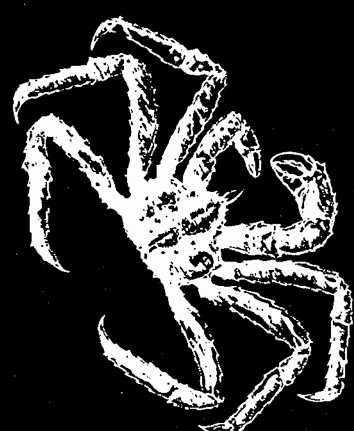
PROCEEDINGS

INTERNATIONAL CRAB Rehabilitation and Enhancement SYMPOSIUM

presented by
Alaska Department of Fish & Game
and
Kodiak College



January 21-24, 1992
Kodiak College

PROCEEDINGS OF THE INTERNATIONAL CRAB REHABILITATION AND ENHANCEMENT SYMPOSIUM

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January 22-24, 1992

Kodiak, Alaska, U.S.A.

Alaska Department of Fish and Game
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PROCEEDINGS OF THE INTERNATIONAL CRAB REHABILITATION AND ENHANCEMENT SYMPOSIUM

Kodiak, Alaska
January 22-24, 1992

Lorne E. White - Meeting Chairman

The purpose of this Symposium was to facilitate the exchange of scientific information regarding early life history, aquaculture, evaluation, larval settlement, rehabilitation, and enhancement of selected crustaceans. Primary species of focus was the red king crab (*Paralithodes camtschaticus*), with papers also on American lobster (*Homarus americanus*), European lobster (*Homarus grammarus*), dungeness crab (*Cancer magister*), Hanasaki king crab (*Paralithodes brevipes*), Atlantic snow crab (*Chionoecetes opilio*), and Southern king crab (*Lithodes santolla\antarctica*).

The Symposium sponsors were: Alaska Science and Technology Foundation, Alaska Department of Commerce and Economic Development, Overseas Fisheries Cooperation Foundation (Japan), University of Alaska, Kodiak Island Borough, and Alaska Department of Fish and Game.

International participants were from: Department of Fisheries and Oceans, Newfoundland, Canada; University of Magellan, Chile; Flodevigen Biological Station, Norway; National Research Institute of Fisheries Science, Japan; Japan Sea Farming Association, and Overseas Fishery Cooperation Foundation, Japan.

Participants from the United Sates were from: University of Maine, University of California, University of Washington, University of Alaska, National Marine Fisheries Service, and the Alaska Department of Fish and Game.

The contents of these proceedings are a record of the Symposium and are not intended as a formal publication. The individual papers are unedited.

The entire Symposium was video tape recorded and the "Forum" section of these proceedings is a condensation of the transcripts from that section. The question and answer sessions are included after most presentations.

Proc. Int. Crab Rehab. & Enh. Symp.
Jan. 1992, Kodiak, Alaska

Keynote Address

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Introduction

I'd like to welcome you all here for this International Crab Rehabilitation and Enhancement Symposium. We need to extend a special thanks to those who traveled a great distance to participate. We have scientists here from Japan, Norway, Chile, and Canada. There are representatives from Maine, California and Washington state. We have Alaskan representatives from the National Marine Fisheries Service (NMFS), the University of Alaska and the Alaska Department of Fish and Game (ADF&G). I'd also like to thank the fishermen, representatives from various communities and the public who are attending. We look forward to all of you participating actively. This will be an exciting symposium.

Background

Historical Fisheries

Statewide harvests of king crab have experienced two periods of dramatic growth and decline. In the early 1960s, the Kodiak king crab fishery was becoming the dominant crab fishery in Alaska. A steady decline in abundance and harvest of the Kodiak stocks followed in the late 1960s. Except for a small resurgence in the 1970s, the Kodiak fishery has never recovered. In 1969, Bristol Bay and Bering Sea crab stocks began an unprecedented period of growth that continued through 1980. Harvests more than tripled, culminating in record catches of 84,308 metric tons (185.7 million pounds) as the fleet shifted much of their gear to this lucrative new area from the Kodiak fishery. Growth in the Bristol Bay fishery management area was largely responsible for the boom during this period, as the Bristol Bay harvest rose from 3904 metric tons (8.6 million pounds) in 1970 to the record catch of 59,020 metric tons (130 million pounds) in 1980. Within three years, however, the industry had collapsed again. King crab stocks were so scarce that the Alaska Department of Fish and Game ordered complete closure of the Bristol Bay crab fishery in 1983. Statewide harvests plummeted to 12,213 metric tons (26.9 million pounds). Catch dropped an additional 4540 metric tons (10 million pounds) by 1985. Depressed stock conditions for king crab in state and federal waters around Alaska still persist today.

Economic Profile of the Fisheries

The economic impact of this collapse has been extensive, involving virtually every participant in the fishery. Between 1980 and 1983, ex-vessel revenues to fishermen fell by more than 50%, dropping by $93.2 million. Processor sales dropped by $178.0 million, a 60% reduction, while sales from wholesalers declined by $304.2 million for a 66% reduction. Fishing vessels shifted into different fisheries and an industry-wide restructuring commenced.

The significance of the collapse may be placed in perspective by considering the fact that the king crab fishery was the second most valuable Alaska seafood industry between 1968 and 1983. Only the combined value of salmon harvested in Alaska exceeded that of king crab, yet, the weight of the statewide king crab catch rarely exceeded one-third of the total catch weight of salmon.

In the early 1980s, ADF&G managers and the NMFS took a number of actions to stop the declining in king crab stocks. These actions included a reduction of the fishing effort, an increase in the level of research into population and stock identification, and bioeconomic modeling of fishery management decisions.

An Alaskan King Crab Restoration Initiative

Through this symposium, we hope to document current technology and to facilitate coordination between researchers and various agencies. Considerable scientific research has been conducted on juvenile king crab by scientists from Japan, Chile and the United States. It would seem that a key element in an Alaskan King Crab Restoration Initiative is an early investment in technical expertise and information.

There is cooperation on this effort between the ADF&G Division of Fisheries Rehabilitation Enhancement and Development (FRED) Division and the Division of Commercial Fisheries. The Alaska Science and Technology Foundation is helping to support this symposium. Japan's Overseas Fishery Cooperation Foundation is sponsoring the participation of Japanese scientists at this symposium. The FRED Division recently developed a cooperative agreement with Chile for the purpose of sharing knowledge and personnel in order to accelerate training on crab restoration research and technology. Continuing cooperation with other countries is also needed. A critical review of king crab restoration proposals by management agencies and universities will be an important aspect of the initial planning for research and restoration work. We are looking to specifically focus the development of king crab culture technology and the development of various habitat improvement techniques which can be used to facilitate the restoration of king crab populations. ADF&G has requested $485,000 in next year's state budget to develop a research and production capabilities for this purpose. A goal of this request is to culture pelagic king crab larvae such that these larvae can be used as experimental animals to evaluate densities, timing and release site considerations and to help understand early life history requirements of Alaskan king crab.

If we are successful in creating an increase in sustainable king crab recruitment to the common property commercial fishery, there is strong potential for good net economic benefits in Alaska. Some of these advantages include:

- Economic demand models developed for red king crab indicate that markets are currently able to accept an increase in the amount king crab without a proportional reduction in price. As such, prices for red king crab do not appear to be sensitive to output levels until catches approach historical harvest levels, similar to that which occurred in 1980.
- There are substitutes for red king crab in the market place but, traditionally red king crabs have brought the highest product prices and are harvestable at comparatively lower costs than other crabs.
- Economic spinoffs in the form of improved management precision and information could be obtained from properly designed research projects aimed at understanding the various factors that make crab populations grow and decline.

Our Challenge at this Symposium

We are seeking your advice as to what steps should be taken in Alaska. I challenge each of you to:

1. critically evaluate the current situation in Alaska;

2. evaluate the status of king crab restoration technology and tools; and,

3. recommend appropriate courses of action for Alaska.

Please be thinking about these 3 points during the next two days and be prepared to make your recommendations on Friday.

Proc. Int. Crab Rehab. & Enh. Symp.
Jan. 1992, Kodiak, Alaska.

A Brief Synopsis of the History and Development of the Kodiak King Crab Fishery

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ABSTRACT

The commercial king crab fishery was pioneered in the '30s by small vessels. The fishery was exploratory through the '40s, developed through the '50s and peaked in 1966. King crab populations then declined with the Alaska Board of Fisheries instituting new regulations in an attempt to establish a stable fishery. The commercial fishery rebounded through the mid to late '70s. However, due to recruitment failures, the fishery was closed in 1983. King crab fishing has been closed since 1983, and the population has remained well below a level to warrant a commercial fishery.

TEXT

The Kodiak king crab fishery was pioneered by salmon fishermen. Beginning in 1936 small amounts of king crab were landed, but catches were not officially recorded until 1950. This period in the history of the fishery was exploratory in nature. Fishermen were locating crab, determining abundance and testing gear types. Once the resource was determined abundant enough to support fishermen, markets had to be developed to sell the product.

During this exploratory period, the Bureau of Commercial Fisheries (now National Marine Fisheries Service) was the management agency. Regulations in effect during this period provided for retaining only males with a minimum width of 5½ inches. In 1949 the size limit was increased to 6½ inches.

In 1950, 60,000 pounds of king crab were landed, and the fishery was on its way to becoming a major force in the economy of the Alaska fishermen. From 1950 to 1959 the catch increased from 60,000 to 21 million pounds. During this period, a pot limit of 15 pots per vessel and area registrations were instituted. In 1959 pots and ring nets were classified as the only legal gear, and a pot limit of 30 pots per vessel was established for Kodiak. As Alaska gained statehood, management authority was transferred to the Alaska Department of Fish and Game.

In 1960 the king crab season was opened year round. Eight processors bought 21 million pounds of king crab at 8 cents per pound from 106 vessels. In 1963 the size limit was increased to 7 inches, based on Kodiak area growth rate studies and to allow male king crab to breed at least one year before being available to the fishery. The early sixties saw continued growth in the fishery until 1964 when the Good Friday Earthquake slowed production.

In 1965 the 30 pot limit for Kodiak was repealed, and a new-shell crab closure went into effect from April 1 to June 15. There were ninteen shellfish processors in Kodiak paying ten cents per pound. The Department had completed king crab tagging studies and had defined four major separate stocks of crab. Also in 1965, the staff report to the Fish and Game Board stated that the stocks could not continue to support the large harvests that were then occurring. The staff recommended the implementation of a quota system to slow the harvest; however, the Board of Fisheries took no action on the proposal.

The development period which began in 1950 peaked in 1966 when 177 vessels delivered 90 million pounds to 32 processors in a 9½ month fishing season. In 1966 the Department issued the first emergency order to protect new-shell and breeding crab and added its first shellfish management position. After examining 12,000 female king crab, of which only three to five percent were barren, the Department stated that Kodiak king crab stocks were biologically sound.

From 1967 to 1970, the king crab fishery expanded to offshore areas in an attempt to maintain the catch levels of previous years. In 1967 the Department started a test fishing program to locate concentrations of prerecruit crab and to estimate future years' production. The first catch projections predicted a continuing decline in future catches. The 1967/1968 season catch dropped to 43 million pounds. In 1968, females examined from eight different areas showed that 16 percent were not carrying eggs.

During the 1968/1969 season, the catch dropped to 18 million pounds, and the fishery was closed by emergency order on February 28th. The Department observed that 25 percent of the females were barren in some areas.In July 1970, the Alaska Board of Fisheries instituted a pot limit of 60 pots per vessel and established a catch quota system. The Department was directed to institute surveys for abundance estimates. The goals of the policy were twofold:

1) Develop and establish a stable fishery, to possibly eliminate extreme fluctuations that had characterized the fishery.
2) Develop and maintain a broad base of various age classes, insuring breeding success.

Sometimes these quotas resulted in low fishing mortalities and carried over large numbers of crabs to following years. This stock pile effect caused extremely short, fast paced seasons. Many areas historically fished later in the year were left unharvested. In 1971 the Board increased the pot limit to 75 pots per vessel. By 1972 the decline had been reversed and harvests started increasing. The 1973 fishery lasted ten days under a fixed quota system and was reopened for an additional eight day fishery.

In 1974 the Board adopted an 8 inch size limit for a second season, as proposed by the Kodiak Advisory Committee. The purpose of the 8 inch season was to provide a harvest opportunity later in the season for areas that had produced larger crab but had not been fished in recent years. It was believed that many of these crab that escaped the 7 inch season would be lost through natural mortality. Since it was indicated that an increase in harvest could be made, the Board decided to increase exploitation on the older postrecruit crab. The Board also adopted a flexible system of harvest guidelines rather than fixed quotas. The Board directed the Department to continue to manage the fishery using a multi-age-class management strategy based on analysis of crab stocks.

In 1976 the Board adopted a fixed opening date of December 1st for the 8 inch season. The December 1st opening date provided an opportunity for all size vessels to participate in the second season. This second season was soon relied on by a large portion of the fleet, because the additional season allowed a second opportunity to fish and provided an extra stimulus to the local economies.

In 1978 the Board lowered the size limit of the second season from 8 inches to 7½ inches. The Department proposed the change because of the large amount of postrecruit crab available between 7½ and 8 inches that year. In 1979 the Board of Fisheries increased the pot limit to 100 pots per vessel. The Board adopted a management plan for Kodiak in 1981. The plan's direction was threefold:

1) Individual stocks of crabs are to be managed as a single unit, and small closures that leave a portion of a stock open should be avoided.
2) Utilization of stocks should be based on overall stock size while considering recruit and postrecruit population levels.
3) A second season for 7½ inch crab will be provided for with an opening between November 15 and December 15.

The 1981/82 season's harvest was the highest of the previous 14 years at 24.2 million pounds. This was followed by the 1982/83 season harvest of 8.7 million pounds, the lowest in 24 years. Although this season's harvest was low, the value of the fishery was the second highest, worth 33 million dollars. The effort level for this fishery is also the highest on record with 309 vessels participating.

In 1983 the traditional red king crab fishery was not opened by the Department of Fish and Game due to poor stock condition.

This was a result of poor recruitment for the previous two years combined with continued low recruitment forecast for the next three years. The population of adult male crab was the lowest the Department had recorded in 13 years of annual population assessments. At that time, the Department established threshold levels of legal males needed prior to considering any further fishery.

In 1984 and 1985 the estimate of legal males on the pot survey remained below the threshold level established for Kodiak Island. However, in 1985 the estimate of legal males in the Southwest District was above the threshold value established for that District. The Department proposed a 450,000 pound harvest and presented this proposal to the Kodiak Advisory Committee. After the Committee's review of both Department and Industry views, the Kodiak Advisory Committee voted unanimously to oppose a fishery in the Southwest District. Their concerns were that a small area open with a large effort level would be destructive to the reproductive potential of the stock. The Commissioner of Fish and Game acknowledged the Advisory Committee's concerns and the Kodiak king crab fishery was closed during 1985.

During 1986 the fishery again remained closed as the estimate of legal males was below threshold values. The Department revised the management plan from a threshold of legal males needed for a fishery to a number of fertilized females needed to maintain maximum reproductive potential of the stocks when populations are depressed. This threshold value for Kodiak Island is 5.1 million fertilized female king crab.

In 1987 a trawl survey was conducted island-wide for the first time to assess both king and Tanner crab stocks. Previous trawl surveys had been limited to Tanner crab assessment in the Shelikof and portions of the Northeast and Eastside Sections of Kodiak Island. This trawl survey estimated a population of 310,000 adult female king crab around Kodiak Island of which 47% were not carrying egg clutches. The 1987 survey results indicated a continuation of the decline in red king crab abundance that had been noted the past five years and the commercial fishery again remained closed.

Since 1987 the Department has continued to conduct trawl surveys in Kodiak and has expanded this survey to the Alaska Peninsula. King crab population levels have remained well below levels that would warrant a commercial fishery.

Although the Kodiak king crab stocks are currently depressed, the Kodiak Area king crab fishery has made major contributions to the management and development of other crab fisheries within the State.

Now the stage is set for the opportunity of enhancement and rebuilding of the Kodiak king crab stocks.

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Review of Recruitment of Red King Crab (*Paralithodes camtschaticus*) the Gulf of Alaska

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ABSTRACT

A review of recruitment of red king crab (Paralithodes camtschaticus) in the Gulf of Alaska provides insight into possible causes of the collapse of the commercial red king crab fishery. Large pulses of recruitment of crab to sexually mature stages correlate primarily with sea surface temperature decreases observed in the Gulf of Alaska. The recruitment response to temperature decreases appears to diminish in recent years of the 35 year history of this fishery. Studies by other investigators of zoeae survival in southeast Alaska did not suggest major variations in survival or in density among the 5 study years in response to the temperature variation observed. Glaucothoe larvae settling rates on artificial substrates in the Kodiak area indicate modest variation between the two years observed. We observed moderate mortality of juvenile crabs on the collectors over one year. Minimal information is available on the survival of red king crab during their second year of life. Observations of pod sized crabs (2-3 year old) does not suggest high mortality rates during this life stage. Mortality of adult crab from age 5 to 8 (legal commercial size) over the past decade is modest. No relationship of adult female abundance with subsequent recruitment of mature animals of the next generation was observed.

No clear cause for the recent red king crab recruitment failure has been identified from approaches used to date. We recommend an experimental approach in future investigations. We recommend culturing and release of tagged crab in replicate at different habitat sites, different stages of development, and at different densities. The survival of the marked animals in response to different treatments would be useful in assessing the effectiveness of rehabilitation strategies and management techniques, and determining the cause of the persistent recruitment failure throughout the Gulf of Alaska.

INTRODUCTION

The red king crab, *Paralithodes camtschaticus* (Tilesius) was valued at $168.7 million in 1981, the most valuable single species fishery in the United States (USDC 1981). The subsequent collapse of the red king crab fishery in the Gulf of Alaska after 1982 continues through the present. All major red king crab fisheries in the Gulf have been closed since 1983 with surveys indicating little indication of imminent recovery (ADFG 1991. The red king crab fishery produced in excess of 1,000,000,000 lbs of crab from 1960 through 1983 with peak annual production over 100,000,000 lbs.

We review selected studies on red king crab that provide insight into the cause of collapse of the fishery and the continued failure of the fishery to recover after a decade of closed commercial fisheries (Blau 1985; 1986; Schmidt and Blau 1986). Possible factors that have been hypothesized by the fishing industry and other researchers as potential causes for the demise of the fishery include:

1. Decreased fertilized egg production (egg predation, overfishing or other adult population reduction)

2. Decreased pelagic larval survival (unfavorable ocean temperatures, low food availability, high larval predation)

3. Decreased glaucothoe larval survival (settling at sites with poor habitat because of unfavorable currents or offshore winds)

4. Decreased survival of first year instars (predation, food limitations, disease)

5. Decreased survival of second year instars (predation, food limitations, disease)

6. Decreased survival of pod sized crabs (age 2 to 4) (predation, food limitations, disease)

7. Decreased survival of recruited crabs (age 4+) (predation, food limitations, disease, commercial fishing bycatch)

We define crab as being recruited in this study when they fully recruit to trawl and pot survey gear at approximately age 5, rather than when males recruit to the commercial fishery at age 8. Five years of age corresponds with the age of first egg extrusion by females. Studies addressing these hypothetical causes of the failure of crabs to recruit into the surveyed populations are reviewed in this report.

METHODS AND MATERIALS

This study reports data from several published reports and other investigations in progress. Commercial crab statistics are from data collected by the Commercial Fisheries Division of the Alaska Department of Fish and Game (ADFG) in Kodiak, Homer and Petersburg. Kodiak pot and trawl survey data for adult crab abundances are from ADFG in Kodiak. Information on pre-recruit juvenile crab is from Dew (1990) and Rounds et al. (1990). Larval data are from Shirley and Shirley (1990). Temperature data are from Royers (1989; 1992). Methods are defined for the data collection techniques used in the study of survival of early instar juvenile crab from the Kodiak area. This study is first reported in this manuscript.

Study Sites

The Gulf of Alaska commercial fisheries for red king crab (*Paralithodes camtschaticus*) extend from Northern British Columbia for several thousand miles along the Aleutian Islands. Additional major red king crab production areas occur in the Bering Sea and within waters of the Russian Republic. The Gulf fisheries consider in this report include the ADFG red king crab management areas of Southeastern Alaska, Prince William Sound, Cook Inlet, Kodiak, Alaska Peninsula and Dutch Harbor. These areas span several thousand kilometers. The commercial fisheries data reported are from the State of Alaska waters and the adjacent Federal Waters of the U.S. (Figure 1). Locations from where data collection locations of weather information reported by Royers (1989;1992) and the location of studies by Shirley and Shirley (1990) on larval survival at Auke Bay near Juneau, Alaska are depicted on Figure 1.

Additionally, data are reported from Chiniak Bay near Kodiak Island (Figure 2). These data represent an investigation into the settling of larvae and planned investigations into their subsequent recruitment into the adult red king crab population.

Collector Project Description

We developed and used artificial substrate collectors similar to those used by Sause et al. (1987) for the collection of scallop (*Pecten alba*) spat. The collector consisted of a 1.8 m by .25 m tubular polyethylene 16 mm stretch mesh filled with herring monofilament gill net (Blau et al. 1991). The tube was secured on both ends to form a sausage-shaped artificial collector with the vertical collectors containing a small float on one end. This collector type was chosen after comparison of results from other types of collectors during earlier investigations (Blau et al. 1990). These collectors were deployed in 1990 at 55 stations (Figure 2) in groups of 10 per station (Figure 3). In 1991, the stations were reduced to five collectors oriented in the vertical position only. Additional collectors with 25 per station were deployed at three stations in Trident Basin and one by Gibson Cove near the city of Kodiak. These stations were chosen because of proximity to boat launch facilities and were known to have king crab juveniles present historically (Powell et al. 1972). These collectors were removed periodically to determine changes in catch per collector and changes in length of crabs captured from collectors throughout the year. New collectors were installed in the spring of 1991. Collectors were removed during September and October of 1990 from all of the abundance index stations. This period was selected to insure no additional glaucothoe larvae were recruiting to the collectors. The contents of the collectors were removed and analyzed with careful sorting and examination with a dissecting scope of residue washed into a fine meshed screen. Juvenile crabs at instar III were observed and sorted visually.

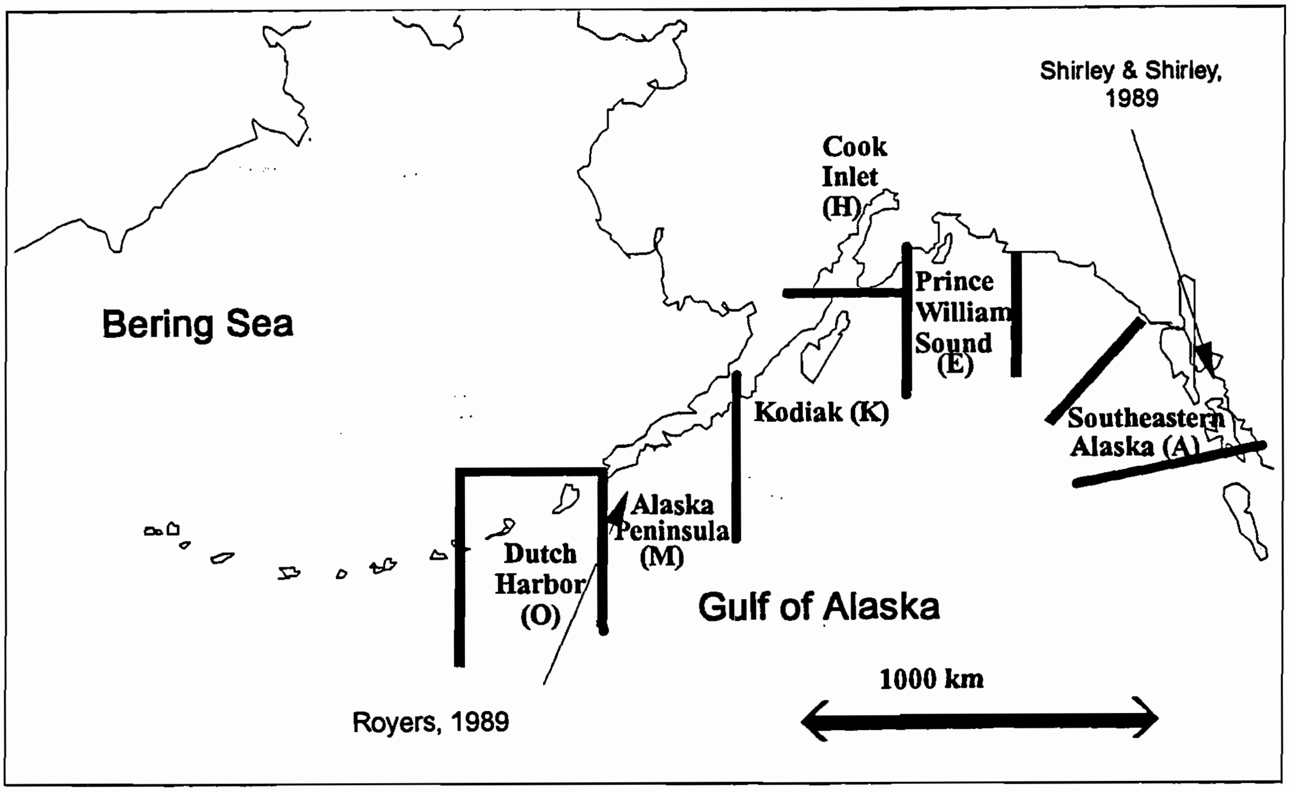

Figure 1. Alaska Department of Fish and Game commercial fishing districts for red king crab in the Gulf of Alaska. Location of temperature data used in this report and location of larvae studies at Auk Bay are also illustrated.

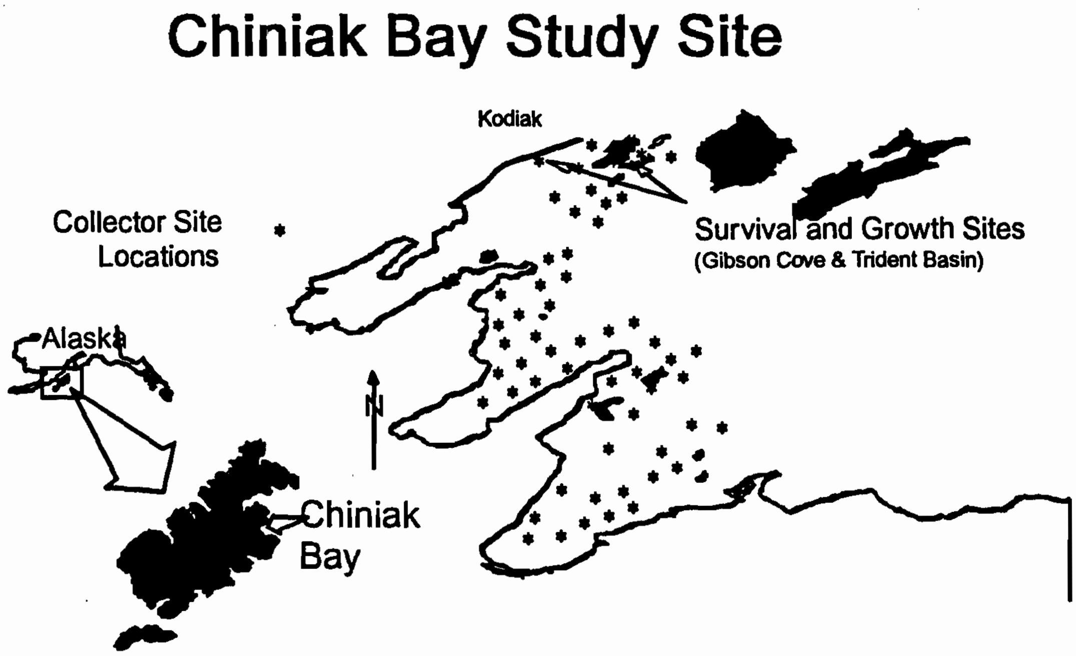

Figure 2. Chiniak Bay on the northeastern portion of Kodiak Island was the study site to research the settlement, growth and indexing of age-0 red king crabs collected in artificial collectors. Collector sites at Gibson Cove and at Trident Basin, where the survival and growth data were collected, are illustrated. The other sites were used to estimate inter-annual variation in settling rates of larval crab.

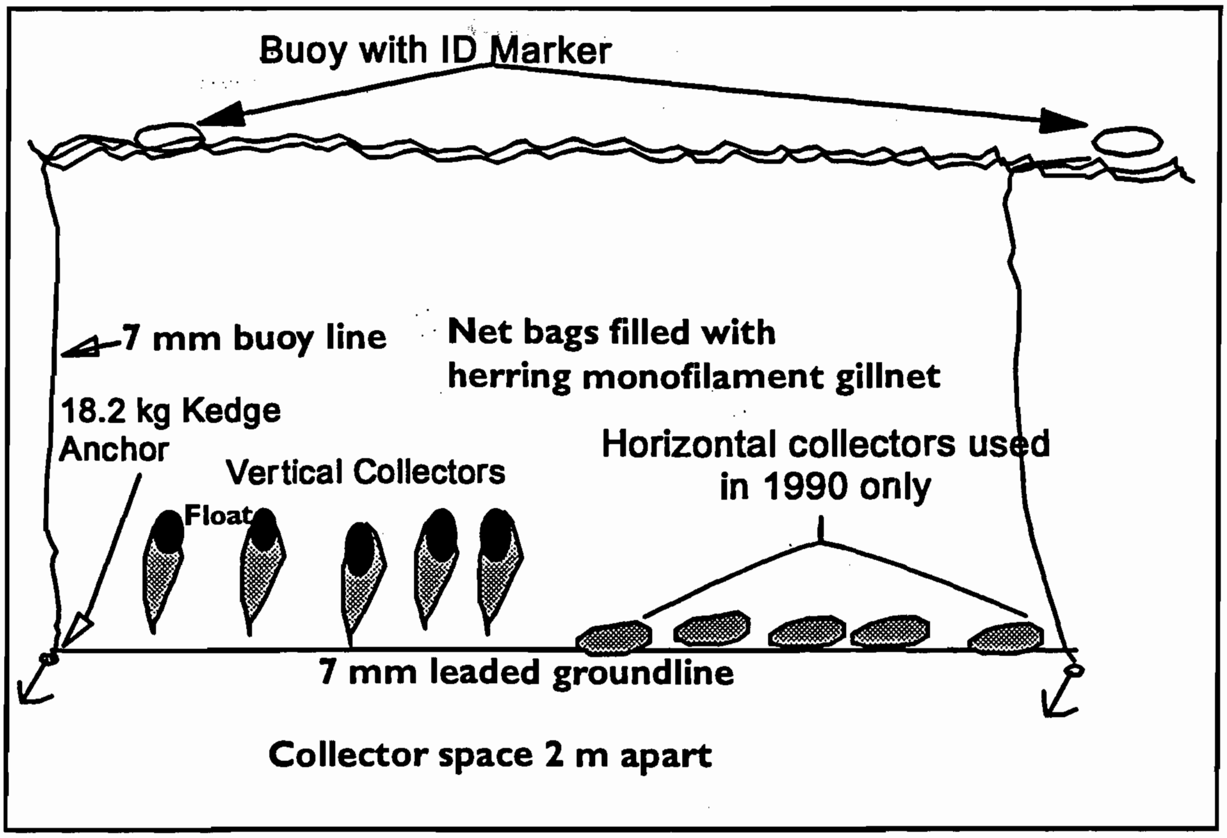

Figure 3. The collector stations design is illustrated with both horizontal and vertical collectors. Only five vertical collectors at each station were used in 1991.

