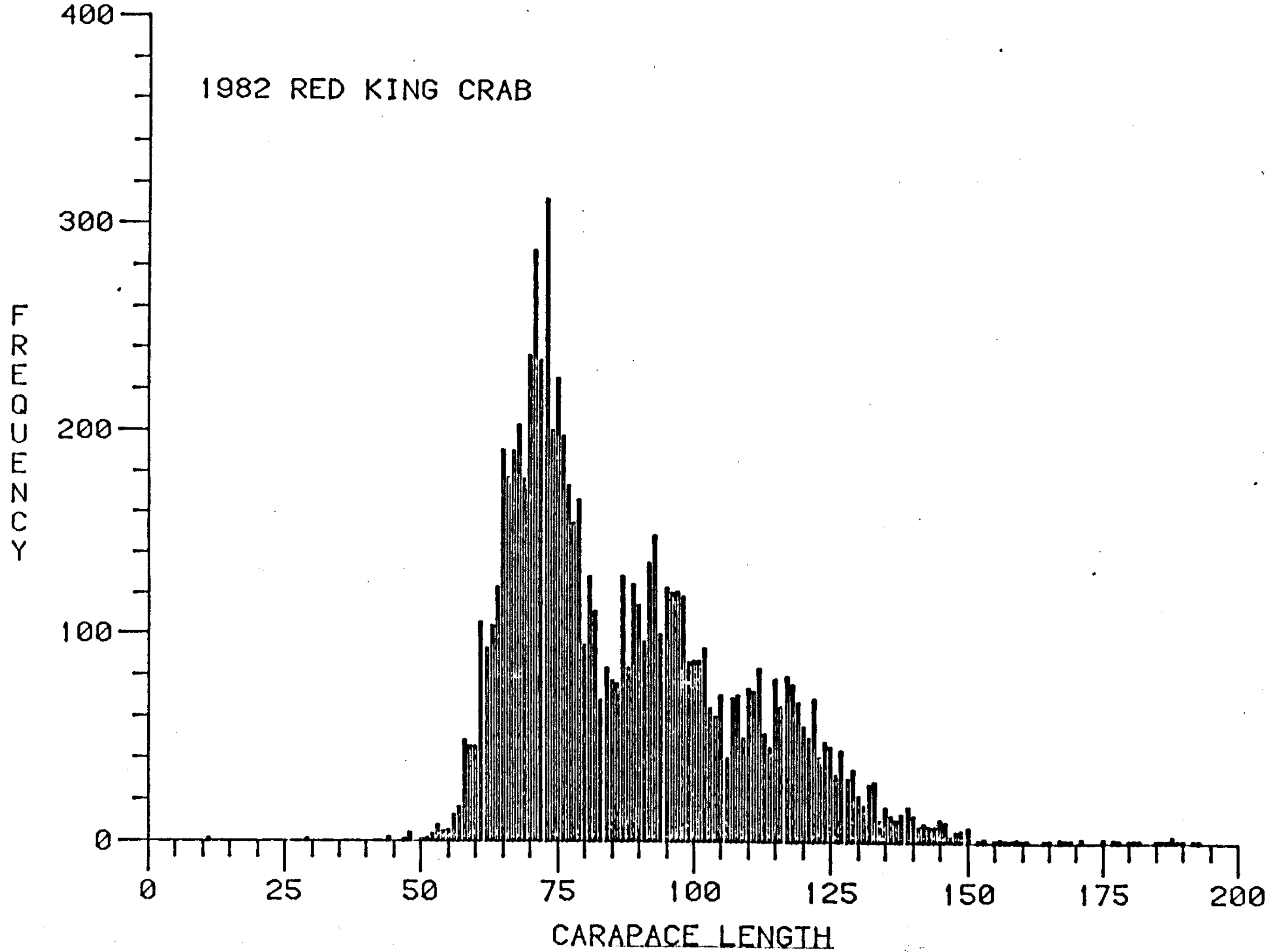

Figure 1: Size frequency histogram for red king crab, 1982.

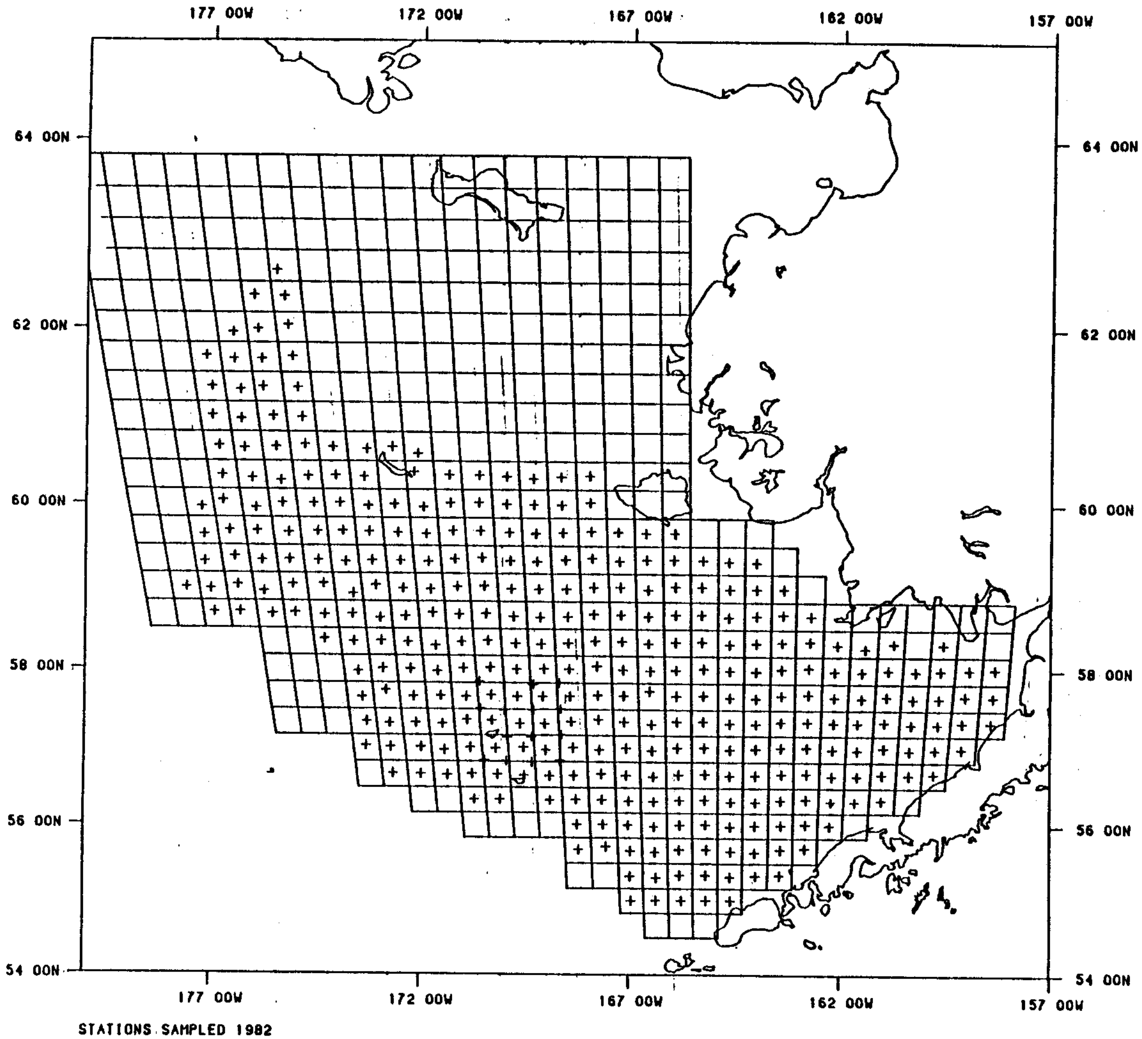

Figure 2: Crab sampling stations, 1982.