RESULTS AND DISCUSSION

Recruitment Variability of Adult Crab and the Recruitment to the Commercial Fisheries in the Gulf of Alaska

We examine the variability of adult crab abundance reflected in commercial landings and adult surveys, both temporally and spatially. These patterns should provide some clue as to the mechanism responsible for the failure of the commercial fisheries.

Major Commercial Production Areas:

Figure 1 illustrates the geographic distribution of the fisheries management areas in the Gulf of Alaska. Major production areas also occur in Bristol Bay, the Aleutian Islands and in waters of the Russian Republic. Figure 4 illustrates the distribution of the landings since 1960 from the major commercial fisheries within the Gulf. The relative landings since 1970, after full development of all commercial stocks had been completed, reflect the similarity in patterns of commercial production across all stocks (Figure 5). Note that the Southeastern Alaska stocks declined after 1985, rather than mimicking the 1983 declines which initiated closures of major production areas (Kodiak, Alaska Peninsula and Dutch Harbor). The red king crab stocks are geographically separated by several thousand km. This distance combined with different orientation of the bays and general topography near these various stocks suggests surface currents and wind patterns as an unlikely candidate to produce common effects on recruitment of larval crabs over such a wide area.

Kodiak Island Management Area Adult Survey Results:

Surveys of adult red king crab have continued from 1972 through the present around Kodiak Island (ADFG 1991). The length frequency of male crabs that recruit to the pot or trawl sampling gear used in the survey are illustrated in Figure 6 (upper) for the years 1972 through 1990. Note that the virtually complete failure of many of the year classes allow aging of the single cohorts or crabs that recruit to the commercial fishery by age 8. These data provide a clear illustration of the effects of the commercial fishery on the relative abundance of crabs of legal size after the 1981 and 1982 fishery (Figure 6, lower). Very high mortality rates, presumably caused by commercial fishing, caused the removal of two age classes of crabs over a three year period (1980 through 1982). Despite this obvious effect of fishing, the primary cause of the extended decline in adult male crab abundance was not caused by commercial fishing activity but rather by consistent recruitment failure (Blau 1986). Figure 7 illustrates a projected mortality rate from the relative abundance of the last measurable unfished cohort of crabs from their 1976 year of hatch. The CPUE values reported in this figure are the cumulative values from the single year class modes illustrated in Figure 6. Note that significant imprecision in survey estimates of relative abundance weaken the observed relationship. As this single cohort of crabs did not suffer the

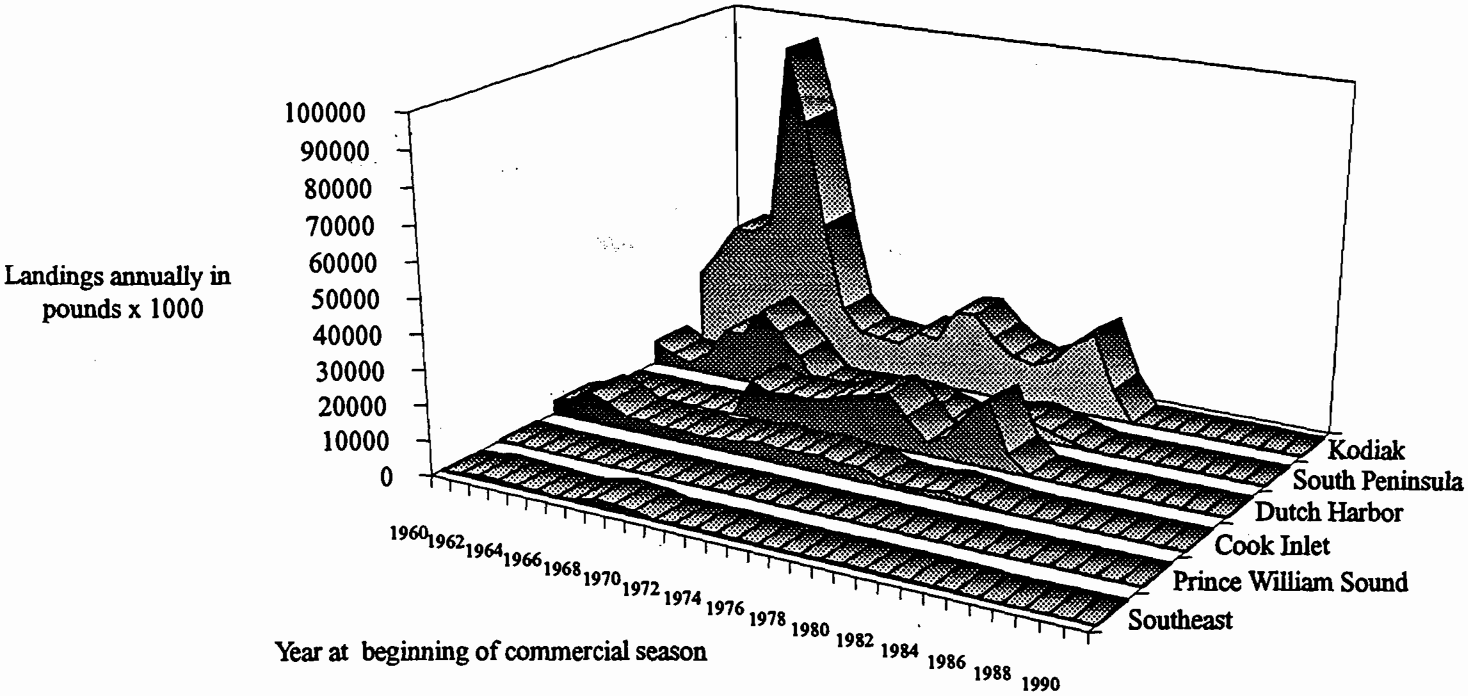

Figure 4. Historical trends in commercial catch of red king crab by management area in the Gulf of Alaska.

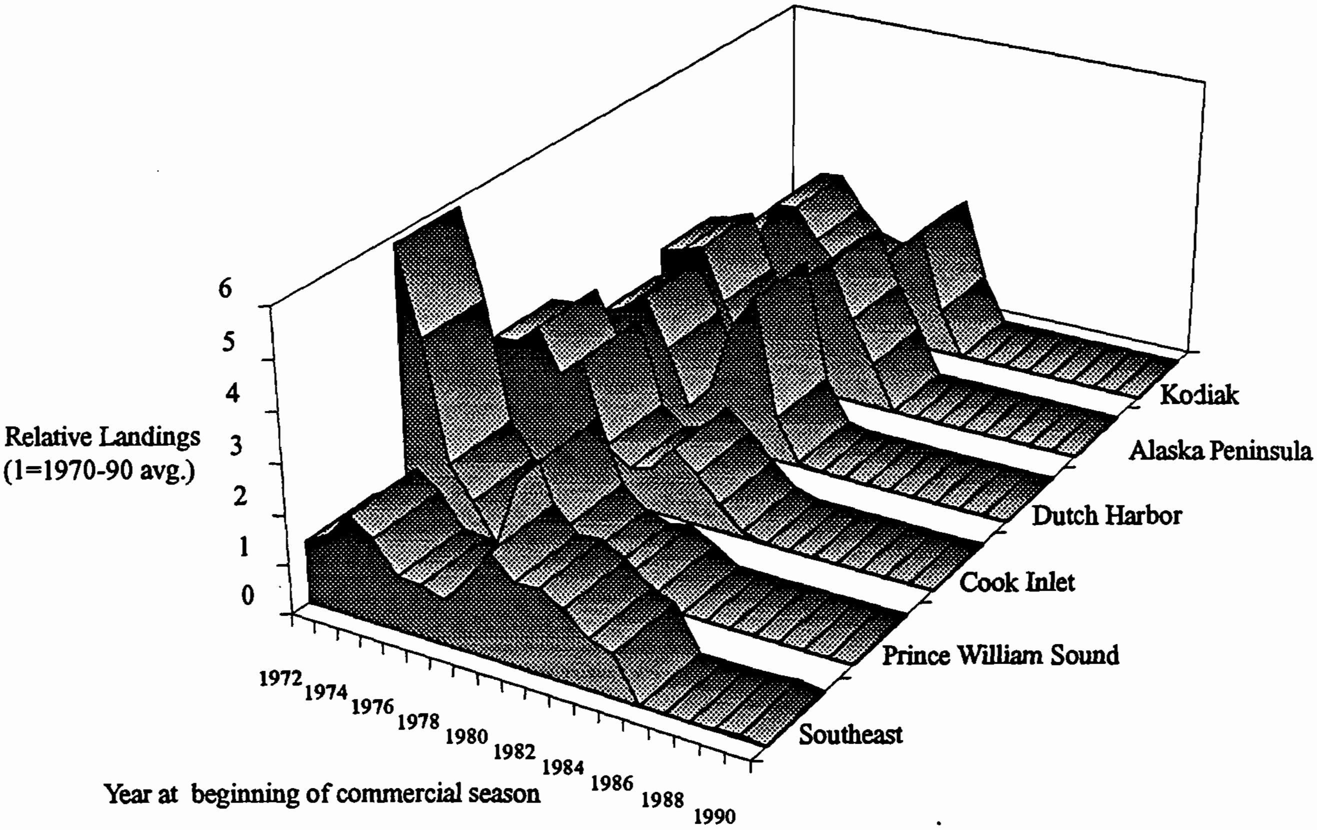

Figure 5. Historical trends in commercial catch of red king crab expressed in relative terms. The value of "1" equates to the 1970 to 1990 average landings for each district.

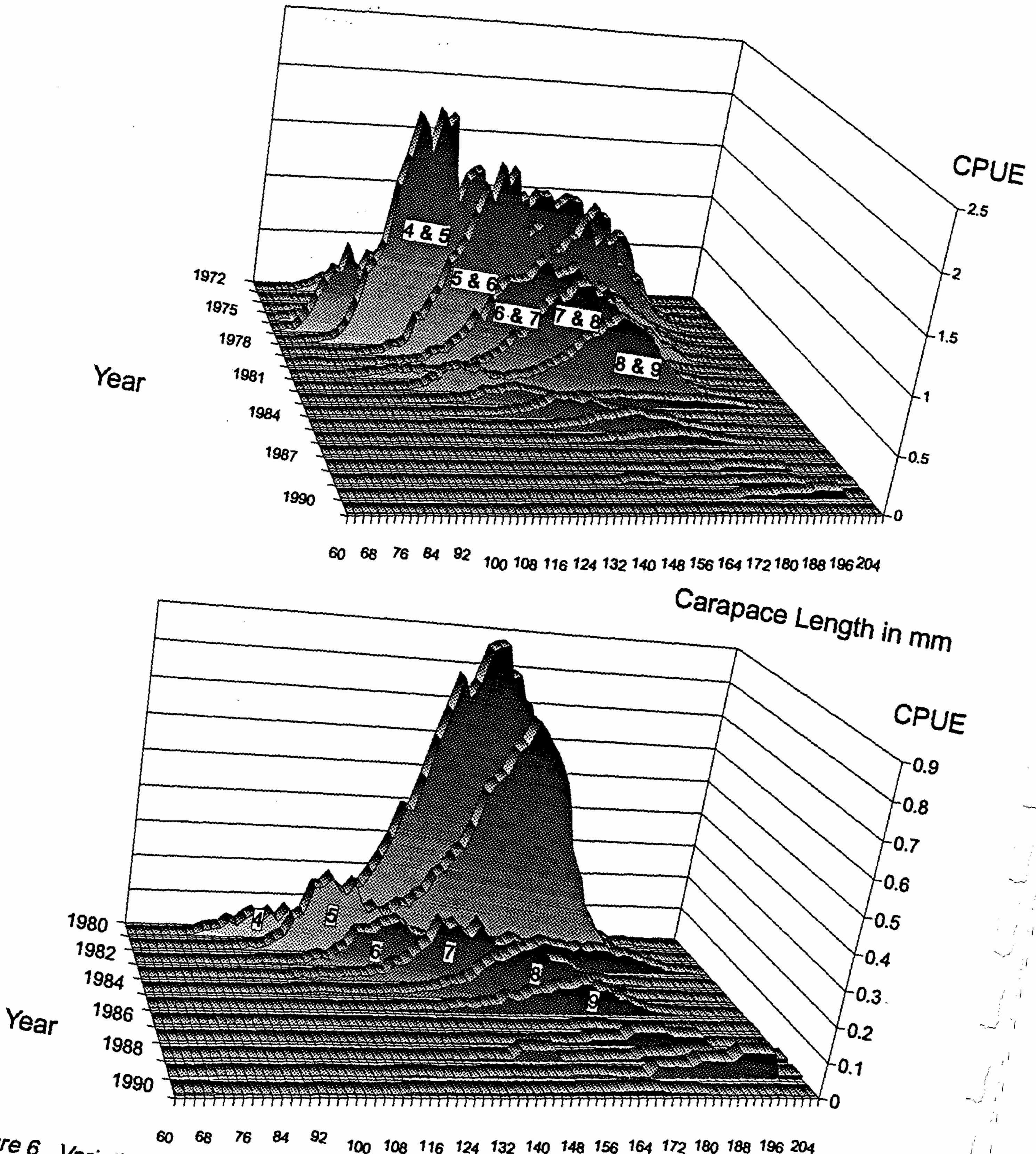

Figure 6. Variation in recruitment of red king crab as illustrated by the Kodiak managment area pot and trawl survey length frequency data. Legal size equates to approximately 148 mm carapace length. Dominant age classes of the modes are listed.

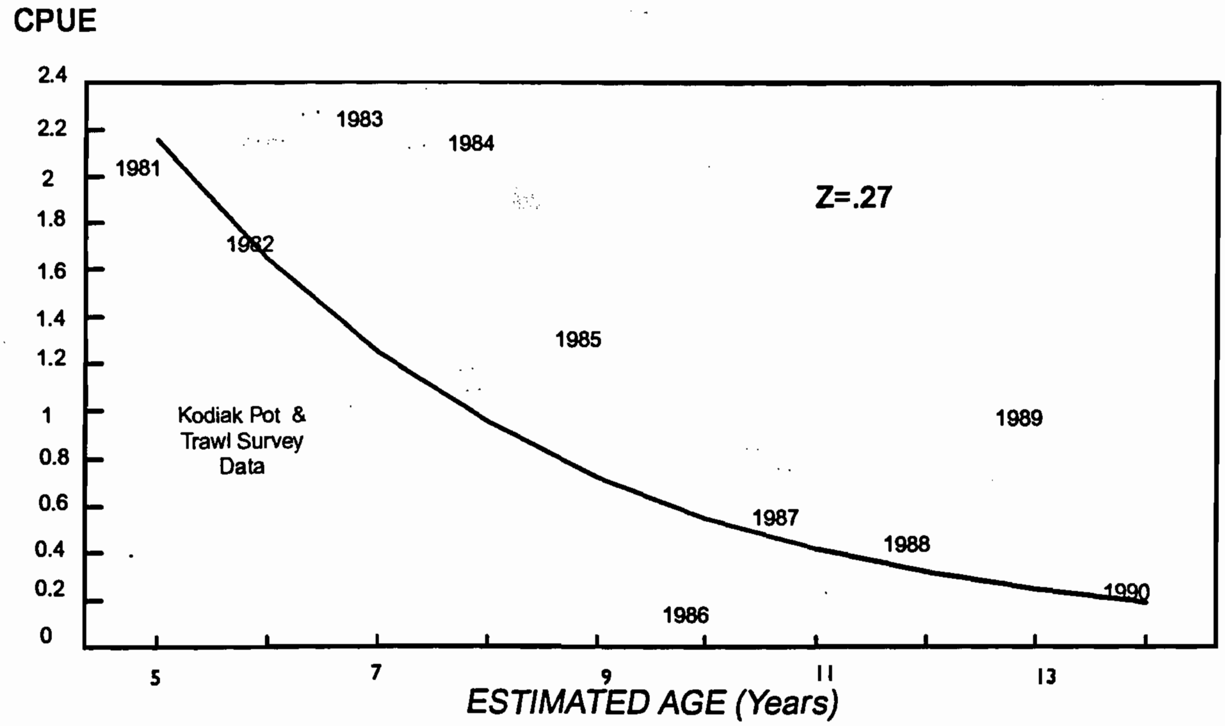

Figure 7. Kodiak management area CPUE trend over time for a single commercially unfished cohort of red king crab from pot and trawl survey data. Survival estimates assume full recruitment to the gear at age 5 and constant catchability over time and over various age/size classes. CPUE values are cumulative values from the cohort depcited on lower Figure 6.

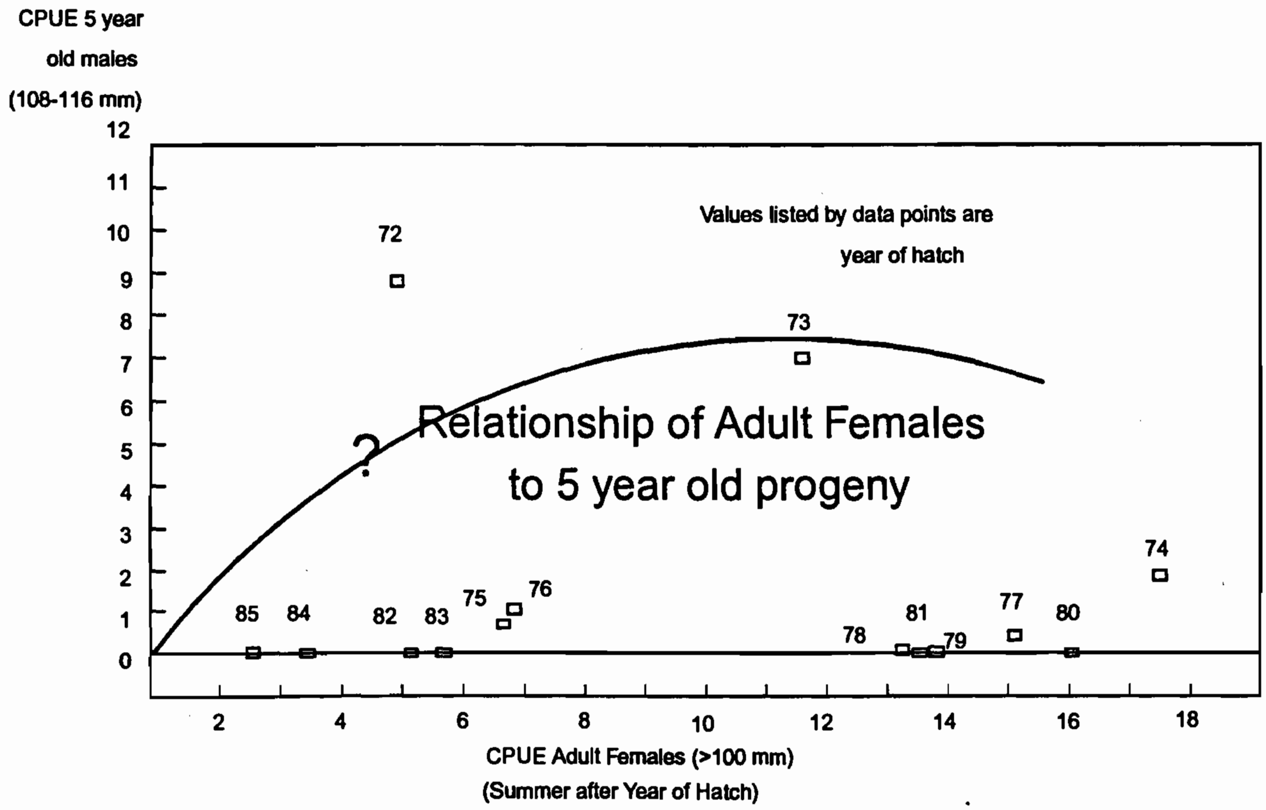

Figure 8. Kodiak management area red king crab survey mature female CPUE relationship (stock) to subsequent CPUE of 5 year old males (recruits).

same mortality rate as legal sized crabs 3 or 4 years older suggests that commercial fishing was the primary cause of the rapid decline of the legal stock of crabs during 1981 and 1982.

Within the limited time period of the Kodiak Island survey, no effect of adult female abundance on the subsequent recruitment of five year old male progeny is apparent (Figure 8).

Relationship of Temperature to Recruitment of Adult Crabs into the Commercial Fishery

Variations in the temperature of the Gulf of Alaska are illustrated by long term Sitka air temperature anomalies (Figure 9) (Royers, 1989; 1992). These data illustrate a cyclic pattern of temperature variation which Royers attributes to lunar tidal cycles in the North Pacific Ocean. Sea surface temperatures (SST) are illustrate on the graph from a location center to the major red king crab production areas (55 Degrees N 160 Degrees W) in the Gulf of Alaska. Figure 10 superimposes this sea surface temperature with male crab landings from the Gulf of Alaska (Figure 4). The male crab landings are offset 8 years and plotted inversely to the SST anomalies. A cohort of crabs become legal size (7 inches in carapace width-approximately 148 mm carapace length) eight years after the spring when they hatch into pelagic larvae. Major increases in the commercial fishery correspond to the decreases in SST during the larval period of the recruited cohort. That the small decrease in SST observed in 1976-77 does not reflect increases in the commercial statistics since the fisheries were closed since 1983. Figure 6 depicts this small cohort as recruiting to legal size during 1984, eight years offset from the small negative temperature anomaly of 1976. Although this relationship covers a 35 year history of king crab fishery, much of the recruitment trends are masked by commercial landings data. Multiple year classes may be present in the commercial fishing data as exploitation rates have varied over time. This is illustrated in the survey data depicted in Figure 6. The absolute temperature appears to have little effect. Note that the 1956 and 1957 period provided a very small decrease when measured against the large commercial landings in some areas during 1964 and 1965, whereas the very major negative temperature anomaly during the early 1970's provided two cohorts of crabs which were harvested predominantly in 1980 and 1981. However, all four rapid drops in temperature were followed by increases in recruitment into the commercial fishery with a general trend of a decreased response of recruitment to temperature declines in recent years. This suggests other factors not directly related to temperature may adversely affect recruitment.

Factors Affecting King Crab Larval Survival

Studies on the factors affecting larval survival during the pelagic phase of their life history are very limited. Relative abundance of red king crab larvae were reported by Wolotira et al. (1984) from the east side of Kodiak Island. These studies indicated

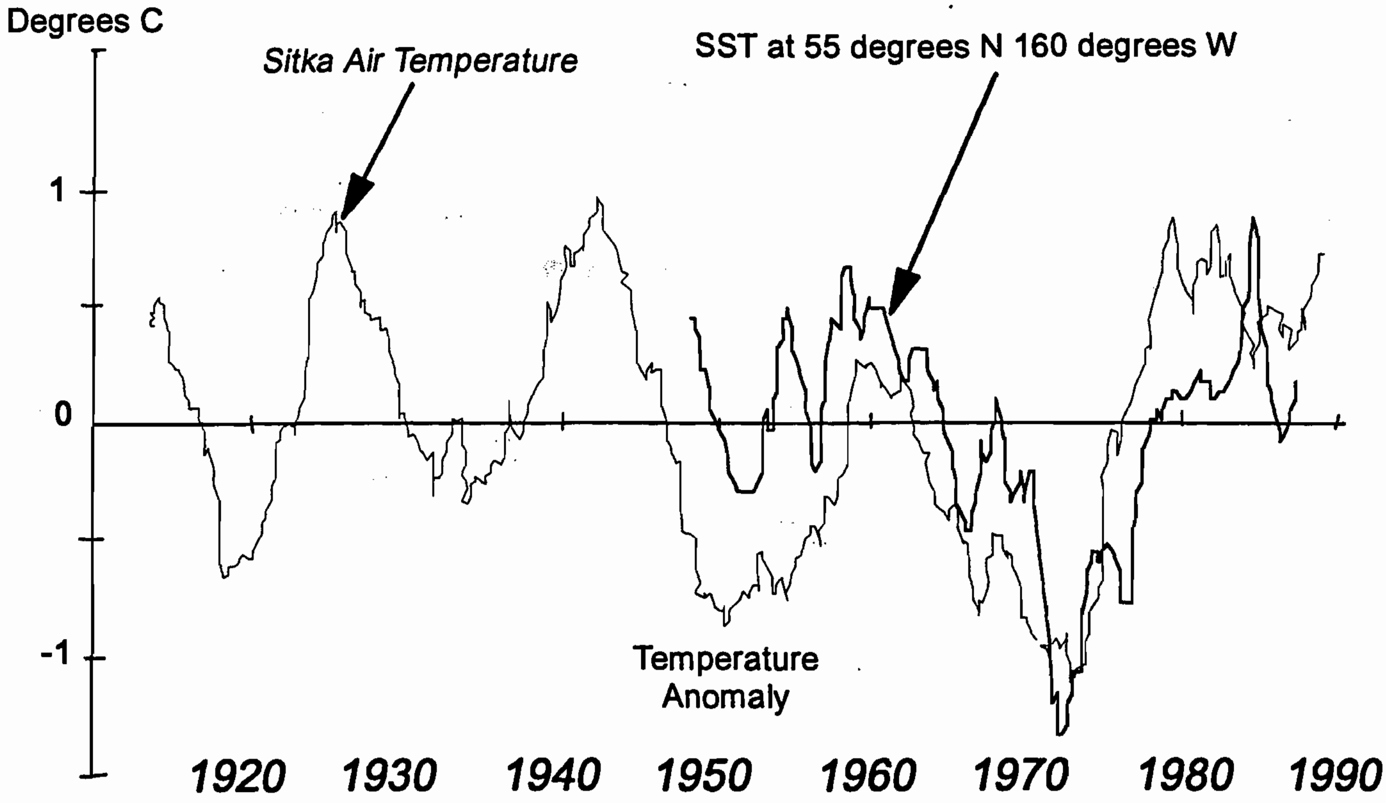

Figure 9. The relationship of sea surface temperature near the historic center of commercial crab distribution in the Gulf of Alaska to long term Sitka air temperatures (From Royers, 1990).

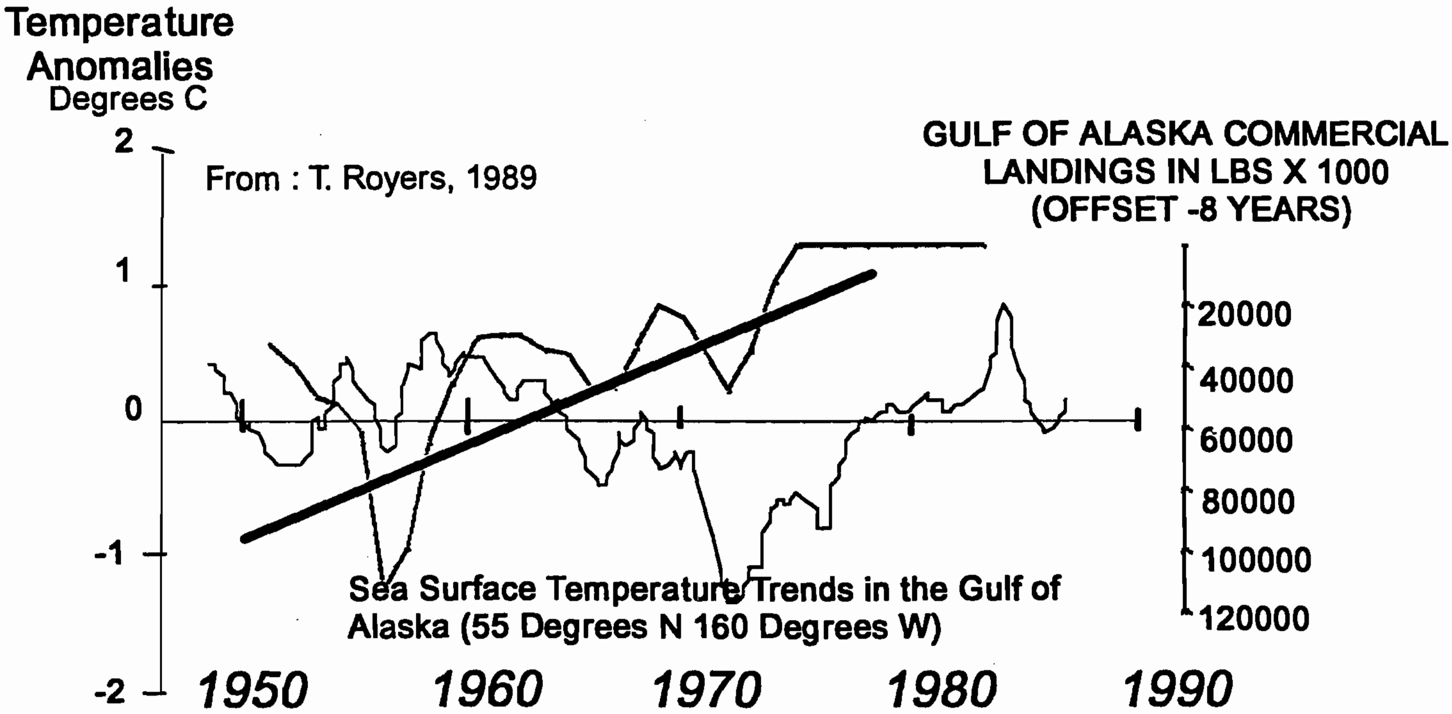

Figure 10. The inverse relationship between sea surface temperature (SST) anomalies and commercial crab landings is illustrated with commercial landings offset by 8 years, the dominant age of recruitment of commercial landed crab.

larvae were most abundant at the heads of bays and did not suggest broad distribution patterns into offshore areas. These bay heads are known from diving studies around Kodiak to be the area where females aggregate in April (Powell et al. 1972). Shirley and Shirley (1990) described the time of appearance of zoea I in the water column from 1984 through 1989. Peak concentrations usually occurred during the first week of May. The period of time 90% of the larvae were pelagic zooplankters ranged from 30 to 60 days. Temperature did not appear to affect survival during the pelagic larval stages (Figure 11: From Shirley and Shirley (1990)). Densities of zoea I larvae summed over the larval period ranged from 45.4 larvae per 100 m^3 to 91.7 larvae per 100 m^3. The point maximum densities reported varied from 10.0 larvae per 100 m^3 to 46.9 larvae per 100 m^3. These densities generally exceeded those reported over the past 30 years for the Bering Sea, a major production area of red king crab (Armstrong et al. 1983; McMurray et al. 1984; Takeuchi 1962;1968). Thus low levels of egg production from depressed adult crab populations do not appear to limit recruitment in this area as major recruitment of young crabs have not been observed from these year classes of larvae. The lack of interannual variation in larval densities and survival does not support the contention that the persistent recruitment failure observed throughout the Gulf of Alaska can be related to this life stage. This inference must be qualified in that the area studied has not contributed to major commercial crab production and little variability in temperatures occurred during the five year period of the investigations of Shirley and Shirley (1990).

Glaucothoe Settling and First Rear Juvenile Crab Survival

Although Shirley and Shirley (1990) reported glaucothoe larval densities from plankton tows in Auke Bay, the results provided limited information because the larvae were continually removed from the water column and settling into the benthos. Study results of settled larvae and subsequent survival to the early instar stages of crabs are reported by Freese and Babcock (1990). The larvae collected on artificial substrates over a two year period demonstrated minor variation between years. Larvae settling times were reasonably defined by the study but limited information on the survival of settled crabs was obtained.

We report new data collected in Chiniak Bay on Kodiak Island on the collection rates of early instar crabs from artificial substrate collectors and their changes in relative abundance over time. In addition, an extensive collector sampling program has been conducted in 1990 and 1991 to index the settling rates of age-0 red king crabs in this area. The study was initiated to determine if relative abundance of age-0 crabs on the collectors reflect relative abundance of future crab cohorts which recruit to adult size in this area. Donaldson et al. (1992) report the growth rates observed during the initial year of this study. Blau et al. (1992) reported the initial year settling rates and comparative data between different collector types used during a pilot study initiated in 1989.