BERING SEA CRAB DATA BASE

MODIFIED FOR USE WITH SOFTWARE AVAILABLE AT NWAFC

by

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and

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INTRODUCTION

During the last 16 years, the National Marine Fisheries Service (NMFS) has conducted benthic trawl surveys in the eastern Bering Sea. These surveys have collected a tremendous amount of data on the epibenthic and near bottom fauna of this region. Data from these surveys extend back to 1966 for red king crabs, <u>Paralithodes camtschatica</u>, and 1975 for five other species of crab: these data have been included in a crab data base stored on magnetic tape at the Northwest and Alaska Fisheries Center (NWAFC). Responsibility for entry and maintenance of crab data belongs primarily to the Kodiak laboratory of NMFS. The files in the data base were provided to us by Dr. Robert Otto of the Kodiak laboratory so that we could examine spatial and temporal patterns of crab abundance against aspects of environmental data from the Bering Sea. In order to make the files compatible with the current software available at NWAFC, we had to transform them from their original card-image format into binary format files. Once this was accomplished, we were able to use the files to make length-frequency or width-frequency summaries and population estimates. Transformation of files (crab files and the special area towed files), methods used to obtain population estimates and length-width summaries, and problems encountered are described in this paper.

TRANSFORMATION OF FILES

File description.

There are two types of files associated with the crab data base. The original files, in card-image format (see table 1), are compatible with software used at the Kodiak laboratory but not with software used at the NWAFC. A second set of files, which we have constructed in binary format (see table 2), are compatible with NWAFC software but are not compatible with Kodiak's software. Within each type of file (card-image or binary) there are two files which are associated with one another, the crab files and the area towed files. The crab files hold the actual crab data collected during each year of sampling (see table 3 for species and years recorded). The areatow files (known in Kodiak's documentation as AREATAG files and elsewhere as ATOW files) contain the area towed for each haul in which crabs were sampled during each cruise. This areatow file is necessary for the population estimation program, CRAB/STATION/POP. Table 4 lists the tapes and the files they contain.

Methods of transformation

Three steps were involved with transformation of the data files from card-image format to binary format:

1) Reformat the crab files into binary, apportioned, files.
2) Reformat the area towed files into binary files.
3) Add cruise numbers to the files (performed during items 1 and 2).

In addition to these items we also scanned the files for errors.

1) Converting the Kodiak crab files into binary files compatible

with the RACE software format was a very simple step which resulted in two new types of files for each original file of character-format data. The first set of files was designed as a first step in the conversion process and has been kept for backup purposes. These are binary crab files with the unmeasured crabs apportioned among the measured crabs (see RACE documentation for APPORTION/UNMEASURED/CRABS on the Burroughs computer and Kodiak's Manual of Crab Sampling Methods for the Trawl Survey in the eastern Bering Sea, May 1976). The programs used were: MAKE/BINE/CRAB, then SORT/BINE (by vessel, cruise, haul, species, sex), then APPORTION/UNMEASURED/CRABS.

For the second set of files a special program, MAKE/BINE/CRAB/TEST, was used as the first step. This program included dates in the output file. Records were then selected by vessel and date and the correct cruise number was inserted using the NEW/MATH program. The files were then scanned using the INVENTORY program to make sure there were no values that were out of range. These are the working files; use them for calculating population estimates, length-frequency summaries, etc.

2) Creating the binary area tow files was a complicated process and we used a variety of options depending on the year of the file. Please see the flow charts in figure 1 for a summary.

USE OF FILES

We were interested in finding suitable indices of abundance of crab for our study. To achieve this, we ran programs which provided us with two items: 1) length or width frequency summaries, and 2) population estimates.

1) Length or width frequency summaries.

To obtain these summaries from the data, we ran the binary apportioned crab file through the SELECT program to choose the subset of data in which we were interested; for example, we could select crabs on the basis of carapace size, sex, and a geographic stratum. We next ran this subset file through the COMPACT program which summed the length or width frequencies for each carapace length or width in the file. The output file from this program was then routed to the BARPLOT or BARPLOT/PREVIEW program to generate a histogram.

2) Generating population estimates.

We were also able to obtain population estimates from the crab files. Starting with an apportioned binary crab file, we again selected a subset of crab, and then sent this subset file and the correct ATOW file to the CRAB/STATION/POP program which generates a population estimate file. This file can then be sent to the printer through the program CRAB/PRINT/STATION/POP, or can be turned into a plot workfile with the program CRAB/STATION/POP/PLOT (Please note - use the parameter file (RACE0330)CENTERS/BINE/STATION/LATLONG as file 2 in this program). This plot workfile can then be routed into the MAP program to display the population estimates in their correct positions on the map.

PROBLEMS ENCOUNTERED WITH THE DATA BASE.

We encountered many problems with the original crab files. The older files, before 1975, are especially suspect. Most of the problems have been corrected, but the following were not:

1) RACEBASE contains two cruises for vessel 14, the R/V Oregon, for 1977. Cruise 770 is a comparative tows cruise with 173 hauls. However, the Kodiak crab data apparently contain only one cruise with 183 hauls. As a consequence, we were not able to insert the correct cruise numbers into the binary apportioned 1977 crab files or the areatow file. This is not a problem if there is no need for any information from RACEBASE. The atow file for 1977 which is included along with the crab files was taken from the Kodiak AREATAG data and should give reliable answers when used in the population estimate program.

2) Files written prior to 1968 do not contain species codes. We did not use these older files, so the problem does not apply to the work outlined in this report.

3) Crab files written prior to 1968 do not contain haul numbers. However, the 1967 file may be useable since it contains the area towed for each haul. At this writing, we have not attempted to use the 1967 file.

4) For the years 1971 to 1973, the crab files (red king only) contained inconsistent vessel codes. By comparing a sample of hauls between the RACEBASE haul records and the Kodiak crab datafile, it was determined that what was listed as vessel 12 in the Kodiak files is now represented as vessel 14 in the RACEBASE haul files. The correction was made in the crab data files which we have on tape. Kodiak has their own copies of the files which have the original numbers. We did use these

files and there were no apparent problems after the switch was made.

5) The 1966 red king crab file may contain some samples which have been recorded with incorrect values for the latitude and longitude. These cannot be corrected using the RACEBASE hauls since no haul numbers were included in the file.