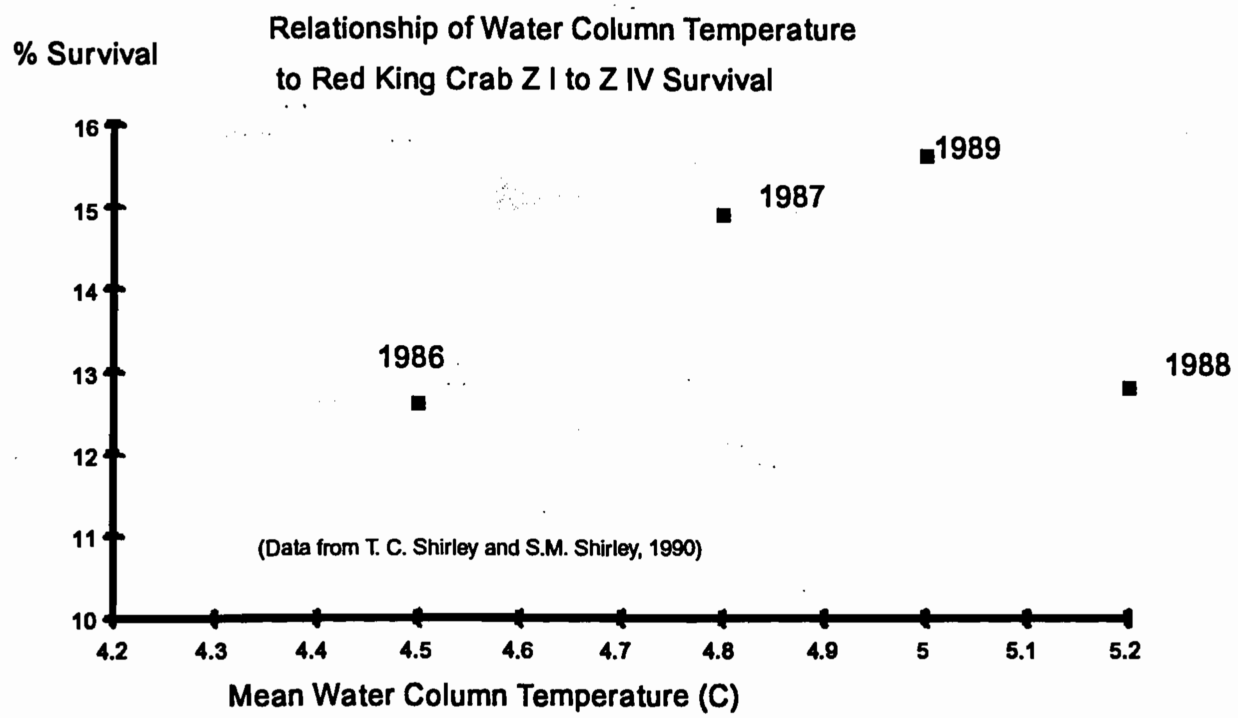

Figure 11. Relationship of temperature to red king crab larvae survival from zoeal I to IV stages at Auke Bay (From Shirley and Shirley, 1990).

We estimate age-0 crab survival from changes in CPUE beginning the second week in July of 1990 through the spring of 1991 (Figures 12 and 13). The sampling period which initiated the survival estimate was the first period at which no glaucothoe larvae were observed on any of the collectors retrieved. Figure 12 illustrates a decline in the initial CPUE during the duration of the study reflective of an annual survival of .15 at the Gibson Cove site. The initial CPUE value was much higher (approximately 50 crabs/collector) than at the Trident basin sites (approximately 15 crabs /collector) (Figure 13). The three Trident Basin sites were grouped because of similar initial densities of crabs and no discernable trend in density over time. No measurable decline occurred in Trident Basin. This suggests that the rate of decline in CPUE may be caused by density dependent effects of initial crab densities on the collectors. The decline in CPUE could be related to mortality or emigration. Recruitment to the collectors may have also occurred but would have required crab to crawl up the anchor line suspending the vertical floating collectors, crawl onto a collector that was touching the substrate or be transported to the collectors from floating debris. There is no evidence that juvenile crabs can move in the water column. Very few age 1 crab on the collectors indicated that some emigration occurred. The collectors average CPUE from the index stations retrieved throughout Chiniak Bay in October of 1990 were 5.34 (S.E.=1.013) crabs/vertical collector compared with 2.3 crabs/vertical collector in October of 1991. Collectors were retrieved at approximately the time period when the population was dominated by instar 5. This period was chosen to insure glaucothoe larvae were not still recruiting to the collectors. If the CPUE values reflect density based declines on the collectors because of initial high settling rates, we would not expect the between year differences in CPUE to reflect a linear relationship to actual settling rates. High densities of glaucothoe larvae settling on the collectors may not be reflected in the CPUE values when the collectors are removed 3 months after initial settling. The absence of measurable declines on the lower density stations suggest density dependent mortality or immigration has a minor effect on the interannual CPUE index since high density stations were relatively rare as reflected by the low mean values reported in both years.

The Survival of Second Year Crab Instars and Pod Sized Crab

The survival of red king crab after their first year of life is essentially unknown. Rounds et al. (1990) presented limited data on mortality rates in laboratory environments, primarily examining cannibalism rates associated with density and habitat conditions. Mortality under natural conditions is unknown.

Survival of pod sized crabs (ages 2 to 4) also has had limited study. Individual pod observations of Age 2 crabs indicate low mortality rates during December to February (Dew, 1990). The trawl and pot surveys conducted by the ADFG and NMFS, provide limited data on relative abundance of age 3 and 4 crabs. As these age classes only partially and apparently inconsistently recruit to

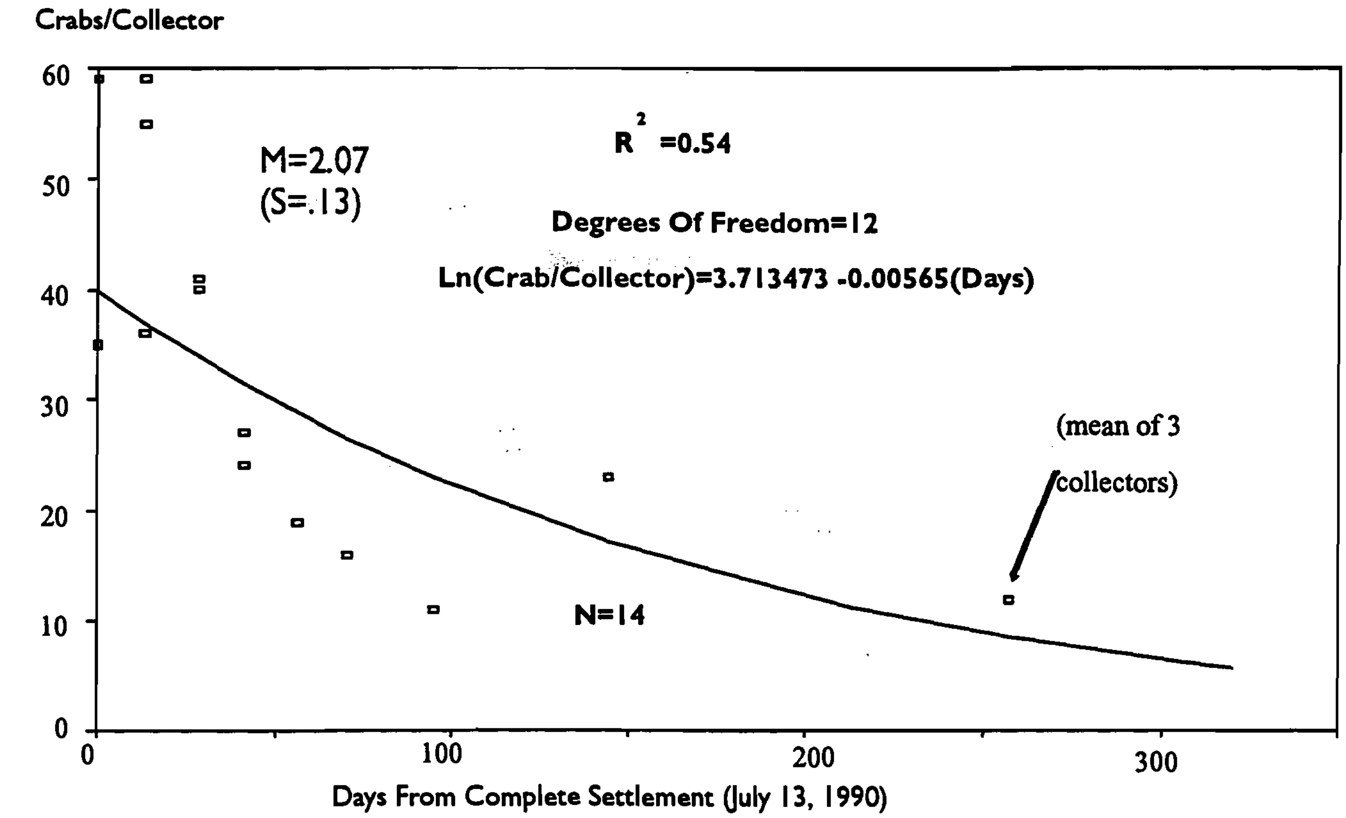

Figure 12. Survival rates of age-0 red king crabs on artificial collectors near Gibson Cove, Chiniak Bay, 1990. Survival estimated by regression assumes no emigration or immigration to collectors.

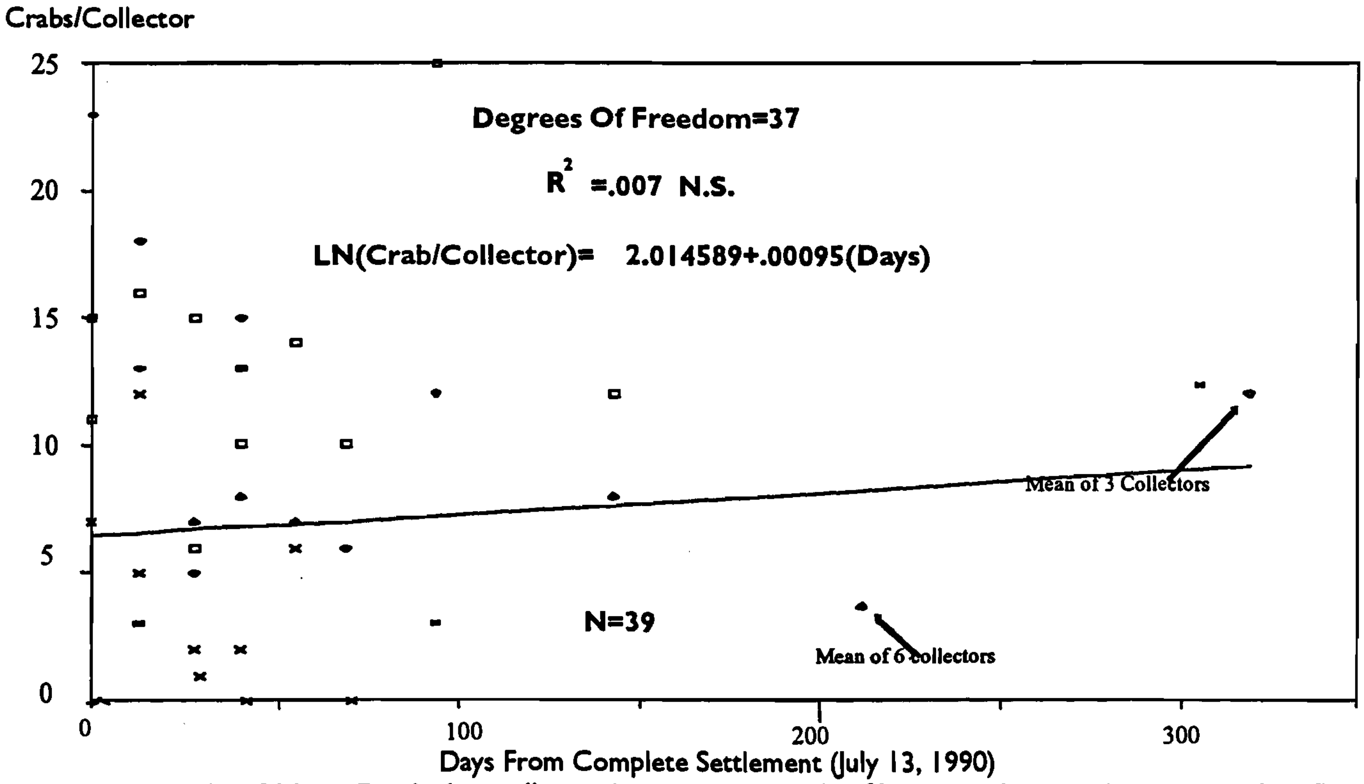

Figure 13. Trident Basin juvenile crab catch per unit effort trend on collectors during first year after settling. No significant change in CPUE was observed; therefore no survival rate was calculated. The different symbols indicate a collector was from a particular station in Trident Basin (3 total). Data from each individual sites also showed no trend and no significant difference in early sampling period CPUE.

survey gear types, annual survival rates are not estimated from these data.

CONCLUSIONS

No single life history stage can be identified as limiting recruitment with the information reviewed in this report. Female adult abundance is not clearly related to recruitment failure although adult biomass decline over time parallels the general trend in extended recruitment failure. Temperature correlates poorly with larval survival in limited study area of Auke Bay but declines in temperature in the Gulf of Alaska which occurred during the hatching and larval stages of red king crab parallel recruitment of adult males into the commercial fishery. Inter-annual variability of larval densities and larval survival indicate no clear trend with temperature. Survival of first year instars appears to be high on collectors when density is low suggesting at least on artificial collectors, sufficient resources are available to sustain juvenile crabs growth and survival.

Because all studies to date have failed to provide any indication as to what component of the early life history has caused the extended recruitment failure of red king crab in the Gulf of Alaska, several hypotheses are proposed for future research. Decreased pelagic larval survival because of temperature creating a non-synchronous hatch time with available food resources remains a potential candidate but limited amounts of data provide little support. Shirley and Shirley (1990) observations suggest larvae appearances correlate with phytoplankton blooms. Release of larvae by the nurturing females may be keyed to environmental clues and not solely dependent upon temperature. However, the limited variation in temperature during these investigations and relatively low stock abundance may have masked any major influence of temperature on recruitment. The high rate of apparent larval recruitment correlating with the negative change rate of temperature anomalies (Figure 10) suggests a complex mechanism that may relate to competitors for food resources, upwelling or currents, or recruitment of potential predators. The temperature data do not explain the sustained recent failure of recruitment in the Gulf of Alaska.

Age 1 and 2 year old (instar 1 to 12) mortality by predation is a potential life stage where high predation rates may occur. Observed mortality rates on collectors suggest densities of settled crabs under the very low stock conditions present in Chiniak Bay may provide sufficient numbers to exhibit density related effects. However, these data also suggest at lower densities, juvenile crabs survival was apparently quite high. These artificial collectors may provide protection from predation, not experienced at natural settling sites.

We suggest a plausible hypothesis for the persistent recruitment failure would include a combination of effects. A linear relationship of larval settlement to variable eggs/pelagic larval survival coupled with depensatory predation of age 0 & 1 juvenile crabs could provide a plausible mechanism for the large recruitment peaks as well as the persistent recruitment failure. Large increases in settled age-0 crabs could satiate benthic predators causing high survival rates to be associated with high densities of juvenile crabs. Potential predators on young crabs include various finfish, such as Pacific cod, various flatfish, halibut, and the starfish, *Pycnopodia helianthoides*. The fish species have shown continued increase in biomass in the Gulf of Alaska over the past two decades and parallel a decrease in the abundance of red king crab. The starfish has recently been identified as capable of preying on juvenile red king crab (Personal communication, Braxton Dew, NMFS, Kodiak). Although relative abundance trends of this species have not been monitored, its distribution is limited to the Gulf of Alaska and does not extend significantly into the range of red king crab in the Bering Sea (Kessler, 1985). This animal is also a food source of pod sized and adult red king crab as observed by Powell(1979) and Dew (1990). Historic biomass levels of large crabs in the near shore areas may have depressed this population sufficiently to limit its impact on juvenile crabs recruitment. The difference in recruitment in red king crab in the Bristol Bay population in the Bering Sea in recent years when compared with the Gulf of Alaska could plausibly be explained by this mechanism whereas most of the other fish species which would be potential predators, have shown parallel increases in the Bering Sea. Large settlements of larval crabs may be required to provide adequate recruitment to overcome large populations of benthic predators. The lack of supporting data on the dynamics and inter-annual trends in abundance of predator and prey suggests this hypothesis is highly speculative.

Production level rehabilitation activities are clearly premature as we must first define what component of early life history limits production. If larvae are reared and released at their first benthic stage, very poor survival may result if high mortality occurs during that juvenile stage. Primary factors affecting recruitment remain unknown but can be reasonably confined to the early life history, although we have postulated a mechanism where adult abundance may affect a predators abundance.

Rejection of feasibility of enhancement activities are also premature for the same reason. Although marine decapod crustacean culture has yet to achieve economically viable returns in any area (from other presentations at this symposium), much of the effort has been used in developing larval culture, rather than enhancement of juvenile survival.

To further understanding of the recruitment process, culture of late instar zoeae or early instar juvenile crabs with tags could be released following experimental protocol (multiple tags would be highly valuable). Variables could include time of release, habitat at release site (including potential predator abundance), density of crabs at release site, and instar and/or larval stage of release. Relative recruitment rate of tagged animals with different treatments would be used as testing criteria. In the absences of cultured tagged animals, juvenile crabs collected by artificial collectors may be released following an experimental protocol into natural habitats where populations of potential predators are controlled by exclosures. Survival rates during the first two years of growth could be monitored within and outside of the exclosures.

Without an experimental approach further progress is unlikely because of the long term commitment and cost of monitoring natural variations in recruitment. Lack of replicates would potentially lead to false conclusions based on spurious correlations. In addition to the value of such an approach to providing potential rehabilitation strategies, such data would provide potentially useful data on harvest strategies for adult crabs. Koslow(1992) addressed the problem of development of management strategies for many highly fecund marine populations from stock-recruitment relationships. He concluded,"..for many marine populations the SR relationship may not be definable or may also be defined with such broad limits as to be of little value as the basis for management. Research into the recruitment process may point the way toward more appropriate population models."

REFERENCE

ADFG (Alaska Department of Fish and Game) 1991. Westward region shellfish report to the Alaska Board of Fisheries. ADFG. Div. Comm. Fish., Kodiak. AK.

Armstrong, D. L., L. Incze, D. Wencker, and J. Armstrong. 1983. Distribution and abundance of decapod crustacean larvae in southeastern Bering Sea with emphasis on commercial species. Final Rept. to NOAA/OCSEAP Contract No. NA81-RAC-00059, RU609.

Blau, S.F. 1985. Overview and comparison of the major red king crab (*Paralithodes camtschatica*) surveys and fisheries in western Alaska (1969-1984). Pages 23-47 *In* Proc. Intl. King Crab Sympos. Univ. Alaska, Alaska Sea Grant Rpt. 85-12.

Blau, S.F. 1986. Recent declines of red king crab (*Paralithodes camtschatica*) populations and reproductive conditions around the Kodiak Archipelago, Alaska. Pages 360-369 *In* Can. Spec. Publ. Fish. Aquat. Sci. 92, Ottawa.

Blau, S. F. , W.E. Donaldson, and S.C. Byersdorfer. 1990. Development of artificial collectors for late larval through early benthic stages of red king and Tanner crabs. Ak. Dept. Fish and Game, Div. of Comm. Fish. , Reg. Info. Rpt 4K90-29. ADFG, Comm. Fish Div., Kodiak, AK.

Blau, S. F. , S.C. Byersdorfer, D.C. Schmidt, W. E. Donaldson and B.A. Johnson. 1992 (In press). First-year indexing of postlarval red king crab abundance by use of artificial collectors in Chiniak Bay, Alaska, 1990. Alaska Dept. Fish and Game, Div. Comm. Fish. Tech. Fish. Rpt., Juneau, AK

Dew, C. B. 1990. Behavioral ecology of podding red king crab, *Paralithodes camtschatica*. Can. J. Aquat. Sci. 47:1944-1958.

Donaldson, W. E., S. Byersdorfer, D. Pengilly, and S.F. Blau. 1992 (In Press). Growth of red king crab in artificial habitat collectors at Kodiak, Alaska. Accepted for publication by Journal of Shellfish Research, January, 1992.

Kessler, Doyne W. 1985. Sea stars, p. 179-213. *In* Doyne W. Kessler [ed.] Alaska's saltwater fishes and other sea life. Alaska Northwest Publ. Co., Anchorage, AK.

Koslow, J. Anthony. 1992. Fecundity and the stock-recruitment relationship. Can. J. Fish. Aquat. Sci. 49:210-217.

McMurray, G. A.H. Vogel, P.A. Fishman, and D. A. Armstrong. 1981. Distribution of larval and juvenile red king crabs (*Paralithodes camtschatica*) in Bristol Bay. U.S. Dep. Commer., NOAA, OSCEAP Final . 53(1986) :479-878.

Powell, Guy 1979. Stars for kings. Sea Frontiers (25) 5:282-285.

Powell, G.C. , B. Shafford, and M. Jones. 1972. Reproductive biology of young adult king crabs *Paralithodes camtcshatica* (Tilesius) at Kodiak, Alaska. National Shellfish. Assoc. 63:77-87.

Rounds, P. M. , C. Broderson and M. M. Babcock. 1990. Effects of cohort density and habitat on survival and growth of juvenile red king crab, (*Paralithodes camtcshatica*) p 209-218. *In* Proceedings of the international symposium on king and tanner crabs, Anchorage, Alaska, USA, November 28-30, 1989. Lowell Wakefield Fisheries Symposia Series, University of Alaska, Alaska Sea Grant Rep. 90-04. Univ. of Alaska, Fairbanks, AK.

Royer, T.C. 1989. Upper ocean temperature variability in the northeast pacific ocean: Is it an indicator of global warming? J. Geophys. Res. 94:18175-18183.

Royer, T.C. 1992. Possible high latitude climate forcing by 18.6 year luni-solar tide. Unpublished manuscript. IMS, Univ. of Alaska, Fairbanks, AK

Sause, B. L. , D. Gwyther, and D. Burgess. 1987. Larval settlement, juvenile growth and the potential use of spatfall indices to predict recruitment of the scallop *Pecten alba* Tate in Port Phillip Bay, Victoria, Australia. Fish. Res., 6:81-92.

Schmidt, D. and S. F. Blau. 1986. King crab research - Kodiak Management Area annual report to the Alaska Board of Fisheries. Pages 318-329 *In* Westward Region shellfish report to the

Alaska Board of Fisheries, Div. Comm Fish., Alaska Dept. Fish & Game, Kodiak.

Shirley, T.C and S.M. Shirley. 1990. Planktonic survival of red king crab larvae in a subarctic ecosystem, 1985-1989. p. 263-285. *In* Ziemann, D.A. and K. W. Fulton-Bennett [eds.] APPRISE-Interannual variability and fisheries recruitment. The Oceanic Institute. Honolulu, HI.

Frieze, J. L. and M. M. Babcock. 1990. The utility of artificial substrate collection devices to determine time and location of red king crab (*Paralithodes camtcshatica*) glaucothoe settling in Auke Bay, Alaska. p. 119-130. *In* Proceedings of the international symposium on king and tanner crabs, Anchorage, Alaska, USA, November 28-30, 1989. Lowell Wakefield Fisheries Symposia Series, University of Alaska, Alaska Sea Grant Rep. 90-04. Univ. of Alaska, Fairbanks, AK.

Takeuchi, I. 1962. On the distribution of zoea larva of king crab, Paralithodes camtschatica, in southeastern Bering Sea in 1960. Bull. Hokkaido Reg. Fish. Lab. 24:163-170.

Takeuchi, I. 1968. On the distribution of zoea larva of king crab, Paralithodes camtschatica, in southeastern Bering Sea in 1957 and 1958. Bull. Hokkaido Reg. Fish. Res. Lab. 34:22-29.

United States Department of Commerce, NMFS NOAA (USDC) 1981. Fisheries of the Unites States, 1980. April 1981. 119 pp.

Wolotira, R., J.E. Munk, and J. Bowerman. 1984. Season distribu tion and abundance of decapod larvae for the Kodiak Island region. Northwest and Ak. Fish. Center Processed Rpt. 84-01. 167 pp.

Proc. Int. Crab Rehab. & Enh. Symp.
Jan. 1992, Kodiak, Alaska

A REVIEW OF ENERGY SOURCES FOR FIRST FEEDING RED KING CRAB LARVAE

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ABSTRACT

The results of studies in Auke Bay, Alaska indicated that some diatom taxa are important energy sources for first feeding king crab larvae and that they were not adept at capturing crustacean prey. The type of phytoplankton dominating the bloom during the hatching period was important in determining daily growth rates of the zoeae. During the spring bloom in Auke Bay, Thalassorsira was found to exist in an adequate abundance to support growth of first-feeding zoeae while Skeletonema and Chaetoceros were poor foods. Hatching concurrently with the spring phytoplankton bloom, water column stability, and starting to feed when suitable diatom taxa are abundant enough, are important factors affecting growth. The timing of egg hatch vs. the existence of the proper community structure of the spring plankton community probably plays an important role in larval recruitment of king crab. Additional study needs to be done in the northern Gulf of Alaska and the Bering Sea. The results of the Auke Bay experiments occur in two papers:

Paul, A. J. J, M. Paul & K. O. Coyle. 1989. Energy sources for first-feeding zoeae of king crab Paralithodes camtschatica (Tilesius) (Decapoda, Lithodidae). J. Exp. Mar. Biol. Ecol. 130: 55-69.

Paul, A. J. J, M. Paul & K. O. Coyle. 1990. Growth of stage I king crab larvae of Paralithodes camtschatica (Tilesius) (Decapoda, Lithodidae) in natural communities. J. Crust. Biol. 10: 175-183.

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REARING RED KING CRABS FROM THE FIRST BENTHIC STAGE

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ABSTRACT

Red king crabs (Paralithodes camtschaticus) are relatively easy to maintain in captivity after they have reached the first benthic stage. If they are supplied with running, high-quality seawater, and if they are isolated from each other to prevent cannibalism, crabs can be held for at least 2 years with high survival and with growth as fast as that of wild crabs. Modified salmon-egg incubators are convenient for holding small crabs. Cannibalism is a serious barrier to rearing large numbers of red king crabs, since isolating crabs from each other is not practical for more than a few hundred crabs. Preventing crowding and providing protective cover reduce cannibalism; providing a high-growth diet reduces it more. Blue mussels (Mytilus trossulus) are excellent food for rearing small numbers of captive red king crabs, but may be impractical for mass rearing because of the labor involved in shucking them before use or removing the shells afterwards. Shrimp, squid, and some fish support slower growth. Crabs >1 g can kill and eat very small (≤15 mm) blue mussels and echinoderms nearly as large as themselves. Crabs offered a choice of foods eat blue mussels and kelp first, and fish last. They eat shrimp shell and also their own cast molts. Rearing huge numbers of young king crabs will require consistently high-quality seawater and the development of an inexpensive diet that supports good growth and controls cannibalism.

INTRODUCTION

During nearly 20 years of oil toxicity studies and crab habitat requirement work, Auke Bay Fisheries Laboratory (ABL) personnel have maintained red king crabs (Paralithodes camtschaticus) of all ages in the laboratory for periods up to 2 years. We have learned a lot about holding and rearing king crabs that would help anyone designing methods to rear large numbers of juvenile red king crabs for experimental work or eventually for stock enhancement. I present here a series of observations on rearing the young crabs after they have settled.

Rearing Juvenile Red King Crabs in the Laboratory

Juvenile red king crabs are much easier to raise than the larvae and glaucothoe. Two factors make it possible to hold juvenile crabs indefinitely with a minimum of effort: a source of running, high-quality (uncontaminated, consistent salinity) seawater; and individual holding containers for each crab to prevent cannibalism.

Most juvenile king crabs reared at ABL have been collected either by hand from the low intertidal area in the winter or spring following their hatching and settlement, or by divers when they were 1-3 years older. They have generally been held in running seawater, at ambient temperature (4-12°C, depending on season), ambient salinity (29-30‰), and under ambient light, unless experimental conditions required something else. They have been held in all kinds of tanks, and in groups and isolated from each other. One of the most convenient holding containers for small juveniles has been salmon-egg incubators, with the egg baskets divided with perforated PVC strips into as many as 20 compartments for individual crabs (Arasmith et al. 1989). Many of these crabs fed, survived, molted, and were active in the laboratory for as many months or years as we had them. Juvenile crabs fed on a good laboratory diet, especially one including a lot of blue mussels (Mytilus trossulus), have consistently been at least as large as same-age crabs measured in the wild.

Three crabs that were brought into the lab as first benthic stage crabs 1½ years ago are still doing well. These were crabs that had settled as glaucothoe onto artificial substrate collectors deployed in Auke Bay to determine when and where settlement occurs (Freese and Babcock 1989). Because these crabs were <2 mm in carapace length at collection, they were maintained at first in beakers that received running seawater through siphons; they were moved to salmon-egg incubators 6 months later, when they were 6-8 mm long. From the beginning, they were fed mostly small blue mussels on the half shell, occasionally augmented with bits of sea urchin, seastar, and kelp.

This small group of king crabs demonstrated that cannibalism is a problem with communal holding of juvenile crabs at least as young as Stage IV. Four were originally collected, and two shared a single beaker until one ate the other when the latter molted to crab Stage IV after 2½ months in captivity. (Cannibalism is also common in groups of 1- to 2-year-old king crabs, and king crab larvae are extremely prone to feeding on each other.)