6) Many of the files contained variations in the station naming protocol. For instance, station G02 might be listed as G02, GO2, G 2, 2 G, or 2G. We corrected as many of these problems as we found, but beware of others.

7) The area towed varies depending on whether it was calculated by Kodiak or Seattle (A different assumption concerning the earth's curvature is used in the two cases). We have used Kodiak values when they are available because we can then compare our population estimates more readily with Kodiak's. This difference remains a problem.

ACKNOWLEDGMENTS

During the course of this work, M.K. McDowell was supported by an internship agreement between the College of Oceanography at Oregon State University and the Northwest and Alaska Fisheries Center. We would like to thank Dr. Robert Otto for help with the data files and for discussion of some of the concerns of our project. We also thank Dr. Murray Hayes, director of the RACE division, for guidance and interest in our project, and Ralph Mintel for his assistance with the computer and programming.

TABLE ONE

Contents of the Kodiak crab files.

Column number	Item
1-2	Vessel
3	Gear
4-6	Station (letter-2 digit code)
7-8	Month
9-10	Day
11-12	Year
13-16	Latitude
17-20	Longitude (4 digit, +100 assumed)
21-23	Fathoms
24-28	empty
29	Sex (1=male, 2=female, 3=unknown)
30-32	Carapace length (=0 for Tanners)
33-35	Carapace width (=0 for kings)
36	Shell condition
37	Egg color
38	Egg condition
39	Clutch size
40	Species code (special Kodiak codes)
41-45	Weight
46-48	empty
49-55	Primary sampling factor
56-57	Secondary sampling factor
58	empty
59	Station type
60	Tow status
61-64	Area towed (pre-1977 ?)
65-77	empty
78-80	tow (haul number)
81-86	Area towed, 1982-present.

This was taken from the Manual of Crab Sampling Methods for the Trawl Survey in the eastern Bering Sea, May 1976. Please see the manual itself for explanation of the codes, units etc.

Contents of the Kodiak atow files.

Column number	Item
1-3	Station
5-7	Tow (haul) number
8-13	Area towed, sq. nautical miles F6.4 format
22-23	Vessel

TABLE TWO

Contents of the binary crab files.

WORD NUMBER	CONTENTS
1	Vessel
2	Cruise
3	Haul
4	Station C3 format, (e.g. 'B02')
5	Station, low order - C3
6	Species code - Seattle code
7	Sex
8	Length
9	Width
10	Shell condition
11	Egg codes (I3) color, condition, clutch
12	Weight (grams)
13	Frequency
14	Stratum (=0)

Contents of the binary ATOW files.

WORD NUMBER	CONTENTS
1	Vessel (I3 format)
2	Cruise (I3)
3	Haul (I3)
4	Station (C3)
5	Station - low order
6	Area towed (sq. nautical miles, F6.4)

TABLE THREE

List of crab species and the years they were recorded (year of survey)

Species	Year
Red king crab (*Paralithodes camtschatica*)	1966-present
Blue king crab (*P. platypus*)	1975-present
Opilio tanner crab (*Chionoecetes opilio*)	1975-present
Bairdi tanner crab (*C. bairdi*)	1975-present
Hybrid tanner crab (*C. opilio* x *C. bairdi*)	1975-present
Korean horsehair crab (*Erimacrus isenbeckii*)	1980-present
Golden king crab (*Lithodes aequispina*)	1978 (one record only)

TABLE FOUR

File names on tape under usercode RACE0330.

Tape name	Number	File names
KODIAK83	2539,2745	REDKING/YR BLUEKING/YR OPILIO/YR BAIRDI/YR HYBRID/YR HORSECRAB/YR GOLDKING/78 ATOW/YR
CRUISETAPE	2217	REDKING/CRUISE/APPORTIONED/YR BLUEKING/CRUISE/APPORTIONED/YR OPILIO/CRUISE/APPORTIONED/YR BAIRDI/CRUISE/APPORTIONED/YR HYBRID/CRUISE/APPORTIONED/YR HORSECRAB/CRUISE/APPORTIONED/YR ATOW/CRUISE/YR REDKING/BINE/APPORTIONED/83 BLUEKING/BINE/APPORTIONED/83 OPILIO/BINE/APPORTIONED/83 BAIRDI/BINE/APPORTIONED/83 HYBRID/BINE/APPORTIONED/83 HORSECRAB/BINE/APPORTIONED/83
BINETAPE	3220	REDKING/BINE/APPORTIONED/YR BLUEKING/BINE/APPORTIONED/YR OPILIO/BINE/APPORTIONED/YR BAIRDI/BINE/APPORTIONED/YR HYBRID/BINE/APPORTIONED/YR HORSECRAB/BINE/APPORTIONED/YR ATOW/BINE/YR

YR = 1970-1983 for red king crab, 1975-1983 for others except where noted.

Note that there were no cruise numbers for 1983 at the time of writing.

FIGURE ONE

Flow chart of steps followed in construction of crab data files:

```
Original Kodiak crab data
  \             \
   \             \_____________
    \MAKE/BINE/CRAB             \MAKE/BINE/CRAB/TEST
     \                           \
      \                           \NEW/MATH (Input cruises)
       \SORT/BINE                  \
        \                           \Combine all crab/cruise
         \                           \files, (cande)
          \APPORTION/UNMEASURED/CRABS \
           \                           \SORT/BINE
            \                           \
 Binary apportioned crab file            \APPORTION
                                          \
                                  Binary apportioned crab file
                                  with cruise numbers.
```

Flow chart of areatow file construction; There were a number of ways to do this:

```
1.  Original Kodiak atow files (1976-1981,1983 only)
       \
        \CRAB/MAKE/BINE/AREATOW
         \
          \SORT/BINE
           \________________________
            \                       \
     Binary area towed file          \ Use DMSIII to insert
                                      \ correct cruise #'s
                                       \ from RACEBASE hauls
                                        \ (except 1977)
                                         \
                               Binary area towed file
                               with cruise numbers.
```

2. This method does not work for 1977 or 1982 data since one vessel made two cruises in those years.

```
RACEBASE haul files
       \
        \ SELECT for vessel, cruise
         \
          \ CRAB/WRITE/AREATOW
           \ (use (RACE0330)PARAM/VESSEL/GEAR/WIDTH as file 5)
            \
             \ CRAB/MAKE/BINE/AREATOW
              \
               \ SORT/BINE
                \____________________
                 \                   \
      Binary area towed file          \ Insert cruise numbers
                                       \ with DMSIII or
                                        \ NEW/MATH.
                                         \
                                   Binary area towed file
                                   with cruise numbers.
```

3. The following is for 1982, 1983, and subsequent years.

```
     Original Kodiak crab data
               \
                \ MAKE/BINE (get vessel, station, haul,
                 \           area towed.)
                  \
                   \ COMPACT (by vessel, cruise, haul)
                    \____________________
                     \                   \
           Binary atow file               \ SELECT (vessel)
                                           \
                                            \ NEW/MATH (insert
                                             \ cruise numbers.)
                                              \
                                   Binary atow file with
                                   cruise numbers.
```

The following has been submitted to a special publication of the Canadian Journal of Fisheries and Aquatic Sciences.