This group of king crabs also demonstrates that our rearing methods work for crabs as young as first crab stage as well as they do for the slightly older crabs we routinely maintain in the laboratory. Their growth and molting records are shown in Figure 1. Note that these crabs are as large as or larger than crabs of the same age measured in the field near where the captive three were collected. Molting and growth rates of juvenile king crabs are strongly related to temperature (Rice et al. 1985; Stevens 1990); that effect can be seen in Figure 1 by comparing the seasonal temperatures of the lab water to the crabs' growth curves. Growth is faster when the water is warmer. If the laboratory crabs had been warmer than the wild crabs for much of their first year, they could have grown faster whether their diet and health were as good as that of the wild crabs or not, but that is not the case here. The intake for the lab seawater is

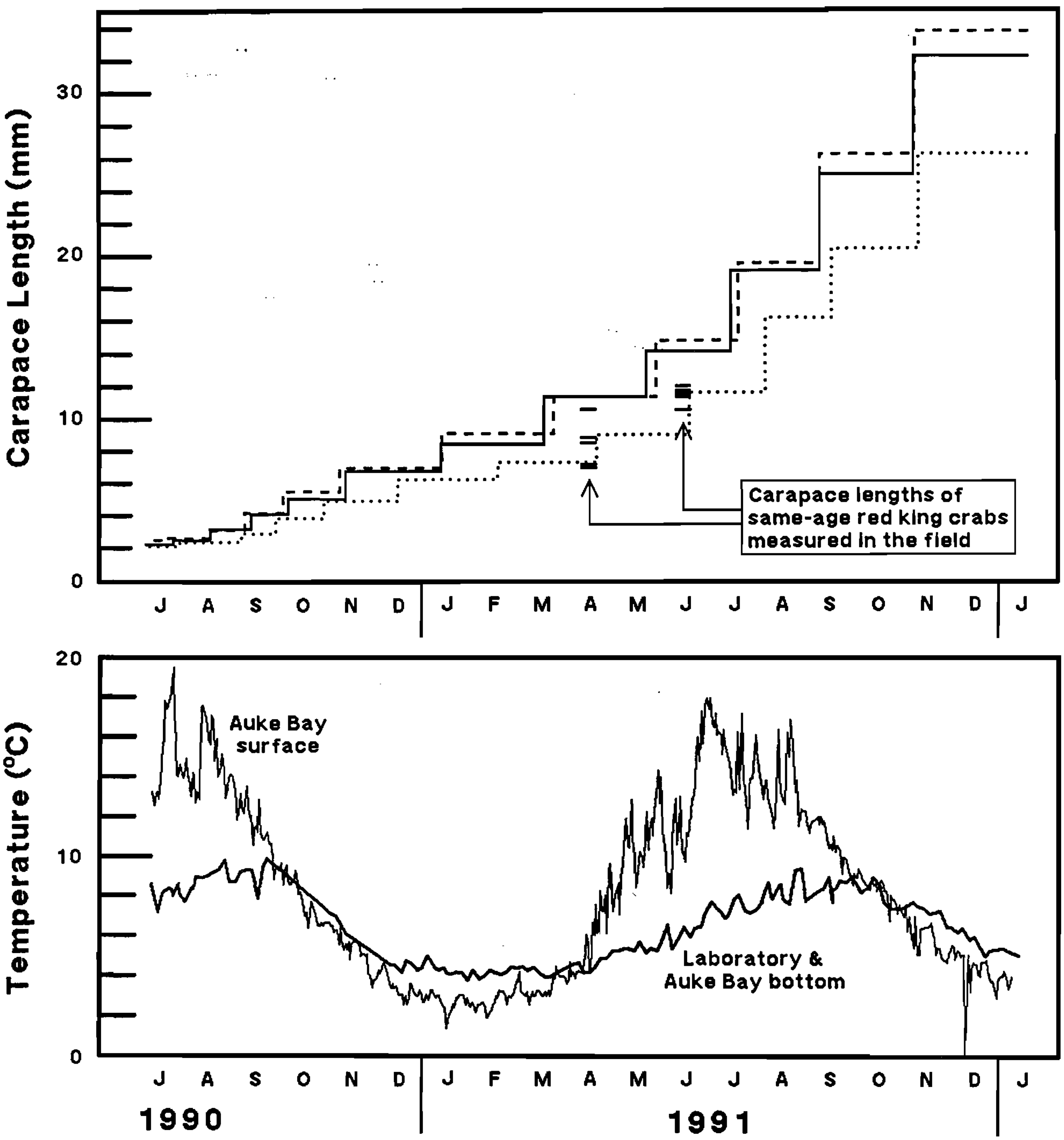
Carapace Length (mm)
30
20
10
0
Carapace lengths of
same-age red king crabs
measured in the field
J A S O N D J F M A M J J A S O N D J
Temperature (°C)
20
10
0
Auke Bay
surface
Laboratory &
Auke Bay bottom
J A S O N D J F M A M J J A S O N D J
1990
1991

Figure 1

30 m below the surface of Auke Bay, where the temperature differs only slightly from that of the running water in the crab incubators. Note that the surface temperatures of Auke Bay (B. L. Wing, NMFS Auke Bay Fisheries Laboratory, unpublished data) are considerably warmer in summer and only a little colder in winter than the bottom (intake and laboratory) temperatures. Juvenile crabs in shallow subtidal areas of Auke Bay are exposed to temperatures between the surface and bottom temperatures, and probably are warmer than the laboratory-held crabs more often than they are colder. Thus, the living conditions we are providing for the laboratory crabs are as good as those of their wild cohorts, or they would not have similar growth rates.

Two major hurdles must be crossed before juvenile red king crabs can be reared on a large scale. One is controlling cannibalism, because it is impractical to maintain more than a few hundred crabs in individual containers. The other is choosing a diet that not only supports good growth, but is cheap and requires minimum labor for preparation, feeding, and cleanup.

Controlling Cannibalism

It appears that preventing crowding and providing cover for crabs to hide in should decrease cannibalism, and this is true to some degree. If 1- or 2-year-old king crabs are offered a choice of substrates, they spend the most time where there is the most cover, and the least time in the open (Rice and Babcock 1989). "Plant" assemblages (either bryozoans and hydroids or plastic aquarium plants) are preferred over cobbles (5-10 cm rocks), shell hash, or shale (1-3 cm pieces), which are preferred over open sand. And if large and small groups of 1-year-old crabs (11 and 3 crabs/group) are maintained for 20 weeks in tanks with sand, cobble, or plastic plant substrates, the larger groups on open sand eat each other more (45%) and the smaller groups in the plants eat each other less (0) than any of the other combinations do (14-36%) (Rice and Babcock 1989).

However, the effect of diet on the amount of cannibalism (Brodersen et al. 1989) is more distinct than the effects of cover and density. A diet of blue mussels supports faster growth in king crabs than a diet of shrimp (commercial Panaeus monodon); after 22 weeks on the two diets, crabs eating blue mussels were 1.4 times as long (carapace length) and 2.5 times as heavy (live weight) as crabs eating the shrimp. When groups of 10 crabs each were fed blue mussels for 112 d, a mean of only 8% were eaten by their tankmates, while 45% of those fed shrimp were eaten (Figure 2). When the diets were reversed (those eating shrimp were switched to blue mussels and vice versa), the trends in cannibalism reversed as well. Moreover, augmenting a shrimp diet with king crab helped; isolated juvenile crabs fed blue mussels have about the same molt rate as groups of crabs fed blue mussels, whereas isolated crabs on shrimp have much longer and

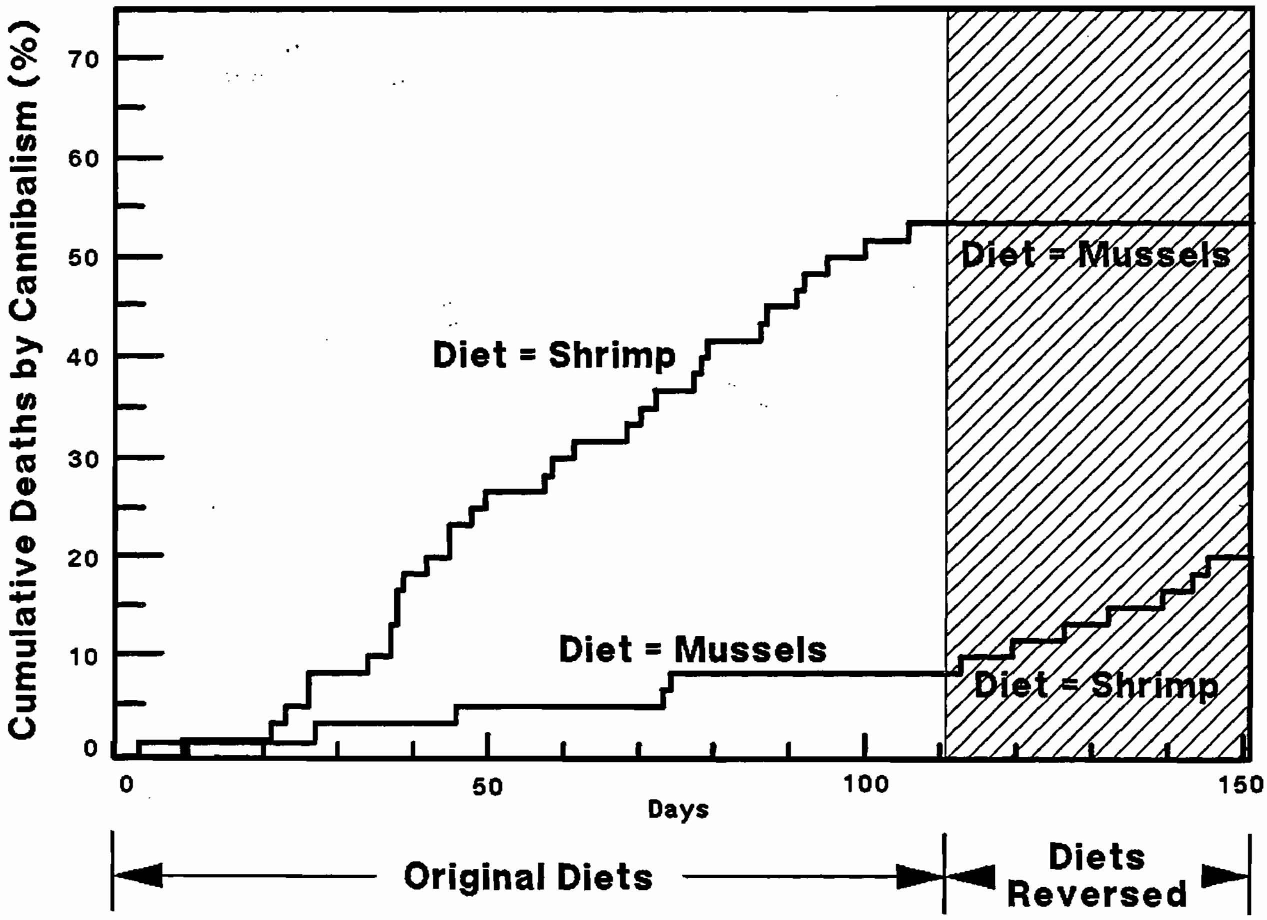
Cumulative Deaths by Cannibalism (%)
0
10
20
30
40
50
60
70
0
50
100
150
Days
Diet = Shrimp
Diet = Mussels
Diet = Mussels
Diet = Shrimp
Original Diets
Diets Reversed

Figure 2

more variable intermolt periods than groups of crabs eating shrimp and each other.

Diets

Red king crabs are omnivorous opportunists that eat all kinds of foods in the wild (Jewett and Feder 1982; Pearson et al. 1984; Fukuhara 1985), and they accept and survive on a wide variety of food items in the laboratory. However, their growth rate varies greatly depending on what they are fed (Brodersen et al. 1989; Rice and Babcock 1989). Figure 3 shows the wide range of growth rates of juvenile king crabs in three different studies, each of which had diet as a variable. Blue mussels support the fastest growth of the single-item diets we have tried at the Auke Bay Laboratory. A mixed diet including blue mussels was next, followed by a straight diet of shrimp tails, then herring. (Herring is a poor laboratory food because of its oiliness, and is associated with mortalities despite supporting a reasonable growth rate.) All the tested diets kept juvenile king crabs alive for many weeks, but crabs fed only kelp or not fed at all did not molt. Eight nonfed crabs survived 14 weeks; six were alive and active at the end of the 16-week study. The growth rate that a diet supports in king crabs is clearly more meaningful than whether the diet simply keeps the crabs alive.

If 1-year-old red king crabs are given a choice of opened blue mussels, pieces of six-rayed seastar (Leptasterias hexactis), shrimp (Pandalus platyceros) tails, halibut (Hippoglossus stenolepis) meat, or kelp (Laminaria), the first items consumed are usually the blue mussels and the kelp. The shrimp meat and the fish are eaten least. The crabs often eat substantial amounts of the shrimp shell, however, and will eat their own cast molts as well if they are allowed access to them long enough; they eat virtually nothing for 2-3 d before and after molting. They will also break off bits of blue mussel shell, and at least some of it is ingested, as evidenced by the blue color occasionally seen in their feces.

Red king crabs >1 g (>11-mm carapace length) can prey on live echinoderms about their own size in laboratory enclosures. They readily eat tar spot sea cucumbers (Cucumaria vegae) and six-rayed seastars (L. hexactis), as well as green sea urchins (Strongylocentrotus drobachiensis)--spines and all--although it often takes several days of shortening the spines before the crabs can break into the urchin's body. They don't kill the prey first, they just eat it. (When these crabs eat each other, they start eating before the victim is dead as well.) They can also open and eat small mussels, about as long as their own carapace.

Prerequisites for Large-Scale Rearing of Juvenile King Crabs

Any facility for rearing king crabs must be situated where high-quality seawater is available at all times. Not only should the water be uncontaminated, but it should have stable salinity

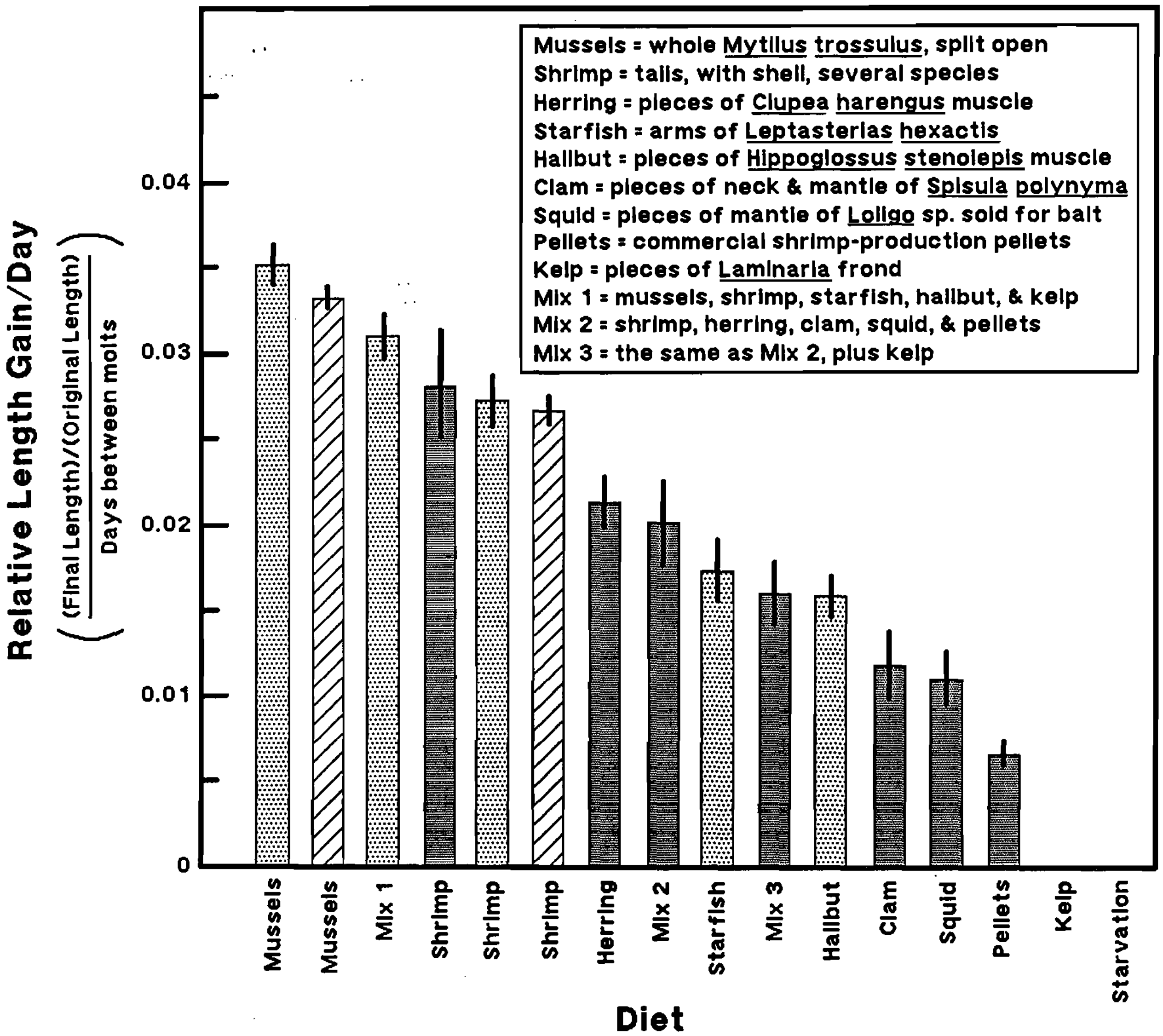
Mussels = whole Mytilus trossulus, split open
Shrimp = tails, with shell, several species
Herring = pieces of Clupea harengus muscle
Starfish = arms of Leptasterias hexactis
Halibut = pieces of Hippoglossus stenolepis muscle
Clam = pieces of neck & mantle of Spisula polynyma
Squid = pieces of mantle of Loligo sp. sold for bait
Pellets = commercial shrimp-production pellets
Kelp = pieces of Laminaria frond
Mix 1 = mussels, shrimp, starfish, halibut, & kelp
Mix 2 = shrimp, herring, clam, squid, & pellets
Mix 3 = the same as Mix 2, plus kelp
Relative Length Gain/Day
(Final Length)/(Original Length)
Days between molts
0.04
0.03
0.02
0.01
0
Mussels
Mussels
Mix 1
Shrimp
Shrimp
Shrimp
Herring
Mix 2
Starfish
Mix 3
Halibut
Clam
Squid
Pellets
Kelp
Starvation
Diet

Figure 3

(near 30‰) year round and should have minimum daily and tidal fluctuations in temperature.

Research is required to determine an appropriate diet for rearing crabs. Foods that support growth rates at least as fast as natural growth should be selected. Labor costs for obtaining the food, serving it to the crabs, and cleaning up uneaten portions must be considered. A method of preventing excessive losses from cannibalism also must be developed; however, diet is one of the most promising possibilities for controlling cannibalism, and this is another important consideration in diet development. The use of some live food should be considered, because it can be made available to crabs without risk of spoilage, and because some practice at predation, however artificial, could only be an advantage to crabs destined for release into the wild.

REFERENCES

Arasmith, P. J., C. C. Brodersen, and M. M. Babcock. 1989. Convenient method for maintaining small crabs in isolation. Progressive Fish-Culturist 51:243-246.

Brodersen, C. C., P. M. Rounds, and M. M. Babcock. 1989. Diet influences cannibalism in laboratory-held juvenile red king crabs (<u>Paralithodes camtschatica</u>). Pages 377-382 <u>in</u> Proceedings of the International Symposium on King & Tanner Crabs. Alaska Sea Grant College Program Report 90-04, University of Alaska, Fairbanks.

Freese, J. L., and M. M. Babcock. 1989. The utility of artificial substrate collection devices to determine time and location of red king crab (<u>Paralithodes camtschatica</u>) glaucothoe settling in Auke Bay, Alaska. Pages 119-130 <u>in</u> Proceedings of the International Symposium on King & Tanner Crabs. Alaska Sea Grant College Program Report 90-04, University of Alaska, Fairbanks.

Fukuhara, F. M. 1985. Biology and fishery of southeastern Bering Sea red king crab (<u>Paralithodes camtschatica</u>, Tilesius). NWAFC (Northwest and Alaska Fisheries Center) Processed Report 85-11. National Marine Fisheries Service, Seattle WA.

Jewett, S. C., and H. M. Feder. 1982. Food and feeding habits of the king crab <u>Paralithodes camtschatica</u> near Kodiak Island, Alaska. Marine Biology 66:243-250.

Pearson, W. H., D. L. Woodruff, and B. J. Higgins. 1984. Feeding ecology of juvenile king and tanner crab in the southeastern Bering Sea. Pages 155-265 <u>in</u> OCSEAP (Outer Continental Shelf Environmental Assessment Program), Research Unit 624, Final Report 53 (1986). NOAA (National Oceanic and Atmospheric Administration), Office of

Oceanography and Marine Assessment, Ocean Assessments Division, Anchorage AK.

Rice, S. D., C. Brodersen, and P. J. Arasmith. 1985. Feeding rates, molting success, and survival of juvenile red king crabs at different temperatures. Pages 187-192 in Proceedings of the International King Crab Symposium. Alaska Sea Grant Report 85-12, University of Alaska, Fairbanks.

Rice, S. D., and M. M. Babcock. 1989. Effects of habitat and environmental variables on red king crabs, and settling of glaucothoe. Pages 49-53 in L. E. Jarvela and L. K. Thorsteinson, editors, Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting. OCS (Outer Continental Shelf) Study, MMS 89-0041. NOAA (National Oceanic and Atmospheric Administration), Office of Oceanography and Marine Assessment, Ocean Assessments Division, Anchorage AK.

Stevens, B. G. 1990. Temperature-dependent growth of juvenile red king crab (*Paralithodes camtschatica*) and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences 47:1307-1317.

Figure Legends

Figure 1.--Growth of three red king crabs maintained in the laboratory after being collected in Auke Bay as Stage I crabs through Stage XII. Sizes of five red king crabs of the same age measured in the field on 16 April 1991, and six measured on 14 June 1991, are indicated.

Figure 2.--Cumulative deaths attributable to cannibalism among groups of 10 1-year-old red king crabs. Six groups were fed split whole blue mussels, and six groups fed shrimp (*Panaeus monodon*) tails, for 274 d; then the diets of each group were reversed for 40 d more. Adapted from Brodersen et al. 1989.

Figure 3.--Growth rates of 1-year-old red king crabs maintained in the laboratory on different diets in three different studies. Rates are for one intermolt period; carapace length attained at one molt is divided by length at previous molt (giving a relative growth rate, to compensate for slightly different initial sizes of crabs), then divided by number of days between molts. Bars with the same hatching indicate crabs in the same study. Foods in Mix 1 were all served together (although crabs were not allowed to run out of food, they often finished individual food items, particularly the blue mussels); mixes 2 and 3 were served in rotation, 3 d on each item. Error bars are standard errors of means.

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THE BEHAVIORAL ECOLOGY AND SPATIAL DISTRIBUTION OF RED KING CRAB AND OTHER TARGET SPECIES: IMPLICATIONS FOR SAMPLING DESIGN AND DATA TREATMENT

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ABSTRACT

We present information on the behavior and distribution of juvenile red king crab (Paralithodes camtschaticus), as determined from diver counts and observations, and from monitoring the long-term movements of sonic-tagged crab in a 490-hectare bay near Kodiak, Alaska. The data from in-situ counts of organisms at 116 dive-stations were used to calculate four measures of nonrandomness for the distributions of Age 0-1 red king crab (RKC01), Age 2-4 red king crab (RKC24), and six other invertebrate species. We determined that all distributions of species individuals were contagious (vs. random), and the degree of contagion measured for RKC was greater than that for other dominant epibenthic species. Interpretation of data from sonic-tagged crab aggregations revealed that RKC continued their highly aggregative podding behavior until at least Age 5, notwithstanding seasonal variations in depth, habitat usage, mobility, dispersion, mixing, and cohort (year-class) integrity of the aggregations. We discuss the statistical implications of sampling contagious distributions, and we make recommendations as to sampling designs and the data treatment required if estimates of precision and comparisons of target-species abundance among years are to be statistically valid.

INTRODUCTION

The Kodiak Island Borough, in order to provide enlightened support for proposals to artificially enhance red king crab (RKC) populations, should know whether or not the long-term effects of releasing hatchery-reared, Age-0 RKC into the marine environment can be measured with some reasonable degree of precision. In order to accomplish a meaningful evaluation of the effects of enhancement, we would need to estimate, for a series of years, the mean density of RKC target populations within plus or minus 10-20 percent, with a 1-in-20 chance of being wrong. The overall objective of this study is to assess the practicality of such a goal and to provide information on the behavior and distribution of juvenile RKC to be used in assembling the elements of a sampling program to evaluate the effects of future enhancement efforts.

Sampling programs to assess annual change in the densities of biological populations are occasionally designed and implemented without adequate knowledge or consideration of the behavioral ecology and the spatial distribution of the target species. If a target species were distributed either uniformly or randomly throughout a geographical area, then representative sampling could be accomplished with a low-density, simple (unstratified), random or uniform sampling design. But true random distributions are rarely a characteristic of biological populations, and spatially uniform distributions are virtually nonexistent (Ludwig and Reynolds 1988). The most common pattern of distribution is the nonrandom, contagious or clumped distribution where individuals of a population are aggregated in dense patches whose areas are small relative to the entire area to be sampled (Elliot 1977). Although investigators can assume that the individuals of most epibenthic, marine species will be distributed nonrandomly, they need to know something about the degree of nonrandomness for each target species prior to implementing a long-term sampling program. The degree to which individuals of a species population are distributed nonrandomly has direct bearing on the number of samples required to obtain any given level of precision for estimates used to test hypotheses of yearly change in the abundance of that population. Preliminary sampling is a recommended way to gain first insight into the degree of nonrandomness that will be present for the duration of a long-term survey.

The importance of preliminary sampling is probably the most neglected aspect of field studies (Green 1979). This paper presents data from a 17-month pilot survey designed to provide quantitative information on the spatial distribution patterns for juvenile (up to Age 5) RKC and several associated organisms in a semi-enclosed bay (Womens Bay) near Kodiak, Alaska. The information presented here should be considered in the design of a sampling protocol to evaluate local changes in juvenile RKC abundance in relation to future population enhancement efforts.

METHODS

Field Sampling

During this 1990-91 exploratory pilot survey by scuba divers, individual organisms of target species were counted in situ and percentage estimates were made of overlying cover and substrate types at 116 dive-stations distributed throughout Womens Bay, a semi-enclosed, 490-hectare bay near Kodiak, Alaska. A discriminant analysis of these data, described in detail by Dew (1991), showed that Womens Bay was composed of three distinct habitat types or strata (Spit, Mid-Bay, and Dock strata), as defined by 14 biological and physical attributes. Inasmuch as the primary emphasis of this study was on RKC, relatively greater sampling effort was directed to strata where aggregations of RKC had been observed in previous studies (e.g., Dew 1990). Unequal sampling fractions among strata resulted in an estimated areal coverage of approximately 4% for the Spit stratum (20% of total effort, 5% of total area), approximately 1% for the Mid-Bay stratum (59% of total effort, 91% of total area), and approximately 5% for the Dock stratum (21% of total effort, 4% of total area).

Because the starting location for each dive and the underwater course followed by the divers was heavily dependent on wind, weather, tidal currents, and bottom terrain, each sampling unit (estimated area covered in a single dive) was drawn from a stratum in a pseudo-random, representative fashion (Caulcutt 1991). The randomness of our sampling of target species within strata was enhanced by the fact that several target species were mobile and moved at will into and out of our small sampling units between dive dates. Each sampling unit was drawn during that time-segment of a census dive when all encountered organisms of target populations were counted. All counts were recorded on writing slates during the dive. Depth profiles were recalled from diver-carried computers that recorded depth at 3-minute intervals during a dive. Organism counts were converted to density values expressed as the catch (number of organisms counted) per 10-minute unit of counting effort (CPUE). Correlations between unstandardized counts and standardized CPUE ranged from 0.93 to 0.99 for the eight species-groups considered, and the actual counts of individual organisms were used for all analyses in this paper.

In addition to 116 census dives, 61 dives were conducted during this study to observe and to collect carapace-length data from RKC aggregations that were tracked for up to 25 months using sonic-tagged "bellwether" crab and diver-carried, directional receivers. These in-situ observations and collections, in addition to 122 surface-triangulated position fixes for tagged crab, provided data with which to quantify seasonal variations in depth, habitat usage, mobility, dispersion, mixing, and cohort (year-class) integrity of the aggregations. Annual records of water temperature were available from continuous-recording underwater thermographs located on the bottom of Womens Bay at mean lower low water depths of 1 m, 9 m, and 13.5 m.

Data Analysis

Data analysis focused on the detection and measurement of spatial patterns of distribution for species individuals within the Womens Bay community. Several pattern-detection indexes can be calculated from typical survey data, and it is generally recommended that the collective information from more than one index be used to detect the presence and assess the degree of nonrandomness for a species (Pielou 1977; Ludwig and Reynolds 1988). The simplest is an index of dispersion (ID), calculated as the ratio of the variance (s^2) to the mean ($\bar{u}$) of sample counts for a species:

$$ID = \frac{s^2}{\bar{u}} \quad . \qquad \text{(Eq.1)}$$

For a uniform distribution the variance is less than the mean ($s^2 < \bar{u}$), and the value of ID for a maximally uniform distribution is 0. For a random distribution the variance equals the mean

($s^2 = \bar{u}$), and therefore ID equals 1. For a contagious distribution the variance is greater than the mean ($s^2 > \bar{u}$), and the value of ID for a maximally contagious distribution is n, or the total number of species individuals in all samples. Because the maximum value for ID is n, the degree of contagion estimated by ID is biased upward for collections with a greater n. A better measure of the degree of contagion is Morisita's departure from randomness (MI) (Vandermeer 1981), an index expressing the ratio of actual to random expectations (equivalent to Lloyd's 1967 index of patchiness), calculated as:

$$MI = \frac{n}{n-1} * \frac{\bar{u} + \frac{s^2}{\bar{u}} - 1}{\bar{u}} = \frac{n}{n-1} * \frac{\bar{u} + ID - 1}{\bar{u}} \quad . \qquad \text{(Eq.2)}$$

The only index whose value for maximum contagion is independent of n, and therefore the most suitable index for comparing the degree of contagion for distributions of unequal n, is Green's Index (GI) (Elliot 1977; Ludwig and Reynolds 1988):

$$GI = \frac{\frac{s^2}{\bar{u}} - 1}{n-1} = \frac{ID - 1}{n-1} \quad . \qquad \text{(Eq.3)}$$

The range of GI is from -1/(n-1) for a maximally uniform distribution to 1 for a maximally contagious distribution. A value of GI = 0 is obtained for a random distribution. In addition to these three indexes, Dew (1991) pointed out that a dominant species which is present at a small proportion of stations is distributed nonrandomly, and that relative niche breadth is therefore a measure of the degree of nonrandomness for the more abundant species in a species-station matrix. Relative niche breadth (RNB) is calculated as

$$RNB = \frac{-\sum(pLogp)}{LogN} \quad , \qquad \text{(Eq.4)}$$

where p is the proportion of n for a species at each sampling station, and N is the total number of stations. RNB is Shannon's habitat diversity or species' niche breadth, expressed as a proportion of maximum diversity possible for a given number of stations, N.

The d-statistic (variance-to-mean ratio test) was used to test for significant departures of ID from 1.0 (departures from randomness):

$$d = \sqrt{2\chi^2} - \sqrt{2(N-1) - 1} \quad . \qquad \text{(Eq.5)}$$

If $|d| \leq 1.96$, agreement with a Poisson series is accepted. If $d > 1.96$, a contagious distribution is likely. The BASIC programs POISSON.BAS and NEGBINOM.BAS (Ludwig and Reynolds 1988) were used to calculate the d-statistic and to test fits of the Poisson and negative binomial models to Womens Bay data.

RESULTS AND DISCUSSION

Species Distributions: Random or Contagious?

Large-scale patterns of environmental heterogeneity should serve notice to investigators that individuals of species populations will be unevenly or nonrandomly distributed throughout the area to be sampled, and that an unstratified random, uniform, or systematic sampling design will not be the most efficient way to sample the area. Womens Bay is composed of three geographically separate habitats (or strata), as defined by 14 biological and physical habitat attributes (Dew 1991), and the data in Table 1 show that individuals of dominant species were distributed unevenly across these three habitats. For example, 96% of the counted Age 0-1 RKC (RKC01) were found in the nearshore dock habitat, representing only 4% of the total bay area. Age 2-4 crab (RKC24) were more evenly distributed among habitats but, inasmuch as none were collected from the Spit stratum, their distribution appeared to be nonrandom also.

For Age 0-1 crab, an unstratified design would allocate approximately 4% of the sampling effort to the area where 96% of the total observed population was located, and 91% of the effort to the area where 0.5% of the population was located. The same unstratified design would be somewhat more efficient for the Age 2-4 target population. In general, the efficiency of an unstratified random or unstratified systematic design decreases as a function of the nonrandomness of the target-population distribution, and Elliot (1977) says "...the more efficient method of stratified random sampling is always preferable to simple random sampling." It is therefore important to obtain some idea of the degree of nonrandomness for the distribution of each target population prior to deciding the level and spatial allocation of sampling effort.