VARIABILITY OF YEAR CLASS STRENGTH OF JUVENILE RED KING CRAB, *PARALITHODES CAMTSCHATICA*, IN THE SOUTHEASTERN BERING SEA *

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Key Words: *Paralithodes*, Bering Sea, recruitment, year class

* Contribution No. xxx of the School of Fisheries, University of Washington, Seattle, WA USA 98195

ABSTRACT

Length-frequency data from trawl surveys of red king crab in the southeastern Bering Sea were examined for size-class modes of juveniles. Modes were compared to results from growth models to find the youngest age class consistently caught in the sampling gear. Plots of the geographical distribution of individuals in large size modes from the aggregated annual data showed that most crabs younger than four years old were caught at comparatively few stations. These catches are interpreted as encounters with podding juveniles. Crabs corresponding in size to four year olds were widely distributed, however, and in some years occurred in well-defined modes of great abundance. Four year old crabs were caught in lower proportion to abundance than older (larger) crabs, but consistent catches over broad regions of the shelf indicate that sampling data for these crabs can be used as an index of year class strength. Year class variability of four year olds is plotted with respect to year of origin for a time series dating 1970-1983, and three large year classes are identified. An index of recruitment success is calculated by comparing abundance of four year olds with size of the spawning stock producing the year class, and possible explanations for the observed variability in this index are discussed. The relative size of a year class entering the commercial fishery was sometimes, but not always, determined by age four.

INTRODUCTION

Major fisheries for red king crab have existed in Alaskan waters since the 1950's (Otto 1981). The southeastern Bering Sea, Kodiak Island, and the eastern Aleutian Islands have been major producing areas. Statewide harvest of P. camtschatica peaked in 1980 at 80,136 metric tons (mt), approximately 74% of this coming from the southeastern Bering Sea. The previous peak in harvest from this region occurred in 1964, when an estimated 29,024 mt was taken by foreign fishing operations. Both peaks in landings followed apparent peaks in abundance of exploitable (large male) crabs as indicated by catch per unit effort data of foreign fisheries prior to 1965 and by U.S. trawl surveys since 1968 (Hayes 1983).

Standard trawl surveys have been conducted annually in the southeastern Bering Sea since 1968 and provide a consistent time series of data. These data show dramatic changes in abundance of exploitable (legal-sized male) crabs during the past decade (Fig. 1). The objective of this investigation was to use the trawl data base to examine variability in the abundance and dynamics of year classes of juvenile crab and to see how these patterns relate to the abundance of spawners and size of harvestable stocks several years later.

MATERIALS AND METHODS

Trawl surveys of the red king crab grounds of the southeastern Bering Sea have been conducted by the U.S. National Marine Fisheries Service every year since 1968, and complete, computerized data sets date to 1970. Surveys were conducted from May to June of each year and therefore assess the stock at similar points in the annual cycle of molting, growth and reproduction. The sampling program utilizes a fixed grid of sampling areas, each 37 x 37 km and now extending over most of the eastern Bering Sea shelf (Fig. 2). At least one sample is taken (centrally) per sampling area, but additional samples (side by side or from a geographical corner of an area) also are common. Carapace length and sex of crabs caught in the trawl gear are recorded along with other information. Area swept estimates are made for each tow and are used to estimate populations of crab in each area; data from all sampling areas are used to provide population estimates for the stock. Size frequencies can be plotted for the aggregated annual data from each year's survey and abundance estimates generated for crabs selected by specified criteria, such as size and sex. Of the thirteen-year time series, data from only one year, 1971, were not used because of reported irregularities in the performance of the sampling gear.

We first plotted the size-frequency data by 1 mm increments for each year's data in order to (1) identify the smallest crabs regularly caught in surveys, and (2) look for large size-frequency modes in the distributions. A computer plotting routine was used to chart the location and size of catch of modes thus observed. This routine also was applied to specific age/size groupings for all years using growth models (see below). All data from 1970 to 1983 exclusive of 1971 were merged and average size-frequencies plotted to examine the average relationship between sampled abundance and size. This was used to estimate relative size-dependent differences in vulnerability to the sampling gear.

Growth models of Weber (1967) and McCaughran and Powell (1977) were used to estimate the expected size range of crabs within each year class at the time of sampling, and this information was used to help identify age classes in the annual size-frequency data. The continuity of size modes through successive surveys (years) was examined. The youngest age class which could be sampled reliably (see Results) was selected, and abundance of these crabs was estimated from each year's data. An index of recruitment success was calculated by dividing the estimated number of juvenile crab in a year class by the estimated number of spawners which produced the year class. The number of spawners also was estimated from survey data.

RESULTS

Plots of size frequencies of sampled crabs from each annual survey generally showed continuous distributions from sexually mature adults down to 40-50 mm carapace length (e.g., Figs. 3-6). However, few individuals smaller than 50 mm were sampled and most of these came from just a few trawl tows in each year. Well-defined modes sometimes were seen for sizes between 50 and 70 mm (1979, 1981; see Figs. 4,6), but these also were patchily distributed. More than 90% of the individuals in this size range came from only three geographically separated tows in each of these years. Large size-frequency modes also were seen around 70 mm (1975), 75 mm (1982), 85 mm (1976), 100 mm (1977) and 115 mm (most years). Crabs measuring 70-85 mm or larger were caught at a large number of stations (usually around 40; Fig. 7) and showed generally gradual, rather than abrupt, geographical trends in abundance. Modes at 100 and 115 mm consisted largely of adult female crabs (e.g., Fig. 3).

Data from growth models of Weber (1967) and McCaughran and Powell (1977) are summarized in Table 1, along with average sizes calculated for juvenile crabs. Male and female crabs grow at similar rates through age four, so that age classes can be defined by size through age four without distinguishing between the sexes. Figure 4 shows the age classes anticipated by these models superimposed on size frequency data from 1979.

Data from 1979 show a pronounced mode of a three-year-old year class, but the extreme patchiness of crabs of this age (noted above) prevents their use as a reliable indicator of year class abundance. Twice in this series of data a high abundance of 3's was followed, in the next year, by a large four-year-old year class (1975-76, 1981-82), but the 3's sampled in 1979 did not show up as 4's the following year. Furthermore, the 4's sampled during 1975 were not detected as 3's the previous year. The size class corresponding to age four (approximately 70-85 mm), being routinely sampled and widely distributed, was selected as the youngest age class reliably sampled in the surveys. Three large year classes of four year old crab were identified as originating in 1971, 1972 and 1978 (Fig. 8). These could be seen as frequency modes in the vicinity of 70-85 mm in plots of data from 1975, 1976 and 1982, respectively (Figs. 5,6).

The mode of four-year-olds sampled during 1982 fits quite well into the model's prediction of size, but this was not the case in 1975 or 1976. The apparent mode around 70 mm in the 1975 data was composed of individuals found in high abundance at only a few stations, indicating that they were three year old crab which were somewhat larger than predicted. The mode centered around 85 mm in that year was composed of individuals which were widely distributed. The size of crabs in this mode was the expected increment in size of crabs in this mode was the expected increment in size for the next year class (approximately 15 mm, see Table 1), and the mode was interpreted to be four year old crabs. The mode around 85 mm in 1976 consisted of crabs which were similarly distributed. These crabs were too large to be 3's and most probably were not small 5's, since a five-year-old year class of this size should have been detected as 4's of approximately 70 mm average during the 1975 survey. Consequently, the 85 mm mode in 1976 also was considered to be four-year-old crabs. Thus, the size criteria established <u>a priori</u> were off center of the apparent mode of four year olds from the sampled populations for these two years. Although the two strong year classes were correctly identified, their abundance appeared to be underestimated by this procedure. That 1975 and 1976 both had strong four-year-old year classes is corroborated by data for male crabs larger than 85 mm in

1977 (Fig. 3); these data show two successive strong year classes. Data from 1983 show that the 1978 year class did not show up as an abundant size mode after 1982 (Fig. 6). Of the three big year classes identified by this analysis, two (1971, 1972) resulted from the largest spawning stock on record. The index of recruitment success up to age four (Fig. 9) indicates remarkable survival rates of the 1971 and 1972 year classes, but moderate rates of survival for individuals hatched in 1978.

The relative vulnerability of various sizes of crab indicated by the size disttributions of survey data averaged for the period 1970-1983 showed that age four crabs are caught in lower proportion to abundance than larger crabs. Maximum catches occur at about age six.

DISCUSSION

The trawl survey data examined in this study provide excellent coverage of the red king crab population of the southeastern Bering Sea. However, the surveys are conducted primarily for short term forecasting and management of the commercial fishery (Otto 1984), and gear and methods consequently focus on sampling of larger crabs. Early life history stages are under-represented in the survey data. In addition to selectivity of gear, patchy distribution of two and three year old crabs due to podding behavior (Powell and Nickerson 1965) imposes problems in sampling. This patchiness was evident in the erratic catches of these two age groups during the surveys. Since high but infrequent catches of 2's and 3's were made at widely varying locations, it appears that tremendous sampling effort would be required for reasonable estimates of their abundance. In these surveys, so few age 1 crabs were caught that little can be concluded about their broad scale distribution or about appropriate sampling of this age class for recruitment studies.

Four year old crabs provided the youngest age class well recorded in the survey data base, but their estimated abundance based on trawl samples cannot be corrected to estimate the true population size. Such a correction would require a known mortality rate from age 4 to 6, when crabs appear to be caught in maximum proportion to their abundance. This mortality is not known for the average condition, and was shown by this study to be highly variable. As a result, the trawled estimate of 4's must be used as an index of their abundance. Although gear performance and/or activity of the animals may affect their vulnerability to sampling gear from year to year, these differences appear to be small compared to differences in year class strength. This is substantiated by experience with the predictive power of the survey for older age classes which show similar variances in sampling data (Otto 1984).

Interannual differences in year class abundance observed by age four vary by about one order of magnitude and are extremely significant in terms of the exploitable population, particularly since large year classes appear to occur infrequently. Unfortunately, these data do not show when during the first four years of life these differences were established. Indices of survival indicate interannual differences which exceed two orders of magnitude. Since populations of known vertebrate predators of benthic king crab do not fluctuate to this extent on short time scales, the involvement of other environmental variables is indicated. Possible explanations for variable survival rates of individual year classes include interannual variations in larval feeding conditions; variable populations of planktonic predators; spatial and/or temporal variations in the distributions, including migrations, of planktivorous fish; spatial variations in the distribution of benthic predators; variability in the timing of larval hatching relative to important predators and prey; and variability of larval transport. Larval feeding (Paul et. al. 1979, Paul and Paul 1980) is clearly important and planktonic feeding conditions may show strong interannual variations in the southeastern Bering Sea (Incze 1983), but no quantitative data exist to show critical relationships in the field. The timing of larval hatching may be important because of the dynamics of populations of predators. Transport may be important because larvae may be advected to regions where the benthic habitat is less suitable for post-larval stages. For example, predation by an abundant flatfish, yellowfin sole (Limanda aspera), can be significant (K. Haflinger, University of Alaska, unpubl. data) and may be increased by spatial overlap and/or by settlement of larvae in regions where the substrate provides little spatial refuge from this predator. Availability of appropriate food in the benthic habitat also may be important. In this regard, it is interesting to note that crabs from year classes showing the highest survival rates (1971, 1972) were larger at age 4 than the 1978 year class, which also was a very large year class, but one with much lower survival rates. Rates of survival and growth of these three year classes were inversely related to stock size, so there may have been a density-dependent effect from the stock as a whole, but not from the year class itself. Since large year classes were produced at times of both reduced and abundant stocks, density-dependent effects do not appear to be the principle governor of year class size. Good survival rates were noted only twice in a twelve year time series, and it may be appropriate and instructive to look for a release from cropping pressures which remain generally high during most years. An important question is whether the same principal factors tend to limit year class recruitment in most years, and whether these same factors predominate regardless of the level of the stock.

In addition to variability of year class abundance by age four, there were considerable differences in the subsequent fate of four year olds. The 1971 and 1972 year classes went on to support record harvests from the southeastern Bering Sea in the late 1970's and in 1980. However, this was not the case with the 1978 year claass, which failed to show up in abundance after the 1982 survey. This particular mortality appeared to affect the entire population (Fig. 6). At present, the cause of this crash in the population of crabs is unknown, but clearly is of major concern to management and to our understanding of this important predator of the benthic ecosystem.

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FIGURE CAPTIONS

Fig. 1. Exploitable stocks of red king crab (male crabs with carapace length $\geq$ 134 mm) in the southeastern Bering Sea as estimated from trawl surveys. Shaded region shows 95% confidence intervals.

Fig. 2. Eastern Bering Sea shelf showing 50, 100 and 200 m isobaths; grid of sampling areas used during benthic trawl surveys; and red king crab grounds sampled since 1968 (shaded). Sampling areas in the grid are 37 x 37 km.

Fig. 3. Size-frequency distribution from the 1977 survey, showing differences in abundance of male (dark) and female (light) crabs. Modes in the female frequencies are accumulating year classes resulting from reduced growth rates associated with sexual maturity.

Fig. 4. Approximate age-size relationship from Table 1:C shown with 1979 survey data. See text regarding frequency mode for age three.

Fig. 5. Size-frequency distributions showing 1971 and 1972 year classes not centered on the size range predicted for four year old crabs (shown by brackets) in the 1975 and 1976 data,

respectively. Four-year-olds appear to be at the upper end of the expected size range in both years (see text for details).

Fig. 6. Appearance of strong four-year-old year class in the 1982 survey (upper and lower) and subsequent failure to show up in 1983 (lower). Results of the 1981 survey are included in the upper panel to show demise of larger crabs as well and to show indication of the 1978 year class as three year old animals. Demarcations between age groups according to the model (Table 1:C) are shown as 3|4 and 4|5. Exploited portion of the population is shown in the lower panel.

Fig. 7. Distribution of juvenile red king crabs of 70-85 mm carapace length from the 1981 survey (smallest four-year-old year class on record).