Table 1. Percentage of total number of organisms, by species, collected at three habitats in Womens Bay.

% Total Area	4.9	91.0	4.1
Habitat	Spit	Mid-Bay	Docks
RKC01 (0-24 months)	3.5	0.5	96.1*
RKC24 (24-60 months)	0.0	43.7	56.3*
E. troschelii	20.0	12.3	67.7*
Metridium senile	13.7	42.4	43.9*
Asterias amurensis	0.2	99.7*	0.1
Tanner Crab	7.4	62.4*	30.2
Telmessus Crab	11.1	40.1	48.8*
Pycno. helianthoides	48.3*	24.2	27.5

* Habitat where species was most abundant.

To compare the degree of nonrandomness among dominant species, four measures of nonrandomness (Eq.1-4) were calculated for two age classes of RKC and six other species, which together composed 97.6% of the 60,868 organisms counted during the 17-month underwater census in Womens Bay. The results (Table 2) demonstrate that the distributions of RKC were the most contagious of the seven species. For example, the contagion measured by MI (Eq.2) for Age 0-1 crab was 30.7 times that expected for a random distribution. The influence of n on ID (Eq.1) is apparent from the fact that it was the only index whose ranking (left to right, Table 2) was inconsistent with that of other indicators (e.g., the degree of contagion indicated by ID, because of a larger n for RKC24, was greater for RKC24 than for RKC01). *Metridium senile*, a sessile anemone that was the most abundant of those organisms enumerated in Womens Bay, had the widest niche breadth (RNB=0.93, Eq.4) and a GI (Eq.3) value of 0.009, suggesting a random distribution. Subsequent testing led to rejection of the hypothesis of a random (Poisson) distribution for *M. senile*.

It is relatively straightforward to calculate indexes of dispersion and RNB, and these measures are useful for comparisons of the relative degree of nonrandomness among species. However, as noted above for *M. senile*, more rigorous methods are required to test the formal hypothesis that a specific distribution is either random or contagious. If a distribution is random, then a frequency distribution of the number of individuals per sample will not differ significantly from a Poisson distribution, where $s^2 = \bar{u}$ (ID = 1.0). The d-statistic (Eq.5) was used to test for significant departures of ID from 1.0. Based on the d-statistic values in Table 2, all of which are greater than 1.96, the hypothesis of a random distribution for any of the dominant species in Womens Bay was decisively rejected. This conclusion was verified by chi-square tests for goodness-of-fit to the Poisson distribution. For all species, chi-square values showed that the probability of fitting the species' frequency distributions to a Poisson distribution was less than 1 in 10,000 ($P < 0.0001$). Additional goodness-of-fit testing showed that data from all but two species classes (RKC01 and *Asterias amurensis*) fit a negative binomial distribution, which is the most commonly used probability distribution for clumped, contagious, or aggregated populations (Elliot 1977).

Table 2. Spatial pattern analysis for dominant species at 116 stations in Womens Bay. Species classes ranked (left to right) by decreasing contagion of distribution.

	RKC01	RKC24	Asterias	Tanner	Telly	Et	Pycno	Metrid
Total(n)	5892	11619	2912	2101	2196	6760	2366	25550
Mean	50.8	100.2	25.1	18.1	18.9	58.3	20.4	220.3
Variance	77241	152831	7787	2389	2098	7582	634	52862
ID	1521	1526	310	132	111	130	31	240
MI	30.7	16.1	13.2	8.2	6.8	3.2	2.5	2.1
GI	0.26	0.13	0.11	0.06	0.05	0.02	0.01	0.009
RNB	0.37	0.46	0.58	0.74	0.75	0.83	0.88	0.93
d-statistic	576	577	252	159	145	158	69	220
Poisson Fit	No	No	No	No	No	No	No	No
Neg Binom Fit	No	Yes	No	Yes	Yes	Yes	Yes	Yes
	--	0.04	--	0.31	0.31	0.49	0.66	1.37
1/k	--	24.9	--	3.2	3.2	2.0	1.5	0.73

The exponent k, a parameter of the negative binomial distribution, tends toward ∞ for a random distribution and toward 0 for a maximally contagious distribution. The reciprocal of k (1/k) is a measure of the excess variance or clumping of the individuals in a population (Elliot 1977). For each Womens Bay species whose distribution fit the negative binomial, estimates of k were calculated by solving the maximum-likelihood equation (Elliot 1977) by iteration. Inspection of the estimates of k and 1/k in Table 2 shows that clumping was high for RKC24 and low for M. senile, which was consistent with the relative degree of contagion established by ID (Eq.1), GI (Eq.2), MI (Eq.3), and RNB (Eq.4).

Dynamics of Contagious Distributions

Thus far we have established that the distributions of all dominant epibenthic macro-organisms in Womens Bay were contagious, that the degree of contagion was greatest for RKC, and that six of the eight distributions examined could be described with the negative binomial model. A primary objective of this preliminary survey was to detect and measure spatial patterns of species in the community. However, because the analysis data were collected over a 17-month period, the resulting 8 x 116 species-station matrix was an end-product of temporal as well as spatial change. Short-term temporal change is not likely to be an important factor in the analysis of spatial patterns for sessile organisms such as M. senile; but it might be important to the interpretation of spatial pattern analysis for a highly mobile species whose activity level changes seasonally, or a species which undergoes a systematic behavioral change during the course of a survey.

Age 0-1 Red King Crab (RKC01)

A description of the behavioral ecology of RKC01 (Dew 1990) indicates that young crab, during their first 18-20 months of life, are distributed as individuals rather than as groups of crab. In the fall of their second year, podding behavior begins and, for at least the next few years, RKC exist predominantly as age-specific aggregations rather than as individuals.

For the class RKC01 (Age 1-24 months), the effect of this transition from an individual to an aggregated distribution, during the period of the survey, can be seen from the chi-square values in Table 3. The greatest deviation between the observed frequencies and those predicted by the negative binomial model were for samples where a single crab was encountered during a dive. The model predicted that there should be only 6 (5.95) dives versus the actual 16 dives in which a single RKC01 was encountered. The discrepancy between model prediction and reality may reflect the behavioral transition that occurred within the class RKC01 during the 17 months of the survey. This suggests that we should stratify species of interest into classes (e.g., RKC0 and RKC1) that, through time, are more homogeneous with respect to behavior.

The failure of the negative binomial model to predict the frequency of individually-distributed RKC01, in contrast to the relatively good agreement between observed and expected frequencies for other (x) categories (Table 3), suggests the hypothesis that planktonic RKC larvae settle to the bottom in a non-contagious, random distribution. The early phases of such a distribution would not be detected with our observational sampling methods because the crab at this point are tiny and cryptic. During the two-year period after settlement, our hypothesized random distribution apparently evolves, as observed below for RKC24, into a negative binomial distribution, perhaps as the end-product of crab movement and habitat-specific mortality rates.

Table 3. Chi-square test to determine if the frequency distribution for underwater counts of Age 0-1 red king crab (RKC01) conforms to the negative binomial distribution.

Number Per Dive (x)	Observed Frequency (Fx)	Expected Frequency (Ex)	Chi-Square (Fx-Ex)^2/Ex
0	65	65.00	0.00
1	16	5.95	17.00*
2	6	3.24	2.35
3	3	2.25	0.25
4	2	1.74	0.04
5	0	1.42	1.42
6	0	1.20	1.20
7	1	1.05	0.00
>=8	23	34.15	3.64
Totals	116	116.00	25.90

Total Chi-Square = 25.90, with df = 6

Not significant @ P<0.001 (Crit. Value = 12.59)

* Area of greatest departure from expectation

Age 2-4 Red King Crab (RKC24)

To obtain information on temporal changes in distribution for RKC24, the movements of two consecutive year-classes (cohorts) of RKC24 (Age 25-60 months) were followed during 1990-92 by means of sonic tags attached to crab carapaces. Primary objectives of sonic tracking were

1) to determine if RKC continue to pod after Age 1-2, which was a question left unanswered by Dew (1990)

2) to determine seasonal variations in depth, high-usage habitats, mobility, dispersion and mixing characteristics, and cohort integrity for aggregations of RKC24.

Sonic tags were affixed to crab of the 1987 cohort in February 1990 and to crab of the 1988 cohort in October 1990. These crab were tracked until February 1992 (i.e., for 25 months and 17 months, respectively). During January-February 1992, when the 1987 cohort was about to turn Age 5, all tagged crab shed their tags in a mass, synchronous molt and tracking ended. Each of 61 daytime dive observations during the 1990-92 tracking period revealed that tagged crab of both cohorts were among large, dense aggregations, variously estimated at 100 to 3000 crab. These observations confirm that RKC continue their highly aggregative podding behavior after Age 2 until at least Age 5.

The tracks of tagged crab are shown in Figs.1-2. Early in the study, a common track was drawn for the single tag marking each aggregation. During the latter part of the study, multiple tags were used, and a track was drawn for each tag. Common features of all tracks include

1) overwintering (November-March) in relatively shallow water, frequently in the vicinity of complex vertical structure in the form of nearshore dock pilings;

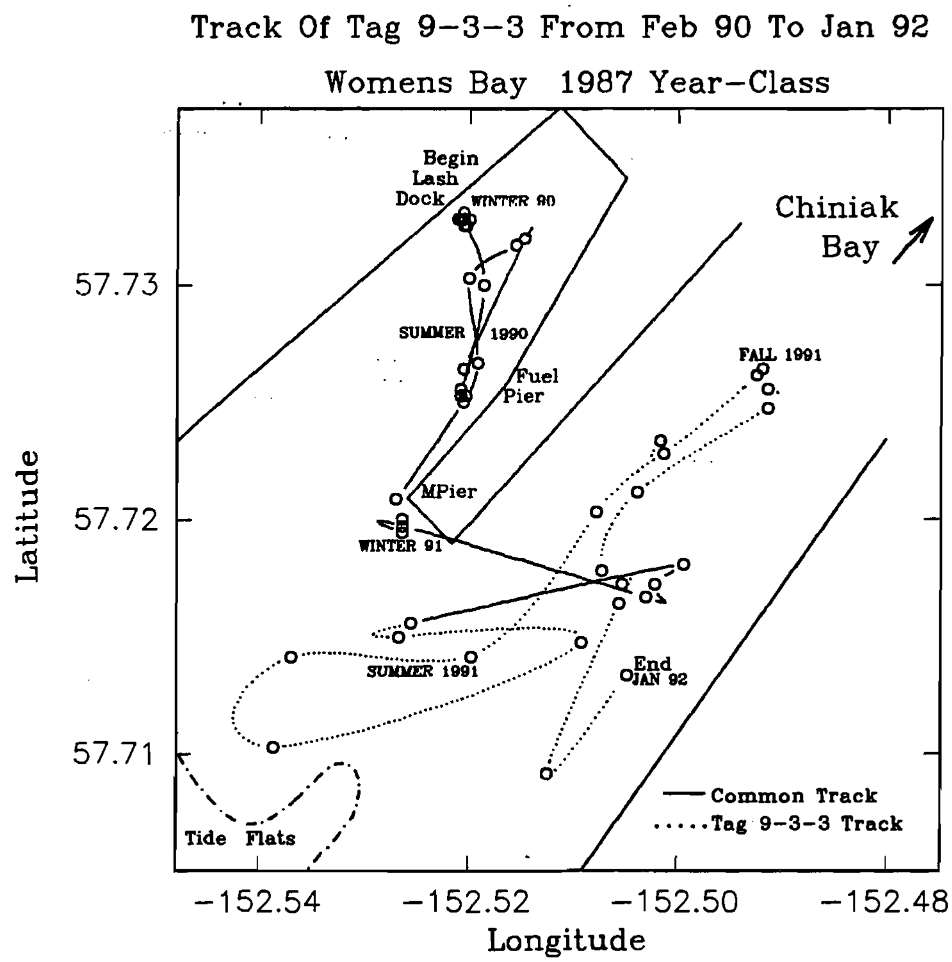
2) a similar spring-summer (April-June) circuit across the inner arm of the bay, through which the crab aggregations spent some time at all of the major dock structures in Womens Bay;

3) at a similar point near the mouth of Womens Bay, aggregations halted their late summer-fall (July-October) movement toward the cooler water of Chiniak Bay and reversed course, thus remaining to overwinter in Womens Bay.

The depth at which crab aggregations were located was a function of water temperature and crab age. In general, crab moved from shallower to deeper water 1) as they grew older (Fig.3A) and 2) as water temperatures increased each spring (Fig.3B). The relationship between crab depth and water temperature was least pronounced (r^2=0.07) for the oldest crab because these crab were now in deeper, more temperature-stable water all year-round.

Similar to the age-temperature effect observed for the depth of crab aggregations, an age-temperature effect also existed for the mobility (meters travelled/day) of crab aggregations. Aggregations of older crab moved greater distances per day than aggregations of younger crab (Fig.4A), but seasonal temperatures also influenced crab mobility. During winter and early spring, crab aggregations were almost immobile and could be found within a relatively small area for months at a time. Mobility increased after April and reached a definitive peak of 100-120 m/day in October, when water temperatures had recently begun a decline from their August-September highs (Fig.4B).

Figure 1


Track Of Tag 9-3-3 From Feb 90 To Jan 92
Womens Bay 1987 Year-Class
Begin
Lash
Dock
WINTER 90
Chiniak
Bay
SUMMER 1990
FALL 1991
Fuel
Pier
MPier
WINTER 91
SUMMER 1991
End
JAN 92
Tide Flats
Common Track
Tag 9-3-3 Track
57.73
57.72
57.71
Latitude
-152.54
-152.52
-152.50
-152.48
Longitude

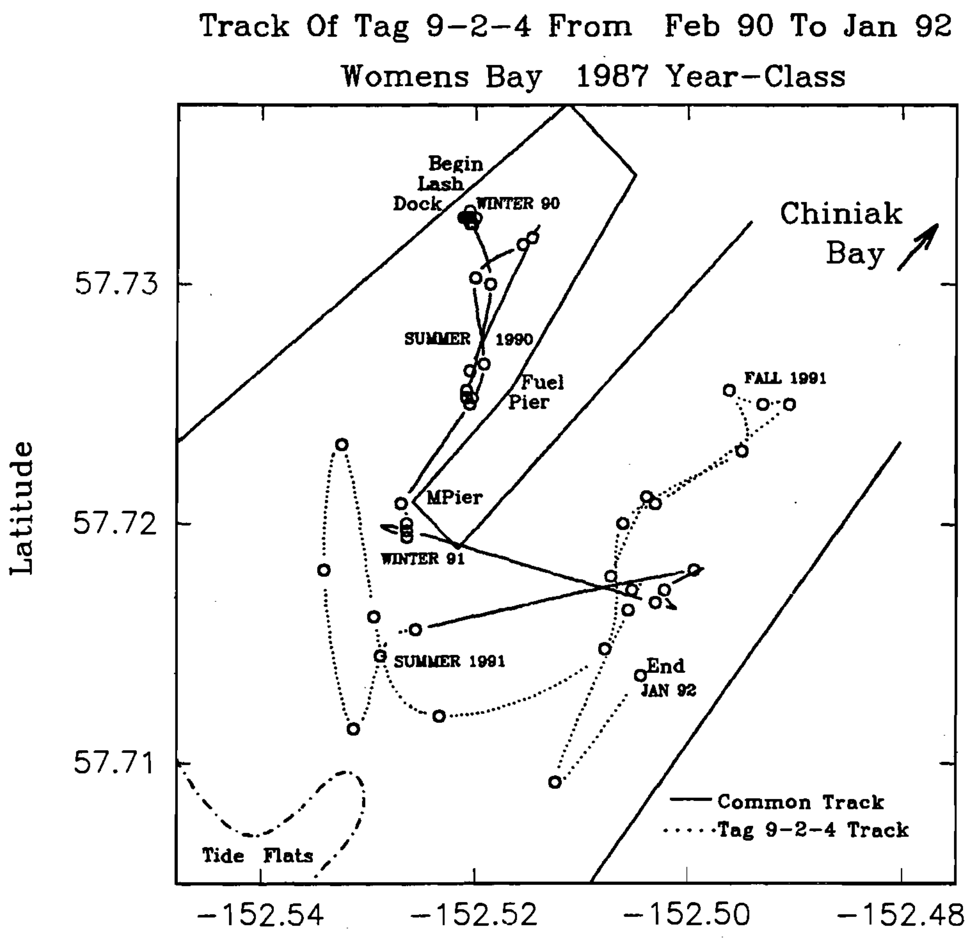
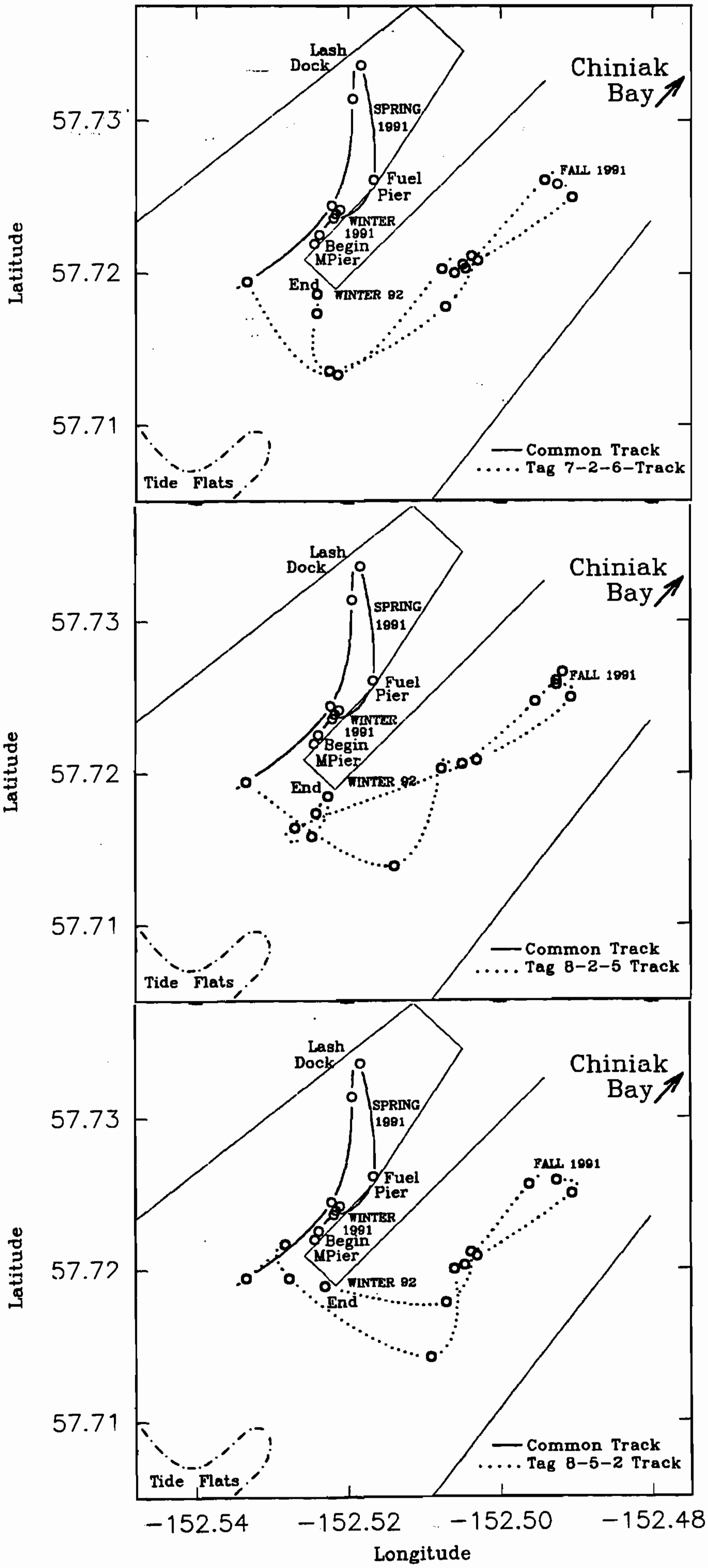

Track Of Tag 9-2-4 From Feb 90 To Jan 92
Womens Bay 1987 Year-Class
Begin
Lash
Dock
WINTER 90
Chiniak
Bay
SUMMER 1990
FALL 1991
Fuel
Pier
MPier
WINTER 91
SUMMER 1991
End
JAN 92
Tide Flats
Common Track
Tag 9-2-4 Track
57.73
57.72
57.71
Latitude
-152.54
-152.52
-152.50
-152.48

Figure 2



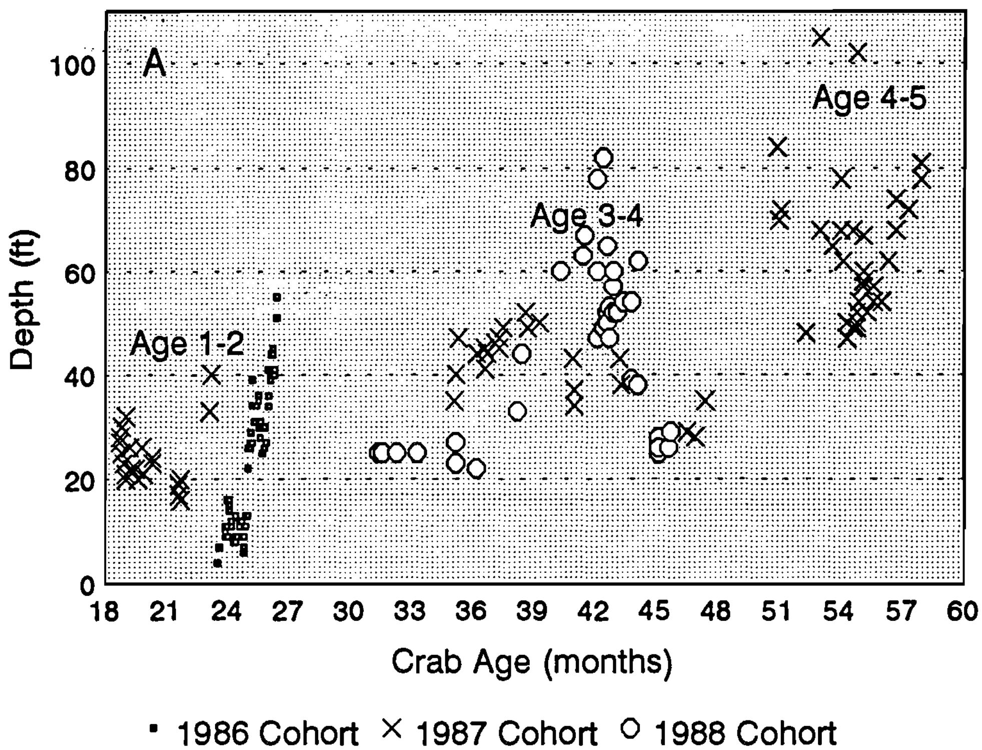
1988 Year-Class
Track Of Tag 7-2-6
Oct 90 To Jan 92

1988 Year-Class
Track Of Tag 8-2-5
Oct 90 To Jan 92

1988 Year-Class
Track Of Tag 8-5-2
Oct 90 To Jan 92

Figure 3

Increase In Depth With Crab Age



Depth of Age 1-2 crab tracked by Dew (1990)

Change In Relationship Between Depth And Temperature With Increasing Crab Age

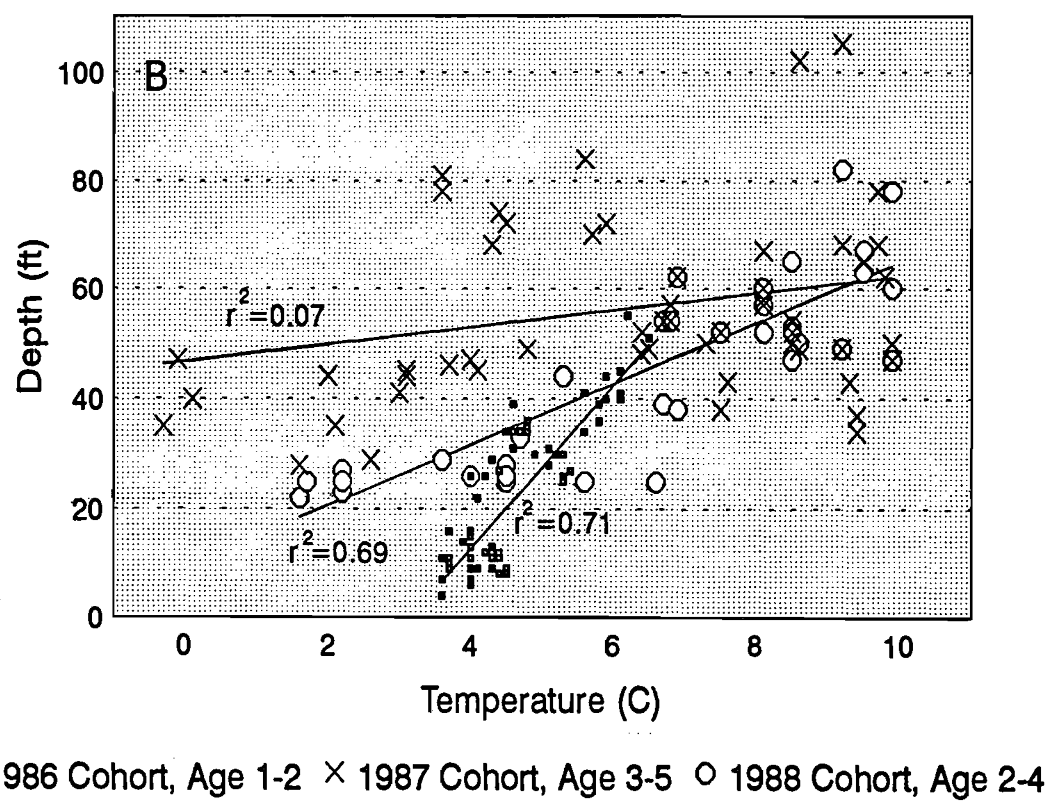
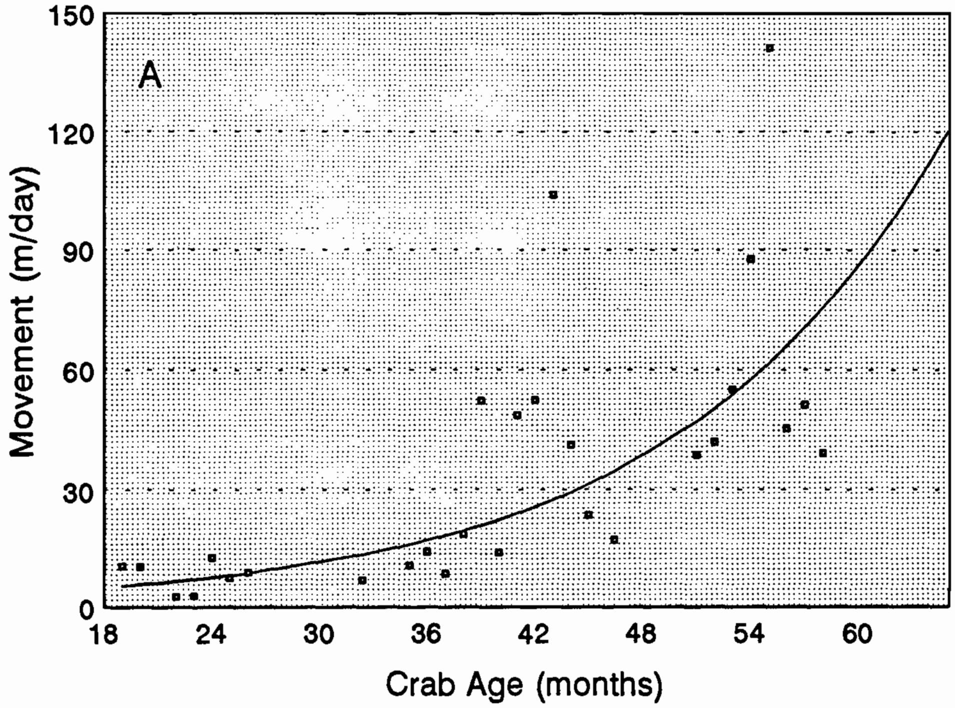
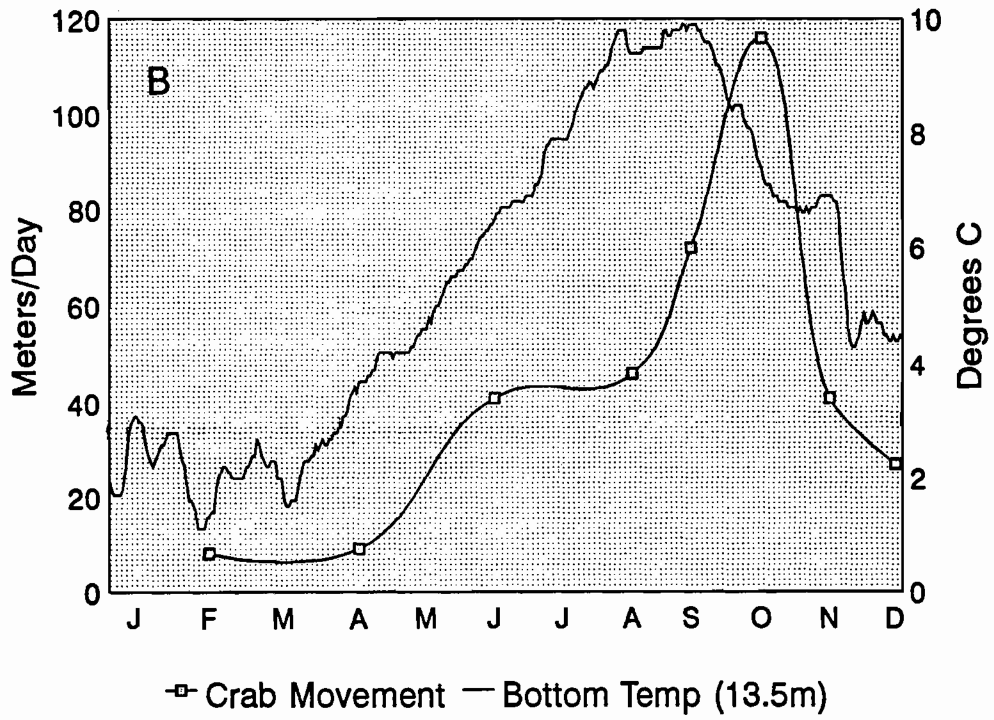


Figure 4

Relationship Between Distance Moved per Day And Crab Age



Seasonal Trend In Daily Crab Movement In Relation To Temperature



Average daily movement of sonic-tagged crab, 1987 and 1988 cohorts.

Inter-cohort and intra-cohort tag-separation distances, calculated from position-fixes of individual, sonic-tagged crab, served as estimates of separation between cohorts and within-cohort density, respectively. The ratio of between-cohort to within-cohort tag-separation distance provided an estimate of cohort dispersion and mixing potential (Table 4; Fig.5). The between:within ratio

Table 4. Sonic tag separation distance (m) between and within discrete cohort aggregations of Age 3 and Age 4 red king crab in Womens Bay. Ratio of between tag-distance to within tag-distance is a measure of separation between cohorts.

	Between-Cohort Distance(m)	Within-Cohort Distance(m) 1988	1987	Avg Ratio B:W	Log Ratio B:W	Temp (C)
17-Sep-91	526	561	310	1.32	0.1195	9.9
26-Sep-91	697	229	656	2.05	0.3122	9.2
02-Oct-91	359	278	229	1.43	0.1551	8.5
04-Oct-91	528	352	192	2.12	0.3273	8.5
10-Oct-91	113	111	113	1.01	0.0048	8.1
11-Oct-91	84	1	85	42.61	1.6295	8.1
15-Oct-91	40	1	41	20.30	1.3075	7.5
25-Oct-91	409	1	410	205.11	2.3120	6.8
07-Nov-91	490	491	1	245.53	2.3901	6.7
15-Nov-91	355	356	1	177.92	2.2502	6.9
16-Dec-91	1208	40	1	619.17	2.7918	4.5
31-Dec-91	1268	1	1	1267.79	3.1030	3.0

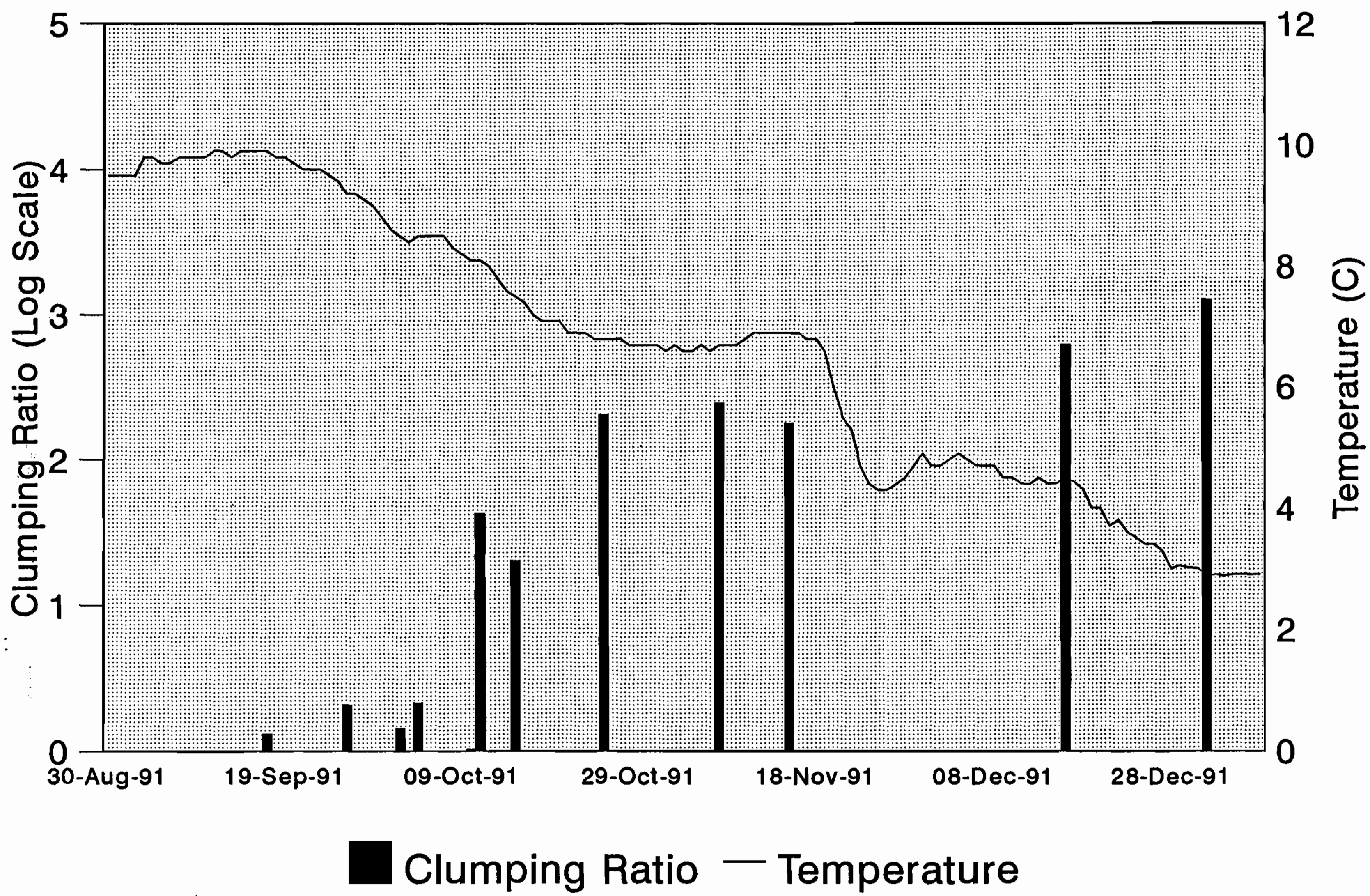
Between-cohort distance = average distance between 2 tags in the 1987 cohort and 3 tags in the 1988 cohort.
Within-cohort distance = nearest-neighbor distance + 1 (Vandermeer 1981).

tended to be low when separation between cohorts was low and within-cohort dispersion was high; i.e., when water temperatures and crab mobility were high. The ratio increased as temperatures dropped, crab mobility decreased, and separation between cohorts increased. The potential for mixing between cohorts was relatively high during September and early October (and probably during August as well) when water temperatures were 8-10°C. The mixing potential decreased rapidly after 10 October, and by mid-December the two densely-aggregated cohorts were 1200-1300 m apart, resulting in a high between:within distance ratio. These observations suggest that random samples from a RKC population might be more representative of the real population density and age-size structure if the samples were collected when water temperatures were near their seasonal maximum and when the potential for age-group mixing was greatest.

Periodic sampling by divers from both aggregations provided size-distribution data with which to assess the age-size structure of each aggregation through time (Table 5). February 1991 length-frequency data (Fig.6A), collected at the beginning of a mass molt for both cohorts, showed a mode at 50 mm (mean = 47.3 mm) for the 1988 cohort, now about a month short of Age 3, and a mode at 70 mm (mean = 64.3 mm) for the 1987 cohort (about a month short of Age 4). The percent overlap (Table 5) between cohort pre-molt

Between Cohort : Within Cohort Clumping Ratio

Ratio Of Tag Separation Distance Between And Within Cohorts

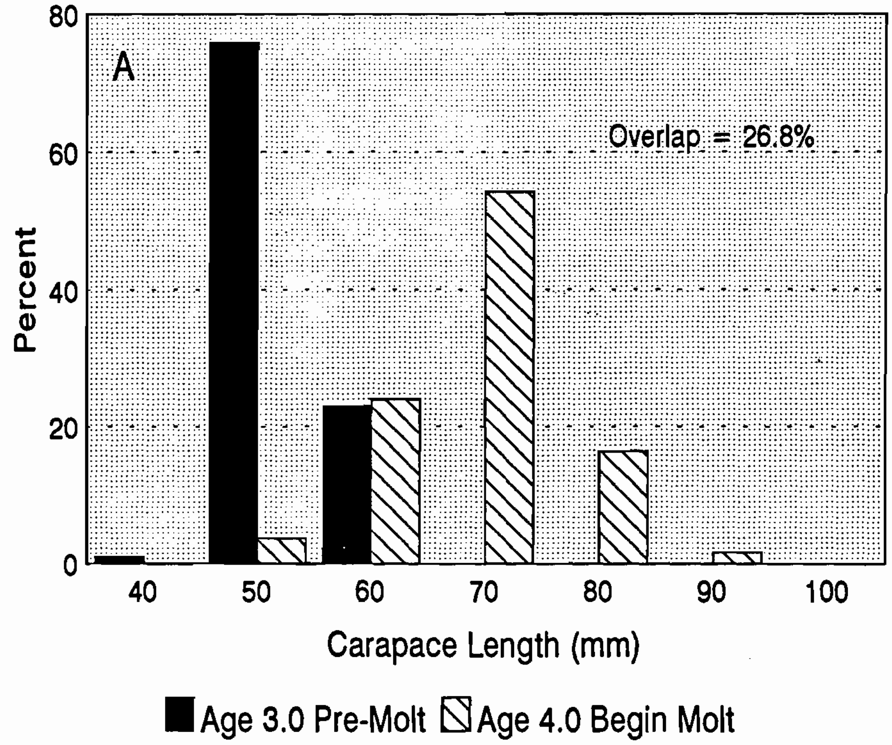


Potential for cohort mixing decreases exponentially as ratio moves above 0.

Figure 5

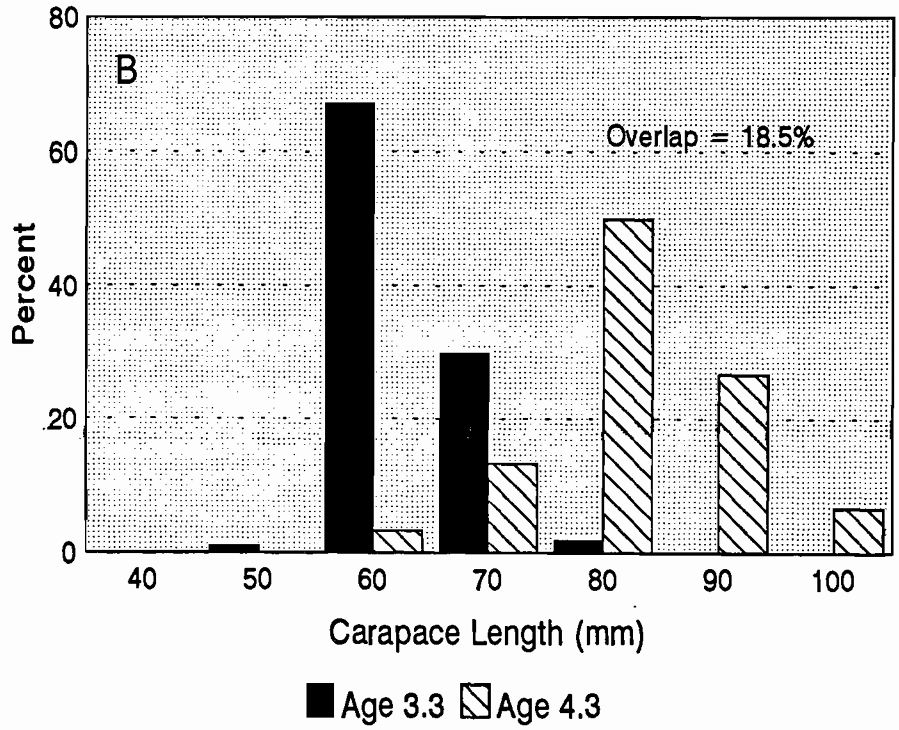
Figure 6

Size Difference Between Two Discrete Aggregations
February 1991



Distance between aggregations approx. 500m

Size Difference Between Two Discrete Aggregations
June 1991



Distance between aggregations approx. 2 naut. miles distributions was 27%. Post-molt June data (Fig.6B) showed that the modes had advanced to 60 mm (mean = 58.3 mm) for the Age 3 cohort and 80 mm (mean = 76.6 mm) for the Age 4 cohort. The percent overlap decreased to 19% (Table 5). An approximate overlap value of 34% was calculated from Weber and Miyahara (1962; Table 2) for the length distributions of three unmixed cohorts passing through the size-range 64 to 111 mm. The low amount of overlap and the location of the modes for pre- and post-molt crab in Fig.6 indicate that the two Womens Bay aggregations tracked during this study remained as discrete cohorts of Age 3 and Age 4 crab up until at least June of their fourth and fifth years of life.

Table 5. Carapace length data collected by divers separately for each of two sonic-tagged aggregations of red king crab.

	Mean CL(mm)		No. Measured		Std. Error			K-S**
	1988	1987	1988	1987	1988	1987	% Overlap*	Divergence
Feb 91	47.3	64.3	174	238	0.27	0.47	26.8	0.732
Jun 91	58.3	76.6	276	30	0.30	1.63	18.5	0.815
Oct 91	77.6	104.1	142	75	0.93	2.37	38.9	0.611
Feb 91	76.0	91.5	271	53	0.72	1.93	50.2	0.498

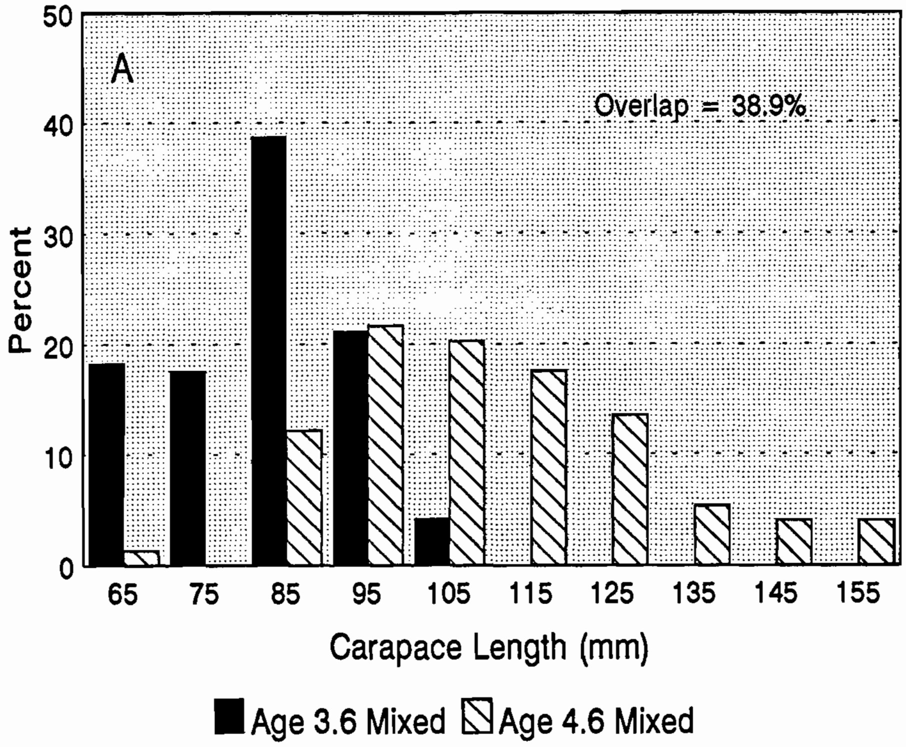
* $\%\ Overlap = \left(1 - \left[\sum\left(\frac{|p_i - p_j|}{2}\right)\right]\right) * 100$, *where p = the proportion of total crab in each length interval of distributions i, j.*

**Kolmogorov-Smirnov Divergence. Critical K-S D value < 0.153 for all comparisons. Therefore reject hypothesis of no difference between L-F distributions for the 1987 and 1988 cohorts (P<<0.001).

Little or no growth was expected to occur during the months following the mass molt observed for both cohorts in February 1991 until the next molt, which occurred as a synchronous mass molt in January-February 1992. Thus, the distinct shift in cohort modes between June (Fig.6B) and early October 1991 (Fig.7A), rather than showing growth, shows the occurrence of mixing between the two cohorts. In addition to inter-cohort mixing, there was an influx of adult crab, ranging in size from 108 to 155 mm (Fig.7A), into the Age-4 aggregation. Even with the influx of large crab into the Age-4 cohort—a factor that tended to decrease overlap between cohort length distributions—the percent overlap between distributions increased to 39% in October from 19% in June. This rather dynamic mixing of at least four age-groups of crab was observed on 1-4 October, shortly after water temperatures had reached their annual maximum in September. It also coincided with a period of sharply increased crab mobility (Fig.4B), as measured by changing latitude-longitude positions of tagged crab.

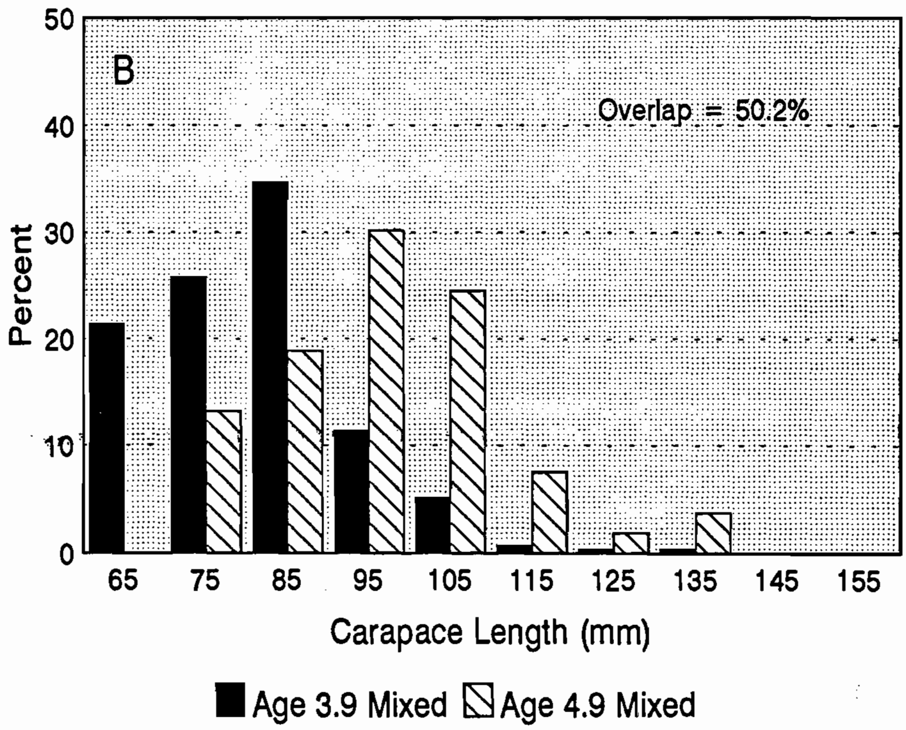
The cohort mixing observed in early October 1991 apparently was not a transitory phenomenon. Pre-molt length data from February 1992 (Fig.7B), collected as measurements of cast shells in mass-molting areas where carapace radio-tags had been shed, show that the Age-3 and Age-4 distributions remained partially mixed, with an overlap of 50%. This value is high relative to overlap values observed for

Size Difference Between Two Discrete Aggregations October 1991



Distance between aggregations approx. 400m

Size Difference Between Two Discrete Aggregations February 1992



Distance between aggregations approx. 0.6 naut. miles

February 1991 (overlap=27%) and June 1991 (overlap=19%), but it is only half of the overlap expected for completely mixed cohorts.

The fact that Age 1-2 RKC form and maintain cohesive aggregations of discrete, unmixed age-groups was reported by Dew (1990). Data from the present study in the form of tag-separation distances, multiple length-frequency plots, and more than 60 in-situ observations indicate that partial mixing between the 1988 and 1987 cohorts did not occur until after June 1991, approximately midway through the fourth and fifth years of life for these cohorts. In February 1992, when the cohorts were about to turn Age 4 and Age 5, mixing was only 50% complete.

Low-density random, uniform, or systematic sampling of a population that is contagiously distributed as discrete clumps of single-age individuals, where a densely aggregated cohort might be encountered by sampling in one or more years but missed entirely in other years, may lead to an exaggerated impression of fluctuations in year-class strength and recruitment instability. For example, Incze et al. (1986) acknowledged this sampling problem for Age 2-3 RKC in the Bering Sea, but they concluded that the disappearance of an Age-4 mode sampled in 1982, rather than being a sampling artifact, was caused by a dramatic, unexplained increase in cohort-specific mortality after 1982 that resulted in the demise of the 1978 cohort. In similar circumstances, when a dominant length-frequency mode of 80-mm RKC, estimated to be members of the 1977 cohort, appeared for the first and last time in the 1984 Bering Sea trawl survey, Stevens (1990) suggested the presence of sampling error, possibly arising from the "extreme aggregation" of these Age-7 crab.

<u>Statistical Implications Of Contagious Distributions</u>

Our preliminary 1990-91 sampling program produced data leading to the hypothesis that RKC were spatially distributed in an extremely nonrandom, contagious pattern. Additional research on the life history and behavioral ecology of RKC confirmed through sonic tracking that the appearance of this spatial pattern was not an artifact of sampling but was a real pattern, intrinsic to the species. Obviously we should not ignore a well-documented species characteristic when designing, implementing, or interpreting data from a sampling program whose objective is to measure annual levels of abundance and to determine statistically significant changes in those levels of abundance.

The population mean is the statistic used to evaluate abundance and changes in abundance. The use of parametric statistics to test hypotheses of significant difference among means assumes that the means of "large" random samples, if such samples were to be collected repeatedly from the population under study, are approximately normally distributed. Because the distribution of means from a nonnormal population will not be normal but will tend toward normality as sample size (N) increases, the requirement for "large" samples becomes more difficult to satisfy as skewness increases (Zar 1974; Sokal and Rohlf 1981). The distribution of means from populations with contagious distributions, such as that observed for RKC and for other Womens Bay species, will not approximate the normal distribution until very large sample sizes are achieved. Just how large N must be to justify the use of the normal approximation in computing confidence limits around a mean drawn from a positively skewed distribution can be calculated from Cochran's (1977) guideline formula:

$$N > 25G_1^2 ,$$

where G_1 is Fisher's measure of skewness. Use of this formula with the skewness values calculated for Womens Bay species shows, for example, that the recommended N (1137) for RKC01 (Table 6) is nearly an order of magnitude greater than the N (116) achieved by actual sampling. If the assumptions of the parametric statistical model are to be satisfied using untransformed data, the only species for which sampling effort in our pilot survey was reasonably adequate were those species whose distributions were the least skewed (i.e., M. senile, Evasterias troschelii, and Pycnopodia helianthoides).

For those species characterized by severely skewed distributions (i.e., distributions for which error variation is not homogeneous, not normally distributed, and not independent of the mean), two relatively straightforward options are open to investigators who wish to test whether observed differences in abundance between locations or time periods are statistically significant. These options are:

1) to use nonparametric statistical tests, also known as "distribution-free" tests

2) to transform the variates.

Nonparametric methods entirely avoid violation of assumptions as to distribution but, for a given sample size, they are less powerful than analogous parametric methods. As a preferred alternative to nonparametric methods, an appropriate transformation of the original data should be employed to reduce violations to a level where parametric methods may be used. As a note of caution, occasional very large catches resulting in extremely skewed distributions are to be expected when sampling a species for which dense aggregations are a species characteristic. The rejection of these very large but predictable catches as "outliers", prior to interpretation and estimation of precision of the data (e.g., Stevens et al. 1991), is not a legitimate option (Caulcutt 1991).

There are many ways to transform data, but in practice most data from samples of distributions of epibenthic organisms are transformed to $Z = \log (X + 1)$, which allows zero values to be used, whereas $\log (X)$ does not. Also $\log (X + 1)$ is a better transformation for small values (Steel and Torrie 1960; Green 1979). Green (1979) also pointed out that when the value of k in the negative binomial is 2 or less, which was true for all k-values in Table 2, the logarithmic transformation is generally applicable. Positive skewness results when most of the catches during a survey consist of zero or low numbers of organisms, and a few large catches draw out the right-hand tail of the frequency distribution. Because log-transformation affects large values more than small ones, it always produces a reduction in positive skewness and results in a transformed data distribution which more closely approaches normality.

The data in Table 6 show the effectiveness of log-transformation in reducing skewness and thereby substantially reducing the minimum sample size required to compute the confidence intervals. After transformation, only three of the eight distributions remained significantly skewed. The increase in precision resulting from log-transformation, as measured by the decrease in the width of the 95% confidence interval around the original arithmetic mean (Elliot 1977), was generally more noticeable for those species whose distributions were the most skewed (Fig.8).

According to Green (1979), the most serious violation of the assumptions of the parametric model, but a violation which can be corrected via transformation after the data have been collected, is heterogeneity of the error variances caused by a functional dependence of the variance on the mean. This violation leads to higher Type-II error rates whereby investigators conclude wrongly that there has been no change in population abundance when actually there has been a change. This type of error would tend to mask any success of population enhancement efforts. High correlation between the magnitude of means and variances is a sign of gross violation

Table 6. Relationship between skewness and sample size (N) required for use of the normal approximation in computing confidence limits. The percent reduction in skewness and N is the result of log-transformation.

	Untransformed Data		Log-Transformed Data		Percent Reduction In:	
	Fisher's	Cochran's	Fisher's	Cochran's		
	Skew	Minimum N	Skew	Minimum N	Skew	N
RKC01	6.75	1137	2.07	107	69.3	90.6
Tanner	6.61	1093	0.43*	5	93.5	99.5
A. amurensis	5.98	895	1.30	42	78.3	95.3
RKC24	4.53	513	2.36	139	47.9	72.9
Telmessus	3.81	362	0.56*	8	85.3	97.8
Metridium	2.56	164	-0.26*	2	110.2	98.8
E. troschelii	2.38	142	-0.12*	1	105.0	99.7
Pycnopodia	1.84	85	-0.21*	1	111.4	98.8

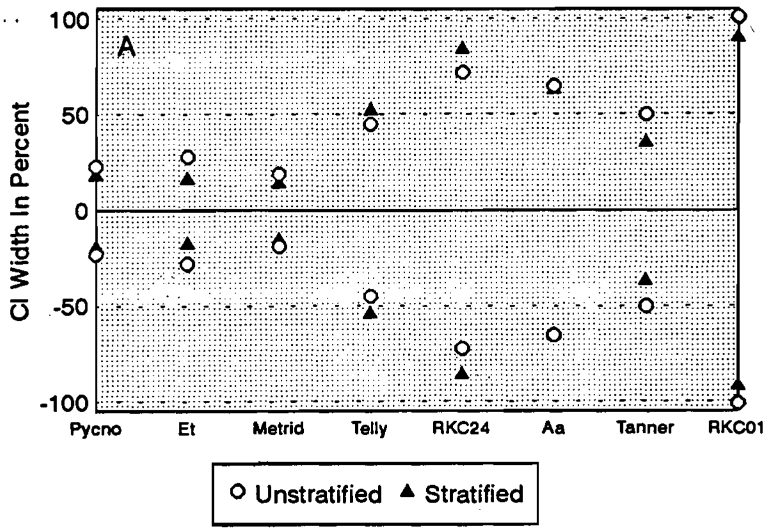
* Not significant (α=0.05)

of the assumption of homogeneity of variance. Log-transformation of the Womens Bay data reduced the mean-variance correlation for the two age classes of RKC from r = 0.995 to r = 0.776 (not signif. df=3) and, for the other six species combined, transformation

Figure 8

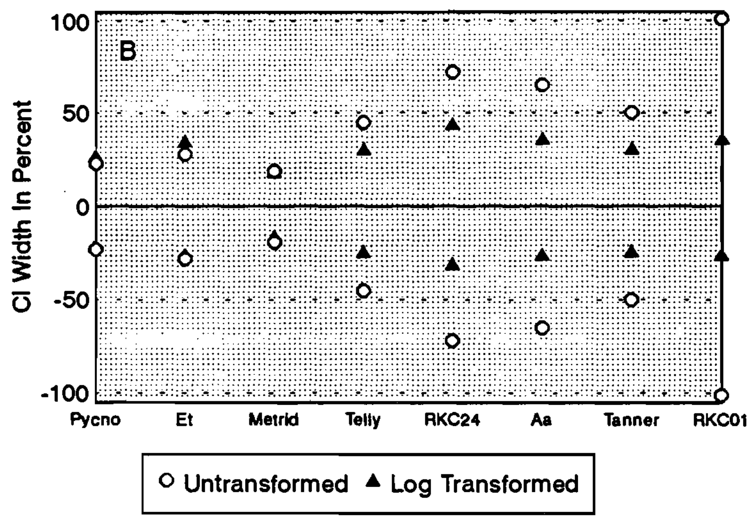
Comparison Of 95% CI For Stratified Sampling Design vs. Unstratified Design For Dominant Womens Bay Species

Untransformed Data - Species Ranked By Increasing Skew



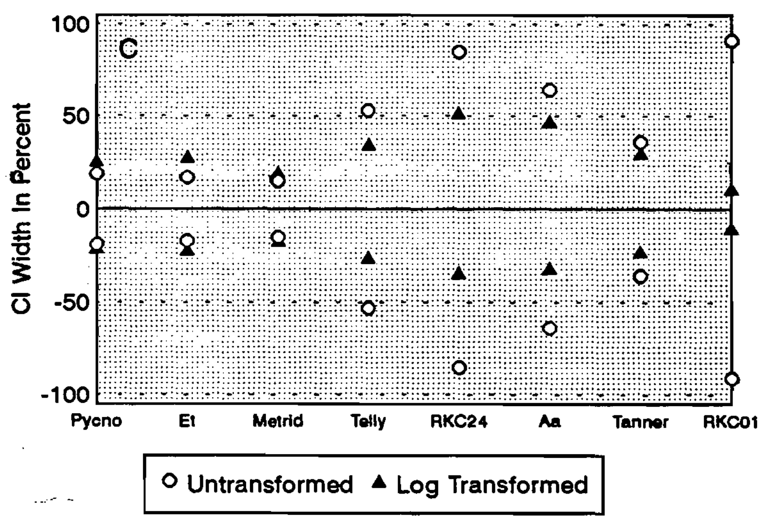
Comparison Of 95% CI For Log Transformed Data vs. Untransformed Data For Dominant Womens Bay Species

Unstratified Design - Species Ranked By Increasing Skew



Comparison Of 95% CI For Log Transformed Data vs. Untransformed Data For Dominant Womens Bay Species

Stratified Design - Species Ranked By Increasing Skew



reduced the correlation from r = 0.924 to r = 0.261 (not signif. df=16).

As opposed to being a single, homogeneous habitat, Womens Bay is composed of three geographically distinct sub-habitats, as documented by Dew (1991). Green (1979) points out that if the area to be sampled has a large-scale environmental pattern, the area should be broken up into relatively homogeneous subareas or strata, and samples should be allocated to each in proportion to the size of the stratum (uniform sampling fraction). If it is an estimate of total abundance over the entire area that is desired, Green (1979) recommends that sample allocation be made proportional to the number of organisms in each stratum (variable sampling fraction).

Because the mean-variance correlations were high for Womens Bay species, Green's (1979) advice to allocate samples in proportion to the mean number of organisms present in a stratum is roughly equivalent to an optimum allocation scheme (Cochran 1977), whereby samples are allocated to a stratum in proportion to its size and the square root of the target-population variance in that stratum (Neyman allocation). It is not advisable to attempt an optimum allocation scheme unless prior knowledge of target-population distributions has been obtained through preliminary sampling. The penalty for oversampling the wrong (least variable) strata and undersampling the most variable strata is a decrease in precision to a level which may be lower than that achieved with an unstratified design (Stuart 1968).

Stuart's (1968) warning with regard to oversampling the wrong strata highlights one of the salient rules of stratified sampling in surveys whose objective is to assess the significance of year-to-year changes in organism abundance. That is, after the initial stratum boundaries have been defined based on knowledge gained from a preliminary sampling program, stratum boundaries are not to be altered thereafter to fit each year's unique data distribution. The strata should be well-defined areas of known size (Elliot 1977), and the samples should be drawn from each stratum only after the stratum boundaries, which shall be nonoverlapping and stable in both space and time, have been defined (Cochran 1977). Annual post-stratification (Otto 1986) is a method that relies on examining the species distribution from each year's sampling survey prior to setting up transient strata specific for that year only. This procedure results in between-year comparisons of population means that are drawn each year from different strata, perhaps encompassing different habitat types. According to McConnaughey and Conquest (in review), this method is not a valid way to proceed and is not recommended.