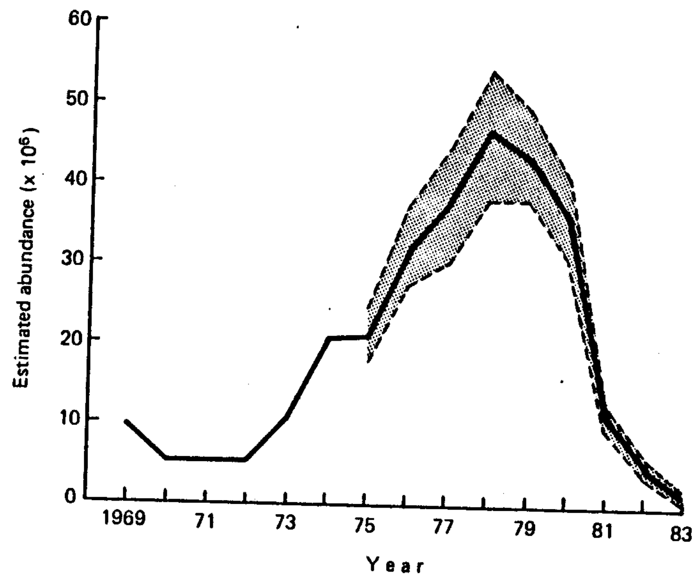
Fig. 8. Estimated abundance of four-year-old red king crabs, with large year classes labeled as to year of origin.

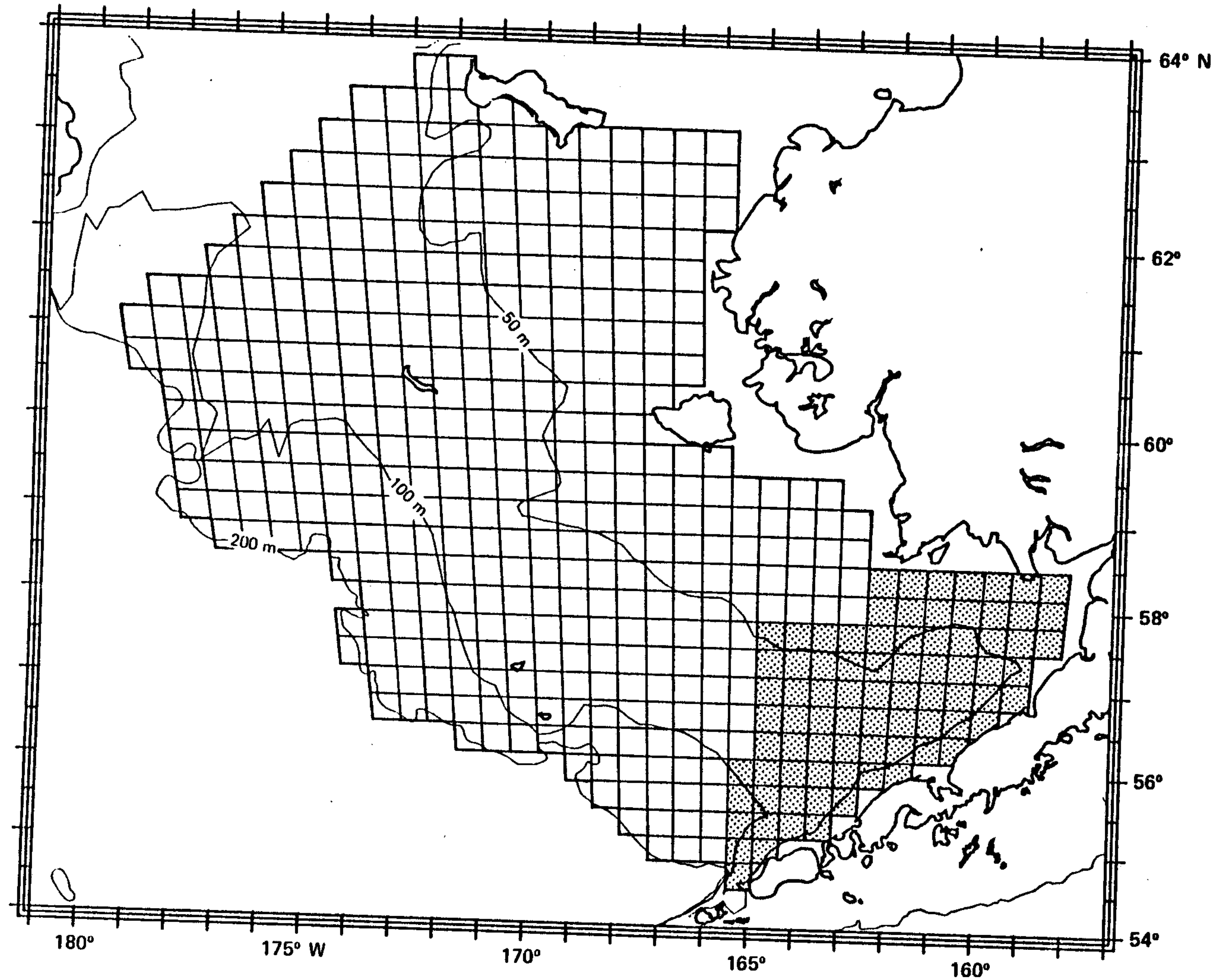
Fig. 9. Relative success of a year class (solid line) calculated by dividing the index of year class abundance by the size of the reproducing female population (broken line). High survival rates apparently were associated only with two of the three big year classes (cf. Fig. 8).

Table 1.-- Growth of red king crab up to first year of sexual maturity, age five.

Model	Age (Yr)	Carapace length of crabs (mm) Male	Female
A. McCaughran and Powell (1977)			
	1	≤ 23	≤ 23
	2	23.1 - 45.1	23.1 - 45.4
	3	45.7 - 68.4	45.5 - 67.4
	4	68.5 - 87.2	67.5 - 84.2
	5	87.3 - 104.4	84.3 - 97.3
B. Weber (1967)			
	1	≤ 23	≤ 23
	2	23.1 - 47.5	(same as males)
	3	47.6 - 69.0	(same as males)
	4	69.1 - 86.0	69.1 - 84.0
	5	86.1 - 101.5	84.1 - 94.0
C. Values used in present study			
	1	≤ 23	≤ 23
	2	23 - 46	(same as males)
	3	47 - 68	(same as males)
	4	69 - 85	(same as males)
	5	86 - 103	86 - 96
	>6	≥ 103	≥ 96

LEGAL RED KING CRAB
and 95 percent confidence interval





64° N
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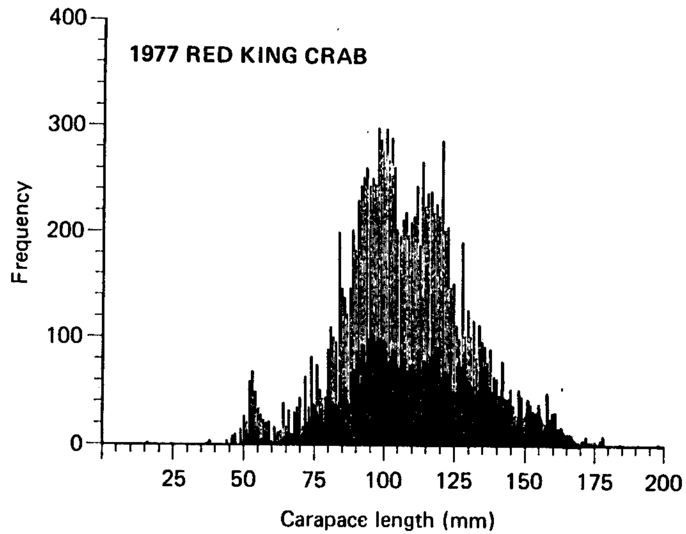
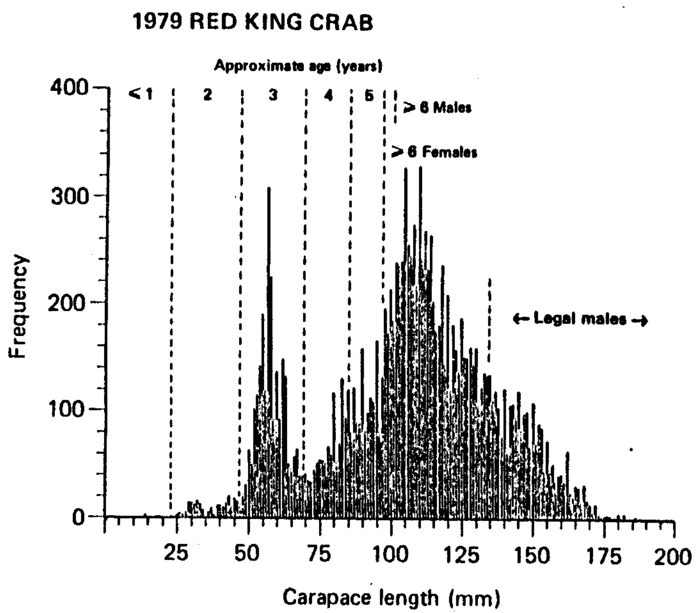
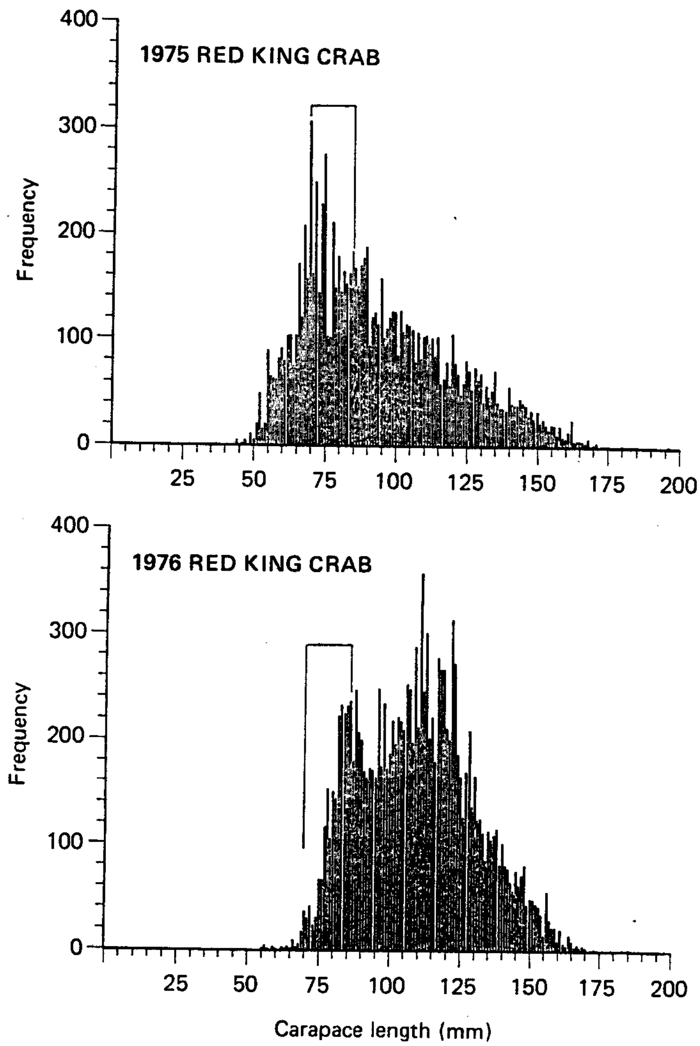
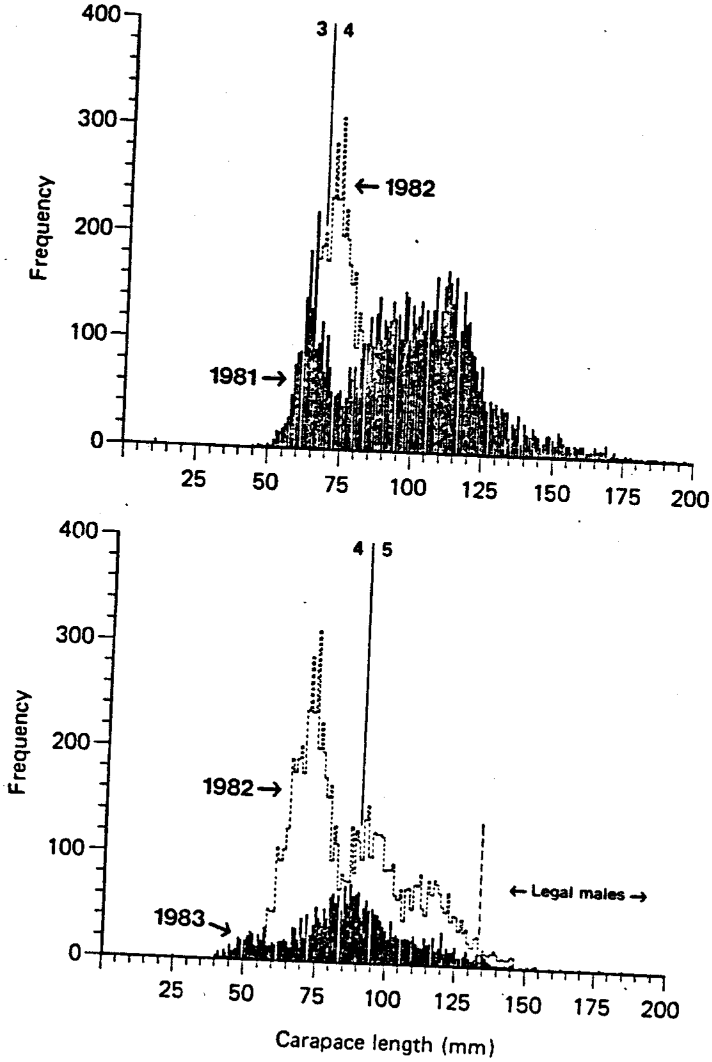
60°
58°
56°
54°
180°
175° W
170°
165°
160°
50 m
100 m
200 m