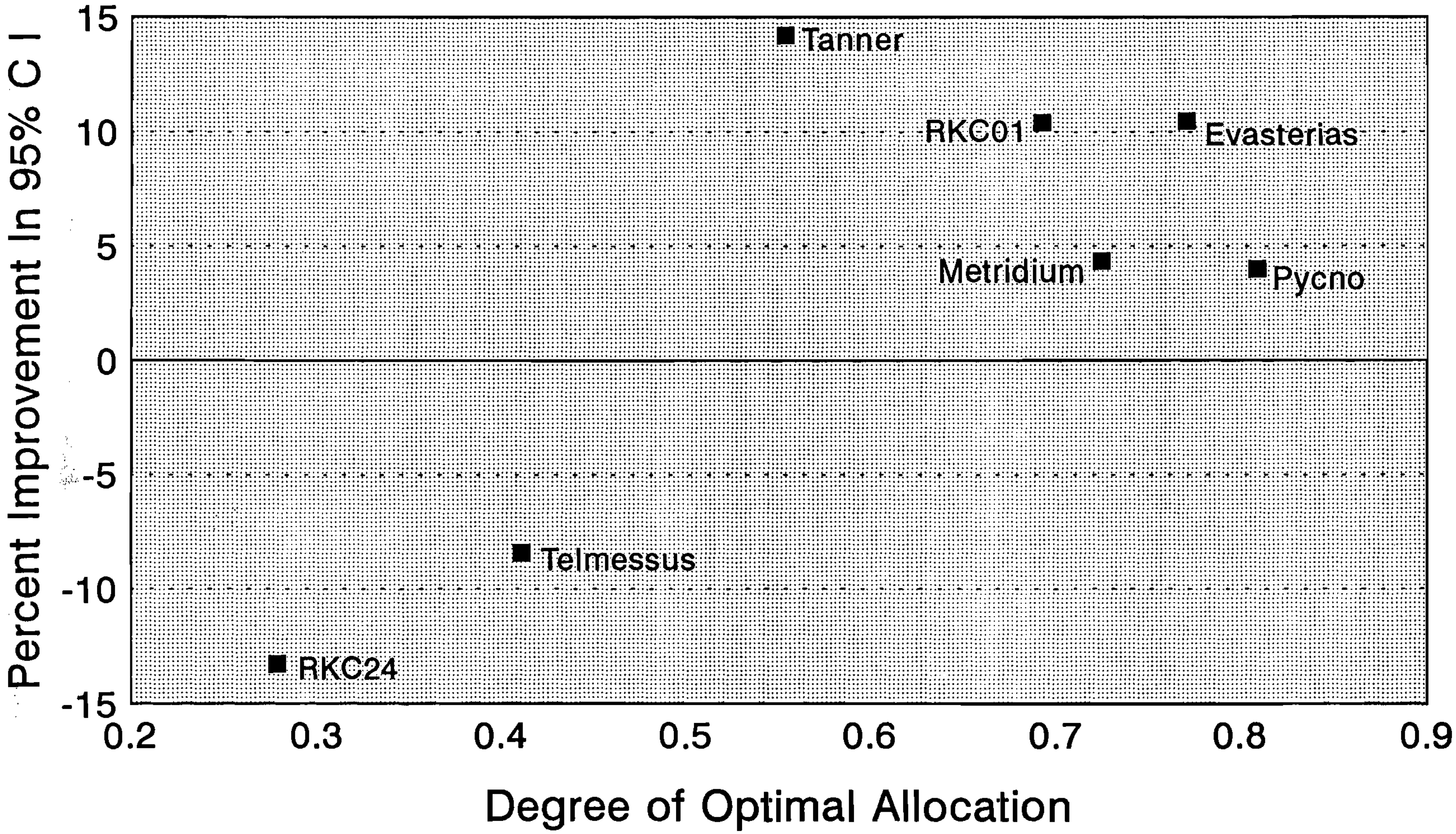
Given the actual allocation of effort in this preliminary survey, log-transformation generally produced a substantially greater increase in the precision of estimates of mean abundance for Womens Bay species than did stratification. For all eight species groups combined, the average increase in precision (decrease in width) of unstratified confidence intervals was approximately 3% for stratification alone (Fig.8A), 22% for log-transformation alone (Fig.8B), and 24% for both stratification and transformation (Fig. 8C). The increase in precision resulting from log-transformation versus stratification was especially noticeable for the primary target organism, RKC01. The narrowest confidence interval for RKC01 (mean±11%) was achieved through a combination of transformation and stratification, for an overall improvement in precision of 90% (Fig.8C). Transformation and stratification had a negligible effect on precision for those species (E. troschelii, P. helianthoides, and M. senile) whose distributions were the least skewed and for whom sampling effort was apparently adequate, according to Cochran's (1977) minimum N (Table 6). Consistent with Stuart's (1968) caveat, stratification resulted in an actual loss of precision for RKC24 and Telmessus cheiragonus (Fig.8A), pointing to the fact that the actual allocation of effort among strata in our pilot study was far from "optimum" for these two species (Fig.9).

The optimum allocation of effort among strata, calculated for each Womens Bay species based on data from the present pilot survey, is shown in Table 7. Because the spatial allocations for RKC01 (95% of total effort at Docks) and RKC24 (91% of total effort at Mid-Bay) are mutually exclusive, it was necessary to set allocation priorities for each target population. That is, given the Table 7 spatial allocation within species, what should be the allocation among species? Given the objectives of the Kodiak Island Borough, all sampling effort should be allocated to RKC, with perhaps a higher priority-weighting for RKC01 than for RKC24, say 1.5 and 1.0. Therefore, out of a hypothetical total of 100 samples to be collected in a year, 60 would be allocated to RKC01 and 40 to RKC24. These samples would be spatially distributed as shown in Table 8, according to the Neyman allocation in Table 7.

The above allocation of 100 samples, to be collected during a twelve-month time period, does not account for the seasonal shifts in crab distribution observed during our pilot study. For example, we observed that RKC of both age groups were abundant at the Dock/Pier habitat only during the colder months of November through March. Capitalizing on this knowledge of the target species, it would be more efficient to stratify the sampling by time as well as space. This revised Neyman allocation, now based on stratum size and the variance observed within each time period, as well as that observed within each geographical stratum, is shown in Table 9. Next we would need to assign priority-weightings to allocate the 100 samples among time periods and crab age-groups. For this particular example, crab groups were assigned equal weights. Because underwater visibility is greater in winter than in summer, and because the crab are more densely aggregated and their mobility is less in winter than in summer, we might assign an allocation weight of 1.5 to winter and 1.0 to summer. Therefore 60 samples were allocated to winter (30 in each crab group) and 40 to summer (20 in each crab group). The spatial distribution of sampling effort among geographical strata was then accomplished (Table 10) using the Neyman allocation in Table 9.

Figure 9

Degree Of Optimal Allocation And Percent Improvement In Precision Due To Stratification



Degree of Optimal Allocation = Correlation X,Y
X = Proportion of Total Effort
Y = Proportion of Standard Deviation

Table 7. The optimum allocation of effort for a fixed sample size (N). Spatial allocation is the Neyman allocation in percent of N for each species.

Optimum %	Spit%	Mid–Bay%	Docks%
RKC01	2.6	2.6	94.8 *
Tanner	2.6	85.3 *	12.1
A. amurensis	0.0	100.0 *	0.0
RKC24	0.0	90.5 *	9.5
Telmessus	1.7	88.8 *	9.5
Metridium	5.2	82.8 *	12.1
E. troschelii	6.9	69.8 *	23.3
Pycnopodia	15.5	75.9 *	8.6
Actual %	19.8	59.5	20.7

* Denotes stratum where the greatest proportion of total effort should be expended. Based on stratum size and stratum variance, as determined in pilot survey.

Table 8. The spatial distribution of hypothetical samples (N=100) using the Table 7 Neyman allocation for RKC01 and RKC24, where 60% of the effort is directed to RKC01 and 40% to RKC24.

	Spit	Mid–Bay	Docks	Total
RKC01	2	1	57	60
RKC24	0	36	4	40
Total	2	37	61	100

Table 9. The optimum allocation of effort for a fixed sample size (N). The spatial and temporal allocation is the Neyman allocation in percent of N for each age-class of red king crab.

	Winter (November–March)		
	Spit%	Mid-Bay%	Docks%
RKC01	1.5	2.9	95.5
RKC24	0.0	94.2	5.8

	Summer (April–October)		
	Spit%	Mid-Bay%	Docks%
RKC01	19.6	20.2	60.3
RKC24	0.0	99.9	0.1

Table 10. The spatial and temporal distribution of hypothetical samples (N=100) using the Table 9 Neyman allocation, where 60% of the effort is directed to winter and 40% to summer. Age-classes of RKC are equally weighted.

	Winter (N = 60)			
	Spit	Mid-Bay	Docks	Total
RKC01	0	1	29	30
RKC24	0	28	2	30
Total	0	29	31	60

	Summer (N = 40)			
	Spit	Mid-Bay	Docks	Total
RKC01	4	4	12	20
RKC24	0	20	0	20
Total	4	24	12	40
Annual Total	4	53	43	

A more optimum allocation of effort in this exploratory pilot survey would have increased the beneficial effect of stratification on the precision of abundance estimates. However, optimum allocation requires a detailed prior knowledge of the variance structure for each target population—knowledge that can be obtained only through preliminary sampling. This pilot survey provided variance data to be used in designing a permanent stratification and effort-allocation scheme for a future, long-term survey. One advantage of permanent strata over the labile, ever-changing strata of the post-stratification method (Otto 1986) is that abundance comparisons among years are more likely to be statistically valid if strata are stable in space and time.

LITERATURE CITATIONS

Caulcutt, R. 1991. Statistics in research and development. Second edition. Chapman and Hall, New York. 471pp.

Cochran, W.G. 1977. Sampling techniques. Third edition. John Wiley, New York. 428pp.

Dew, C.B. 1990. Behavioral ecology of podding red king crab,Paralithodes camtschatica. Canadian Jour. Fisheries and Aquatic Sciences 47(10):1944-1958.

Dew, C.B. 1991. Characterization of preferred habitat for juvenile red king crab in three Kodiak bays. NMFS final report to the Kodiak Island Borough. 49pp. Available from: C.B. Dew, NMFS Kodiak Laboratory, PO Box 1638, Kodiak, AK 99615.

Elliot, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Scientific Publ. No. 25. Freshwater Biological Association, Ferry House, UK. 157pp.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley, New York. 257pp.

Incze, L.S., R.S. Otto, and M.K. McDowell. 1986. Recruitment variability in juvenile red king crab, Paralithodes camtschatica, in the southeastern Bering Sea. In G.S.Jamieson and N. Bourne (eds.), North Pacific workshop on stock assessment and management of invertebrates. Canadian Special Publ. of Fisheries and Aquatic Sciences 92:370-378.

Lloyd, M. 1967. Mean crowding. Jour. Animal Ecology. 36:1-30.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical ecology. John Wiley, New York. 337pp.

McConnaughey, R.A. and L.L. Conquest. Comparison of three methods of interpretation of trawl data for lognormally distributed populations. Fishery Bull. (In review). 35pp.

Otto, R.S. 1986. Management and assessment of eastern Bering Sea king crab stocks. In G.S.Jamieson and N. Bourne (eds.), North Pacific workshop on stock assessment and management of invertebrates. Canadian Special Publ. of Fisheries and Aquatic Sciences 92:83-106.

Pielou, E.C. 1977. Mathematical ecology. John Wiley, New York. 385pp.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. The principles and practice of statistics in biological research. Second ed. W.H. Freeman, San Francisco. 859pp.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill, New York. 481 pp.

Stevens, B.G. 1990. Temperature-dependent growth of juvenile red king crab (Paralithodes camtschatica) and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Canadian Jour. Fisheries and Aquatic Sciences 47(7):1307-1317.

Stevens, B.G., R.A. MacIntosh, and J.A. Haaga. 1991. Report to industry on the 1991 eastern Bering Sea crab survey. AFSC processed report 91-17. 53pp. Available from: R.A. MacIntosh, NMFS Kodiak Laboratory, PO Box 1638, Kodiak, AK 99615.

Stuart, A. 1968. Basic ideas of scientific sampling. Griffin's statistical monographs, No. 4. Hafner Publ., New York. 99pp.

Vandermeer, J. 1981. Elementary mathematical ecology. John Wiley, New York. 294pp.

Weber, D.D. and T. Miyahara. 1962. Growth of the adult male king crab, Paralithodes camtschatica (Tilesius). U.S. Fish Wildl. Svc. Fish. Bull. 62(200):53-75.

Zar, J.H. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ. 620pp.

Proc. Int. Crab Rehab. & Enh. Symp.
Jan. 1992, Kodiak, Alaska

A BRIEF REVIEW OF REARING CONDITION OF EGGS, LARVAE AND POST-LARVAE OF KING CRAB (*PARALITHODES CAMTSCHATICUS*) IN JAPAN

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ABSTRACT

The catch of king crab has decreased substantially. In 1970, a research project for stock enhancement using methods such as the release of seed was started in Hokkaido, northern Japan. During this research project, the technique of seed production was developed. Many results concerning the development of large scale rearing methods of king crab larvae were obtained.

The author worked on this project from 1971 to 1980. Throughout the life history from egg to adult (see below, "1. life history"), survival, growth, and oxygen consumption rates, behavior and other factors which are easy to observe or measure, were taken as indices (see below, "3. Indices"). Environmental conditions (see below, "2. Environment") such as water temperature which affect these indices were combined with salinity and hypoxia, and the ranges of tolerance and the optimum conditions were examined and the best rearing condition was determined.

King crab larvae are more tolerant of variations in environmental conditions compared to other crustacean species living in the cold sea, and rearing is easier.

1. Life History
    - Eggs attached to the pleopod
    - Zoeae
    - Glaucothoe
    - Young crabs
    - Adult crabs

2. Environment
    1) Non-bio-environment
        - (1) Water temperature
        - (2) Exposure to the air
        - (3) Light intensity and light-dark periodicity
        - (4) Pollution on the rearing water
        - (5) Quality of water
            - * Salinity * pH * Pollution * Hypoxia
    2) Bio-environment
        - (1) Population density
        - (2) Food and its supply
            - * Quality * Quantity

3. Indices

1) Morphology
   (1) Embryogenesis
2) Size
   (1) Length
   (2) Weight
3) Molting
4) Respiration
5) Survival
6) Behavior

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SEED PRODUCTION AND RELEASE PROCEDURES OF KING CRAB

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ABSTRACT

King crab, Paralithodes camtschaticus (Tilesius), and Hanasaki king crab, Paralithodes brevipes (H. Milne Edwards et Lucas) are important crab resources in the northern waters of Japan, but their stock situation has gradually decreased and is becoming more serious. Thus, technical developments are being conducted to establish new procedures to enhance the resources.

In the Japan Sea Farming Association, an investigation was started on king crab and Hanasaki king crab at Akkeshi Plant in 1982. It is believed that when seed production techniques for Hanasaki king crab is established, it is fully applicable to king crab.

1) Rearing of Brood Stock

Egg-bearing crab of both species were caught immediately before natural hatching in the sea of Okhotsk off the coast of Hokkaido--for king crab from the end of March to early April--and at the Pacific coast of northern Hokkaido--for Hanasaki king crab from mid-August to the end of September.

The two species of crab were reared in polyethylene tanks of 8 m^3, in vitro. Since the water temperature in a natural environment was below 0° C, the rearing temperature in the tank was raised to 3-4° C to achieve better growth. After hatching was completed, parent crab of the two species were reared in on-land tanks, and their mating, fertilization and egg-bearing were observed.

2) Rearing of Larvae

Both species started hatching from January to February of the following year, and continued for about two months. The larvae were collected with the rearing water overflown from the spawning tank and were transferred into small tanks (0.5 m^3). Then the larvae were accommodated into a rearing tanks.

The rearing tanks were made of concrete (20 to 50m^3), and sand-filtered sea water was applied for rearing. The larvae were kept at the hatching temperature (3-4° C) at first, and then the water was gradually heated until it reached 8° C, and the larvae were reared in natural conditions.

The standard density was 10,000 individuals/m^3 but actually the density either increased or decreased depending upon hatching rate.

Foods at the zoea stage (king crab 1-4 stages, P. brevipes 1-3 stages) are diatom (Thalassiosira sp.) and nauplius stage of Artemia. At the glaucothoe stage no feeding was done; and at the juvenile stage, mysids and minced fish meat were given.

For king crab, the survival rate at each larval stage was about 100 percent at the zoea stage, more than 80 percent at the glaucothoe stage, or about 80 percent in total. For P. brevipes, even in favorable rearing conditions, it was 80 percent at the zoea stage, 50-60 percent at the glaucothoe stage, or about 40-50 percent in total. However, rearing techniques have improved and the survival rate is approaching close to 80 percent.

3) Juvenile Nursing, Release and Tracing

a) Juvenile Nursing
At the young stages of both species of king crab, one can observe serious cannibalism when they are reared in high density on-land tanks, and thus mortality increases. Since the young stage crab's carapace length is less than 1.8mm, a high mortality will occur if they are released to the natural environment. Therefore, it is necessary to rear the young crab in nursing facilities in the sea until they reach a suitable size for release.

The experiments were carried out assuming the necessity of nursing. It was also found that nursing is one of the essential factors in obtaining more effective results for the enhancement of both species.

b) Release and Tracing
Due to the small size of seeds which normally hide under seaweeds, gravel, reefs, and so on, it was quite difficult to recapture the seeds and this is the main problem we had in tracing.

Recently, a new method was established to collect young crabs with seaweeds, sand, and gravels from the seabeds, using a specially designed pump on board the vessels. Its excellent survey capabilities and recovery rate as high as 90 percent have improved the survey methods. It is believed that because of such improvements, we will be able to find methods to recover the stock of Hanasaki king crab by releasing artificially produced seeds to a given area and conducting regular surveys in and around the release areas. It is also expected that we can apply this method to king crab in order to contribute to the stock enhancement.

TEXT

Red king crab (*Paralithodes camtschaticus*) and Hanasaki king crab (*Paralithodes brevipes*) are two of the major crab resources of northern Japan archipelago. The stocks have, however, decreased in recent years, therefore, rehabilitation and enhancement programs have been implemented at the Akkeshi Plant in Hokkaido by the Japan Sea Farming Association (Figure 1). Seed production technology of these species was started in 1982. In 1985, the same plant also started the production effort on release procedures technology.

Adult red king crab are captured in the March to April period off Hokkaido in the Okhotsk Sea where water temperatures are close to 0° C. At the Akkeshi Plant, the adult crabs are held at 3 to 4° C water temperature and are held as brood for seed production. Some crabs are held for a whole year to watch egg development.

Adult Hanasaki king crab are captured in August and kept till spring to hatch out. At the time of capture, water temperatures in the wild range from 17-18° C while the hatchery water temperatures are 8° C.

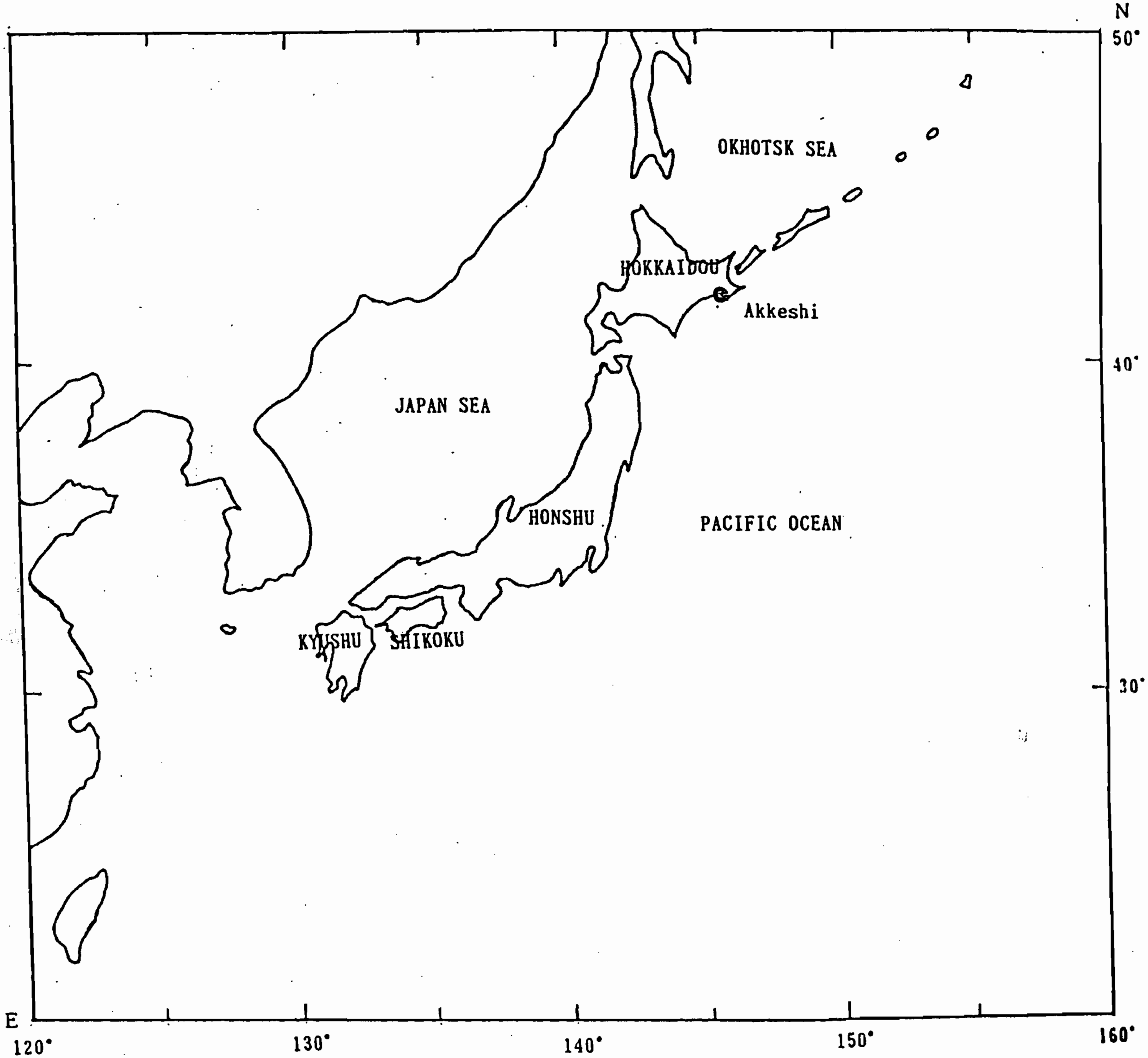

Figure 1. Japan archipelago showing the location of Hokkaido and Akkeshi, location of the [illegible]eshi [illegible]ant [illegible]の位置

Adult king crab are held in square shaped 8 m^3 tanks that are made of reinforced plastic FRP. King crab larvae are collected from the larger tanks via an overflow line to a smaller, 0.5 m^3 cylindrical tank. Hatching usually starts in January and continues for two months.

Enumeration of larvae is done by making several one liter subsamples from the smaller cylindrical tank. The larvae must be uniformly distributed in the tank before the subsamples are taken. The larvae are then hand counted and returned to the small tank. Once the enumeration process is finished, the larvae are transferred into larger tanks for rearing. The transfer process is completed at night.

The Akkeshi Plant is experimenting with several types of rearing tanks. The cylindrical plastic tanks have a 4 ton capacity and the 50 ton tanks are similar to salmonid raceways and are made of concrete.

Figure 2 depicts the current levels of survival being experienced at the Akkeshi Plant for red king crab. Survivals are at 100% from Z_1 to Z_3 and 80% at the Z_4 to glaucothoe. Water temperatures are at 3 to 4° C at the start of the rearing process and gradually rise to 8° C where they are maintained. To standardize water quality in the rearing water we add nannochloropsis.

In feeding the red king crab, we use the diatom *Thalassiosira* sp. and *Artemia* sp. nauplii. The long strands of *Thalassiosira* facilitate feeding zoeal crab. Recognizing these feeding needs has made a significant improvement in the survival of zoeal stage. Early stage zoeal consume a larger portion of diatom while late stages consume more of the *Artemia* sp. nauplii.

Natural *Thalassiosira* sp. is collected from the sea and cultured. *Artemia* cysts are purchased and shipped from North America and are hatched at the Akkeshi Plant.

The glaucothoe stage is not fed as it is not necessary. Our observations are that this stage does not feed. The viability of the C_1 crab is, therefore, dependent upon the Z_4 viability.

The culture of the Hanasaki king crab is similar to the red king crab except there are only three zoeal stages for the Hanasaki. The rearing time is, therefore, reduced to approximately 40 days from Z_1 to C_1. Overall survival is again 80% to C_1 crab (Figure 3).

Figure 4 depicts the annual production of (red) king crab from 1982 to 1987 at the Akkeshi Plant. With a few exceptional years, slightly less than 200,000 young crab were produced per year. Densities were maintained at about 7,000 per m^3.

Hanasaki king crab annual seeding production from 1982 to 1991 is displayed in Figure 5. The annual production varied from less

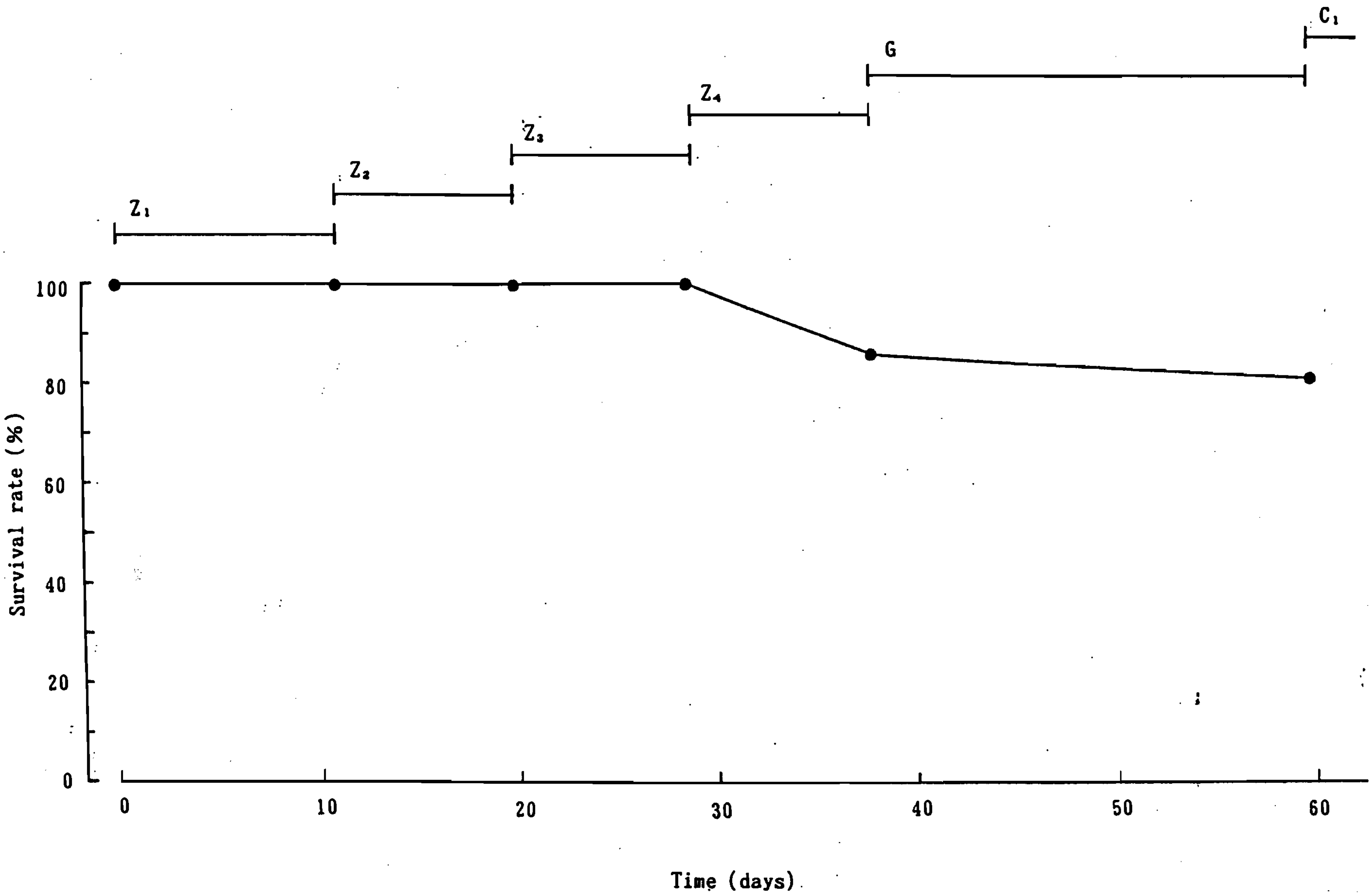

Figure 2. Survival curve and metamorphic stages of king crab (P.camtschaticus)

No.12 タラバガニの変態と生残(1987)

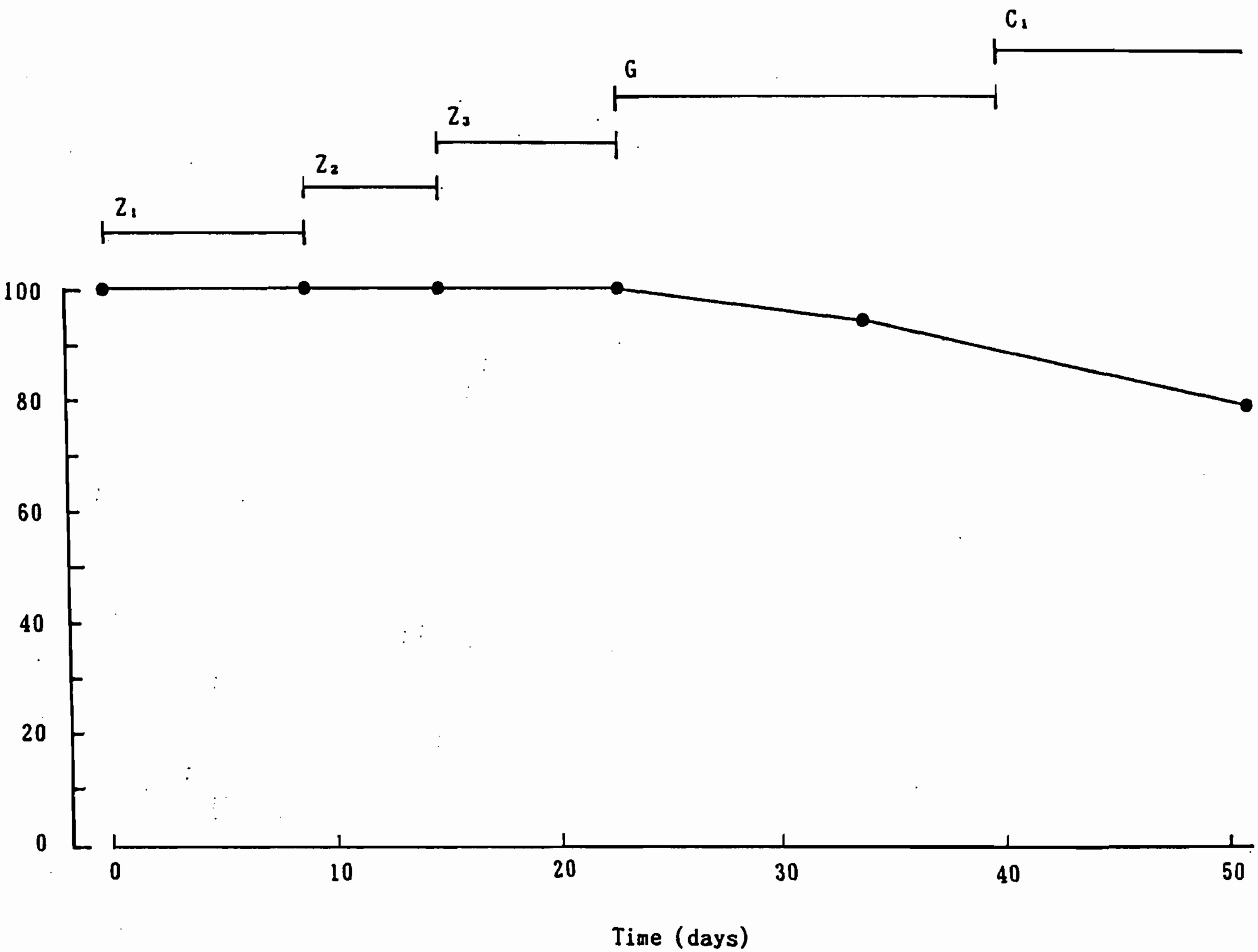

Figure 3. Survival curve and metamorphic stages of hanasaki king crab (P. brevipes)

No.13 ハナサキガニの変態と生残(1991)

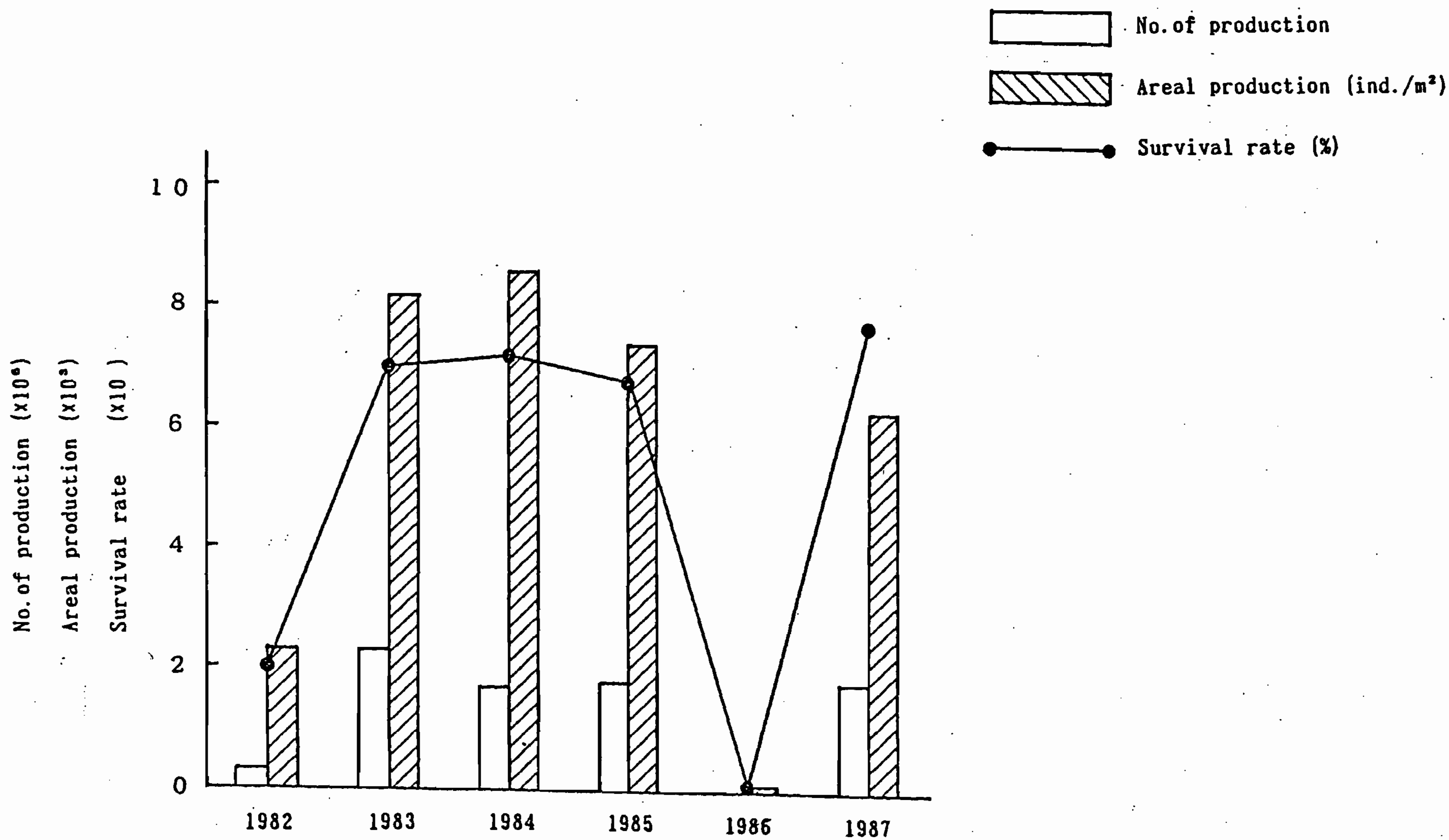

Figure 4. Annual fluctuation of seeding productions of king crab.