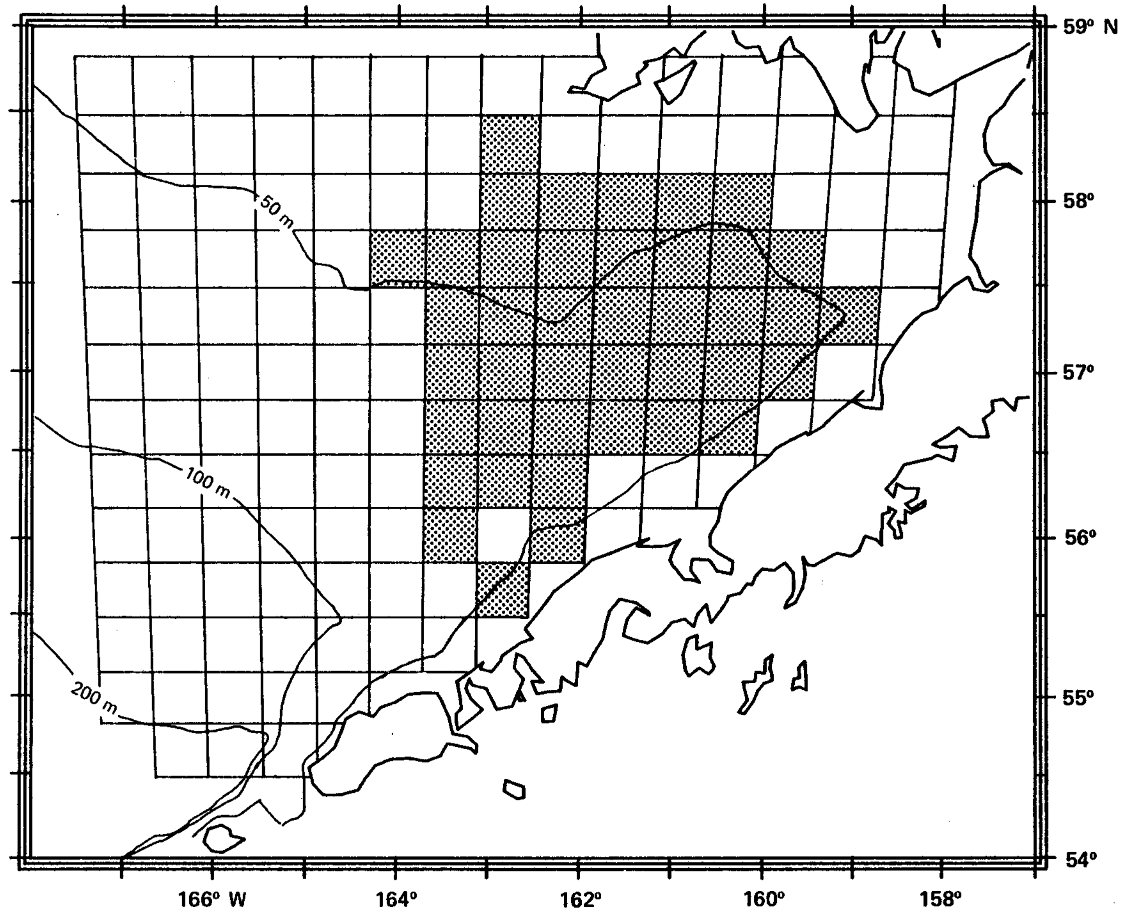
1977 RED KING CRAB
Frequency
400
300
200
100
0
25
50
75
100
125
150
175
200
Carapace length (mm)


1979 RED KING CRAB
Approximate age (years)
< 1
2
3
4
5
> 6 Males
> 6 Females
← Legal males →
400
300
200
100
0
Frequency
25
50
75
100
125
150
175
200
Carapace length (mm)


1975 RED KING CRAB
1976 RED KING CRAB
Frequency
400
300
200
100
0
25
50
75
100
125
150
175
200
Carapace length (mm)



400
300
200
100
0
Frequency
3
4
← 1982
1981 →
25
50
75
100
125
150
175
200
400
300
200
100
0
Frequency
4
5
1982 →
1983 →
← Legal males →
25
50
75
100
125
150
175
200
Carapace length (mm)



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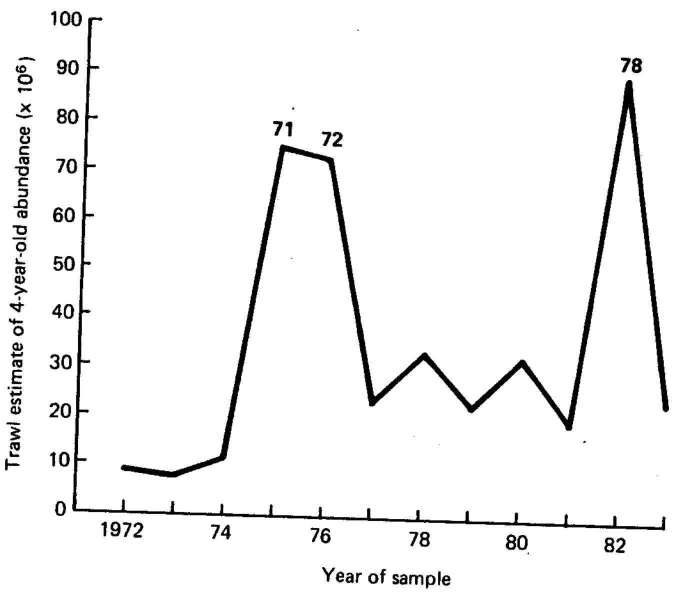
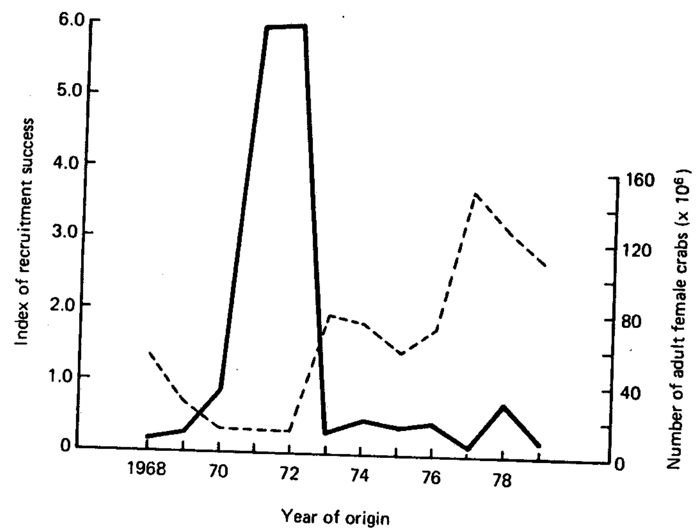
58°
57°
56°
55°
54°
166° W
164°
162°
160°
158°
50 m
100 m
200 m



Trawl estimate of 4-year-old abundance (x 10^6)
100
90
80
70
60
50
40
30
20
10
0
71
72
78
1972
74
76
78
80
82
Year of sample



6.0
5.0
4.0
3.0
2.0
1.0
0
Index of recruitment success
1968
70
72
74
76
78
Year of origin
160
120
80
40
0
Number of adult female crabs (x 10^6)