No.26 タラバガニ種苗生産の推移

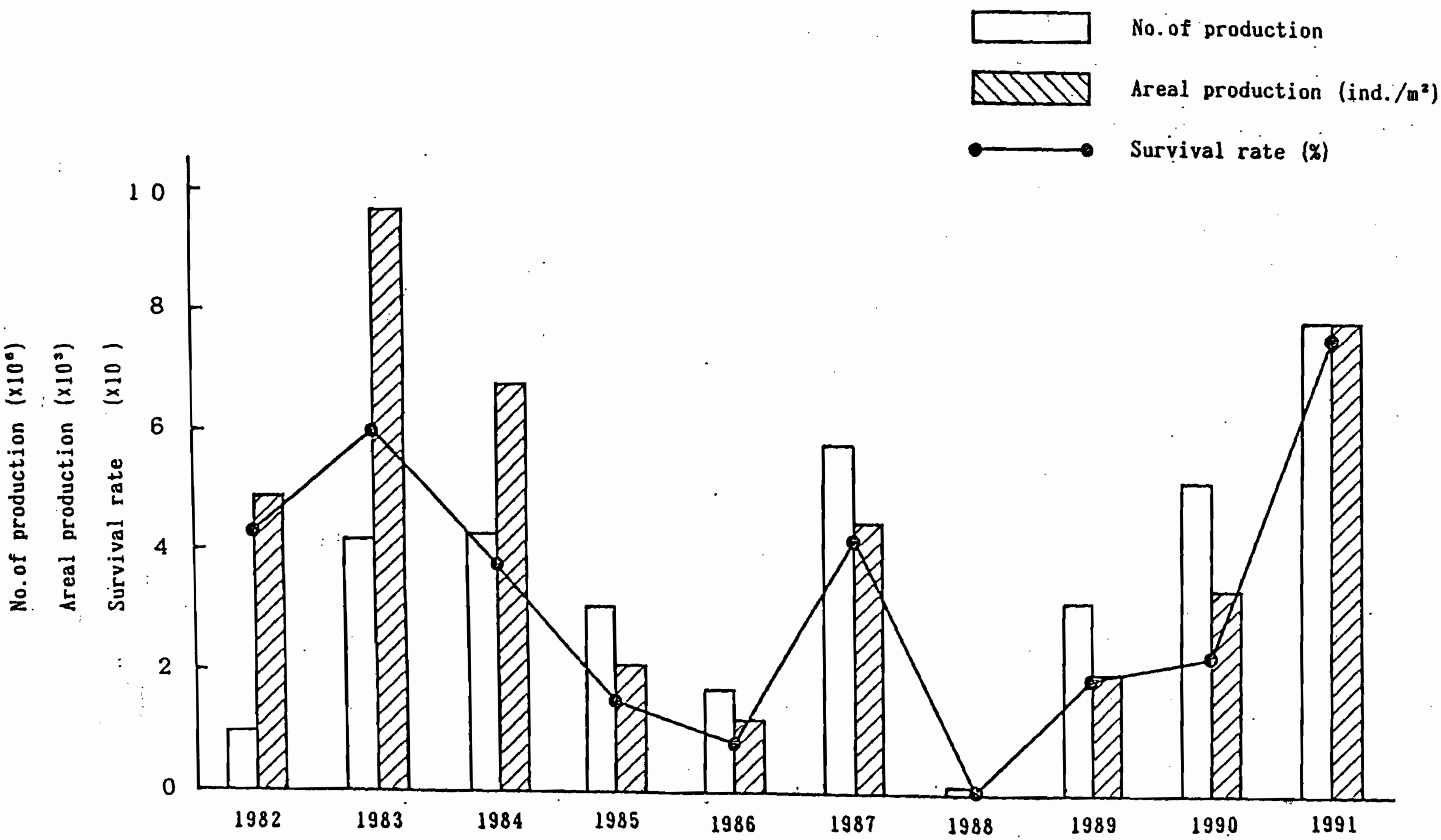

Figure 5. Annual fluctuation of seeding productions of hanasaki king crab.

No.27 ハナサキガニ種苗生産の推移

than 10,000 in 1988 to 800,000 in 1991. The 1991 density was 8,000 per m^3. The production goal target is 10,000 per m^3.

Experimentation is also underway with intermediate culture of Hanasaki king crab from C_1 stage to approximately 200 days. In the experimental design, we used densities of 300, 200, 100, and 50 C_1 crab per one meter long collector bags. The design of the experiment is similar to the technology that is applied to mariculture for the collection of larval scallop (Figure 6). Results to date indicate that crab stocking density in the collector bag should be 50 or less. Mortality was 30 to 40% over a 200 day period (Figure 7). The highest mortality appears to take place over the first 60 day period.

An artificial reef or liberation nursery experiment is also currently underway. The purpose of the experiment is to study density and survival over time for Hanasaki king crab. In the experiment, we created artificial reefs that were 5 m x 5 m in dimension. The reef was built with "ballast" or rock ≈40 mm in dimension and lined with sandbags (Figure 8). Densities stocked varied between 1,000 to 3,000 crabs per m^2. A special suction pump was used to dredge young (2-3 mm size) crab out of the artificial reef. Figure 9 depicts the varied survival over time.

Question: What is the annual operating cost of the Akkeshi Plant?

Answer: The cost is $100,000,000 yen per year ~ or roughly $800,000 per year at 125 yen per dollar. Other species and research are also being undertaken at the plant.

Question: Why did the plant stop production of red king crab?

Answer: The adult red king crab has a migration pattern that makes evaluation difficult and would not benefit our local fishermen if successful. Therefore, we changed to a species (Hanasaki) whose migration pattern was limited so we can better evaluate and benefit our local fishermen.

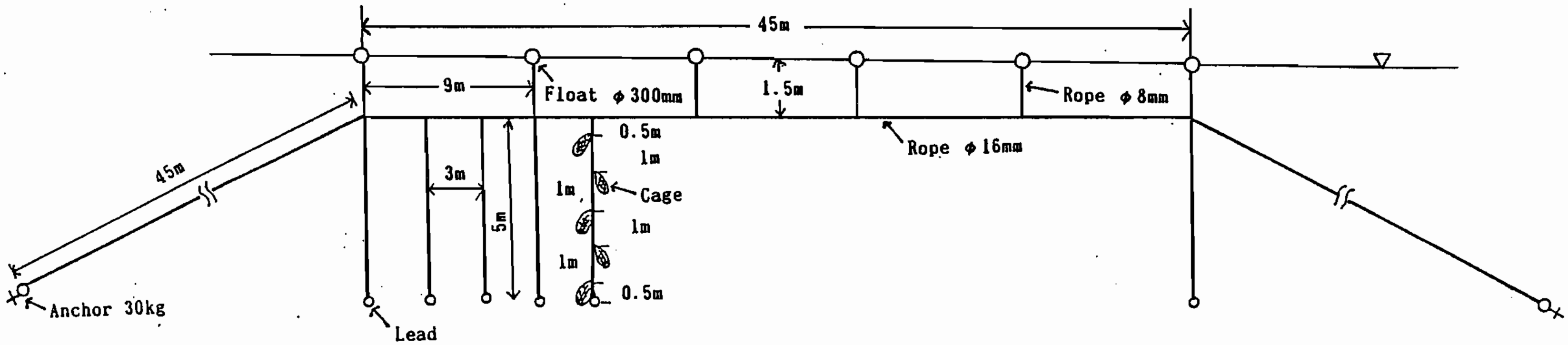

Figure 6. Schematic drawing of breeding facilities of hanasaki king crab.

No.28 ハナサキガニ中間育成施設の構造(1982, 1983)

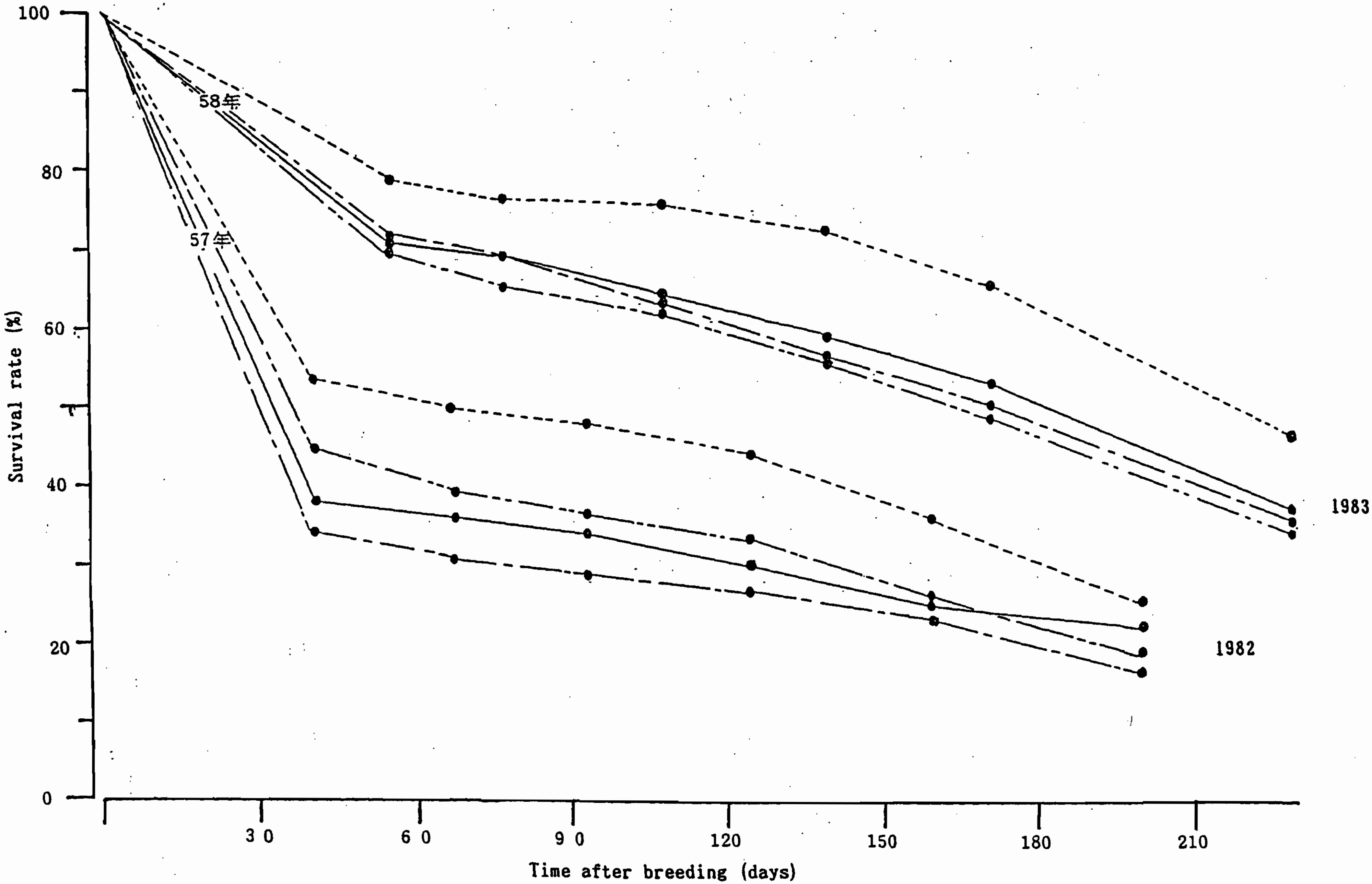

Figure 7. Influence of the density in cages for survival rate of hanasaki king crab.

No.29 ハナサキガニ中間育成の密度別試験の生残(1982. 1983)

50 ind./cage
100 ind./cage
200 ind./cage
300 ind./cage

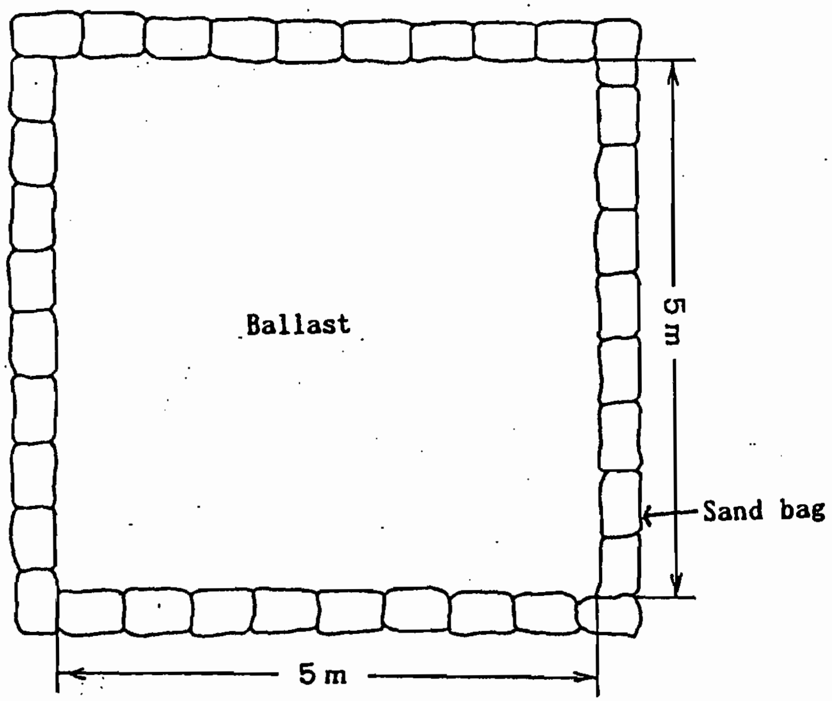

Figure 8. Overview of artificial reef for liberation experiments of hanasaki king crab.

No.30 ハナサキガニ放流マウンドの構造 (1991)

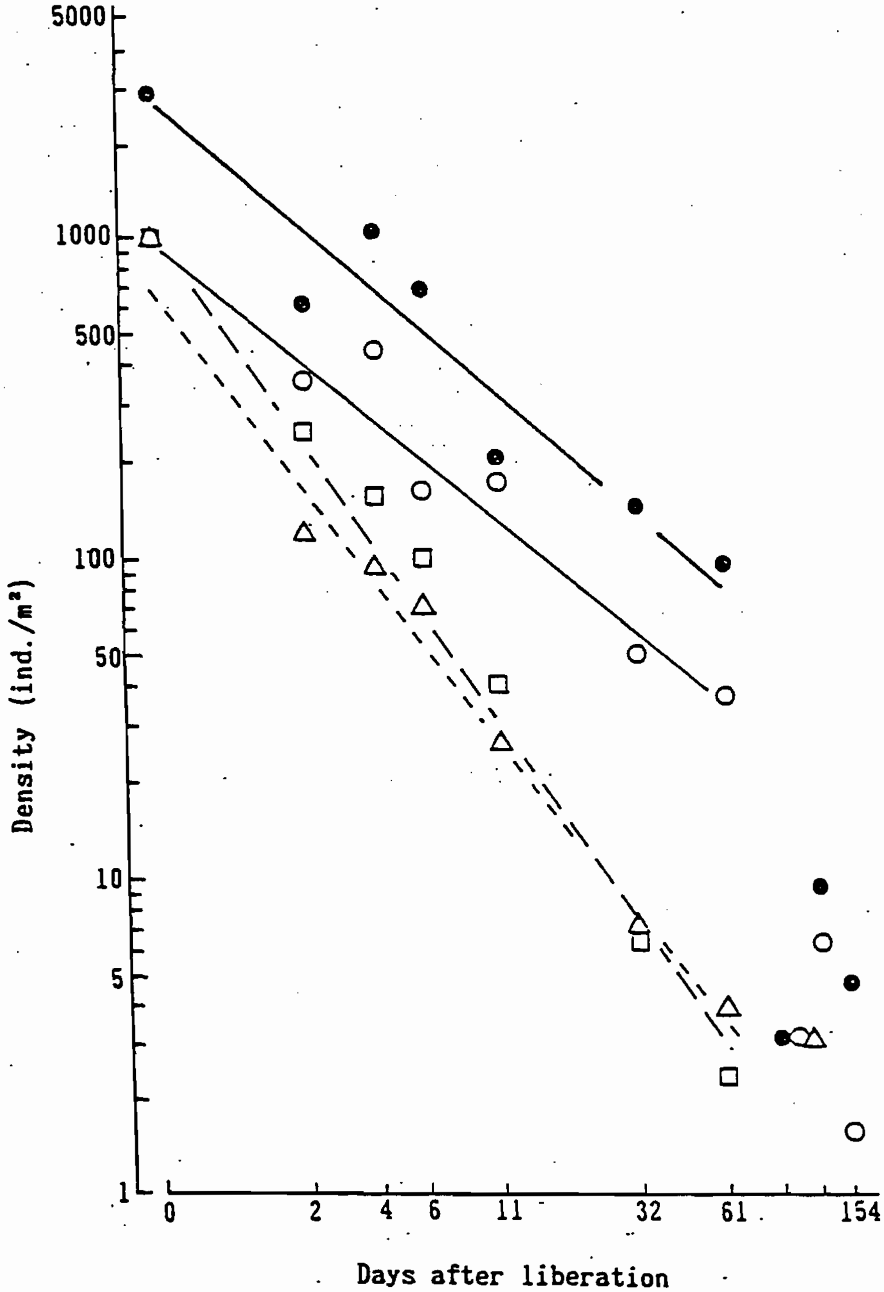

Figure 9 Change of distribution density of hanasaki king crab in artificial reef during the liberation experiments.

ハナサキガニの放流マウンド内の残存密度(1991)

● : 3000 ind./m²

○ : 1000 ind./m²

□ : 1000 ind./m² (without ballasts)

△ : 1000 ind./m² (without ballasts and sand bag)

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PRINCIPLE OF COASTAL FISHERIES DEVELOPMENT IN JAPAN

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ABSTRACT

Japan has a long history and many successful experiences in coastal fisheries development.

Since the establishment of the 200 mile economic zone, coastal fisheries development efforts have been accelerated in many fields and its contributions are remarkably valuable for expansion of the fisheries industry.

Intensive and extensive aquaculture procedures are traditional techniques and are still the most popular ones used among fishermen.

When discussing intensive aquaculture, cage, pen, pond and enclosure culture are still important procedures for fish and prawn; and raft and long line culture are important for shellfish and sea weeds. With regard to extensive aquaculture, release programs for salmon fingerlings, baby clam and abalone contribute to the enhancement of each stock.

In addition, Sea Farming techniques have been expanded recently and are valuable procedures used in coastal fisheries development. Sea Farming techniques consist of: improvement of farming grounds, seed production and release, environmental protection and management of resources for harvest.

Many projects are currently established using the Sea Farming techniques for fish, crustaceans, molluskan shellfish and others. Many successful results have been obtained.

As a new idea, marine ranching techniques have been developed and have also become popular. These techniques are a composite combination of not only biological elemental techniques, but also engineering techniques to improve a particular ground for better harvest of valuable marine products.

In this presentation, the Japanese situation will be introduced as an example for future development of Alaskan coastal fisheries. And finally, some suggestions will be offered regarding the enhancement of King crab in the Alaskan waters as follows:

1) Among the various possible procedures, application of Sea Farming techniques is recommended.

2) An oceanographic and ecological investigation system should be established for scientific estimation of the grounds.

3) A careful inspection concerning the effects of over-fishing in farming fields should be carried out and the present situation of King crab productivity should be confirmed.

4) Mass production techniques of the seed have to be developed scientifically and technologically.

5) Monitoring and survey systems have to be organized for environmental protection of farming fields.

6) A complete management of the new resources have to be enforced including the organization and education of fishermen.

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THE SOUTHERN KING CRAB (Lithodes santolla): A BIOLOGICAL PERSPECTIVE AND ITS POTENCIAL AS A CULTURED SPECIE.

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Keywords: Southern King crab, Lithodes santolla/antarctica, biology habitat, reproduction, feeding, behaviour, diseases, growth, development.

ABSTRACT

A biological review of the southern King crab, Lithodes santolla, shows the knowledge to be concentrated among adults, then juvenile and larval stages. Within the biological areas, most of the studies are fisheries biology and population dynamics oriented, less research has been conducted in reproduction, development, habitat, feeding. Biological knowledge as ethology, diseases, natural habitat have been poorly studied.

The crab lives all along the chilean fjordic coast and the Argentina southern continental shelf, at depths ranging from 2 to 80 metres, waters of 5-16 C and 26-30 ‰. The crab matures at 80-114 mm. The 2.1 mm egg is incubated by the female (in numbers ranging from 3.000-40.000/female). The embryonic development last 285 days. Three planktonic zoeas and one glaucothoe preceeds a benthic juvenile. The specie shows a depth dependent migrational pattern. Juvenile and adult southern King crabs feed on gastropoda, foraminifera and algae. Growth occurs by molting, which decreases as the animals get bigger. A rhizocephalan barnacle parasites the adults and juveniles.

None of the existing biological knowledge has been yet massified for maricultural purposes, information on clevel larval rearing stages, reproduction and diseases are expected to enhance the declining populations.

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RESUMEN

Una revisión de la información publicada en centolla, Lithodes santolla, mostró que el conocimiento está concentrado en adultos, luego juveniles y estadíos larvales. Entre las áreas de la biología, la mayoría de los estudios se concentran en aspectos de biología pesquera y dinámica poblacional. Menos investigación ha sido realizada en reproducción, desarrollo, habitat y alimentación; en tanto que existe poca información en áreas como etología, enfermedades y habitat natural.

La centolla habita a lo largo de los fiordos chilenos y la plataforma continental del Sur argentino, a profundidades desde 2 a 80 metros, aguas de 5 a 16 C y 26 a 30 %o. Madura a una talla de entre 80 a 114 mm. Los huevos (de 2.1 mm) son incubados por la hembra en números que oscilan entre 3 a 40 mil por hembra. La embriogenesis dura 285 días. Existen tres larvas zoeas planctonicas y una megalopa en el desarrollo larval. Juveniles y adultos se alimentan de gastropodos, foraminiferos y algas. La especie muestra un comportamiento migracional con respecto a la profundidad. El crecimiento ocurre por mudas, la tasa de crecimiento decrece con la edad. Un parásito rizocefalo se encuentra en porcentajes de hasta 10 % de las poblaciones.

Nada del conocimiento adquirido ha sido aún masificado para propósitos de maricultura, aún falta información clave en el desarrollo de estadíos larvales, enfermedades, reproducción, alimentación, la cual mejoraría la posible práctica de cultivo de la especie.

INTRODUCCION

The southern King crab (Lithodes santolla), has been biologically studied in the last thirty years by research teams at the University of Magellan (Patagonian Institute and Faculty of Sciences), Chilean Fisheries Institute (IFOP), the Austral Scientific Research Center (CADIC) in Ushuaia and University of Concepcion.

Extensive knowledge has been generated in different areas of biology: Reproduction, habitat, development, feeding, parasitism, population dynamics (abundance and distribution) and mostly in fisheries biology.

Scientific information is very disperse, thus, one of the objectives of this study was to compile all the available published information on the crab.

Since intensive efforts are being concentrated in cultivating the specie, (in the last five years), a state of the art is required to better understand or focus the forthcoming research.

MATERIAL AND METHODS

A complete review on the southern King crab biology (Lithodes santolla) was possible by compiling the very dispersed information (scientific publications, technical reports and internal reports). Eigthy three references were found among the following libraries: Patagonian Institute of the University of Magellan, Austral Scientific Research Institute (CADIC) in Ushuaia, Argentina and the Fisheries Chilean Institute (IFOP).

The following journals were revised: Annals of the Patagonian Institute, Gayana, Physis, Marine Biology and Crustaceana, all the search was also conducted in Current-contents.

The analyzed information was under the following biological cathegories: distribution, habitat, reproduction, behaviour, feeding, population dynamics, development, growth and parasitism/diseases. The southern King crab search was entered in a bibliography software system (Papyrus).

The potential for cultivating the specie was evaluated upon the present biological knowledge and the required technologies.

RESULTS

Natural Distribution

The southern King crab lives all along the fjordic chilean coast, from Valdivia-40 S to Cape Horn-55 S (IFOP, 1969) and along the eastern south-american coast, from Cape Horn up to Camarones Bay-44 S. (Vinuesa et. al., 1989).

The specie is also found in the Falkland Islands and it has also been reported up to the Uruguay coast (Angelescu, 1960).

Habitat

This large size crustacean seems to prefer areas of low velocity flows, with sandy/muddy bottom, free of rocks and seaweeds (Angelescu, 1960). In Chile, Stuardo and Solis (1963) have reported that the hydrological habitat seems to be limited to a water temperature ranging between 5 and 12 C. During the summer season, in the Argentinien Patagonia coast, a high dispersion pattern is observed, for instance, the crabs are found between the isotherms of 8 to 16 C (Angelescu, 1960).

Reproduction

In the Beagle Channel, Lithodes santolla matures at a size of 75 mm of cefalothorax length (Vinuesa et. al., 1980), while in the Balleneros Channel most of the 100 mm individuals are sexually inmature (Campodonico et. al., 1983). In the southern most chilean fjords, maturing sizes rangING from 80 to 114 mm are reported (Guzmán and Ríos, 1986).

The fecundation process ocurrs between november to february with a december peak (Vinuesa, 1987). In chilean waters egged crabs can be found since october to january (Oyarzún, com. pers.). A comparison of fertilization success was made by Campodonico (1986, 1987), he found a lower percentage in 1986 compared to 1985.

The fertilized females hold a complete egg-mass, with the exeption of parasited individual (Campodonico, 1987). A conservative egg-number range for the specie is between 2.930-39.303 per female (Vinuesa, 1987). The fertilized egg measures 2.1 mm, a comparative table was taken from Vinuesa 1987.

Specie	Egg number Min.	Max.	Size mm
Paralithodes camtschatica	12,600	350,000	1.1
Paralithodes platypus	30,000	160,000	1.2
Lithodes aequispina	9,500	30,100	2.1
Lithodes murray	388	3,582	2.45
* Lithodes santolla	2,930	39,303	2.1 *
Lithodes couesi	2,600	5,500	2.3
Paralomis granulosa	1,540	8,220	2.3

Development

The embryonic development of L. santolla has been worked by Vinuesa, in general, the process last for 285 days. The embryo shows two stages of rapid growth, one between the fecundation and gastrula and a second one at the end of the development proccess. Epibiosis in eggs is reported to be scarce and a reduced mortality is observed (increasing as the embriogenesis progresses).

Hatching occurs right after the molting process, between november and december (showing location and interannual variations).

The larval development (Fig. 1) has three zoea stages, a megalopa o glaucothoe stage and a juvenile stage (Campodonico, 1971; Campodonico et. al., 1982; Oyarzún com. pers.):

Stage	Cephalotorax Length (mm)	Wide (mm)	Days
Zoea 1	3.75	1.88	6.3
2	3.75	2.06	7.1
3	3.83	2.06	7.6-8.0
Glaucothoe	2.16	1.80	?
Juvenile	10.00	----	?

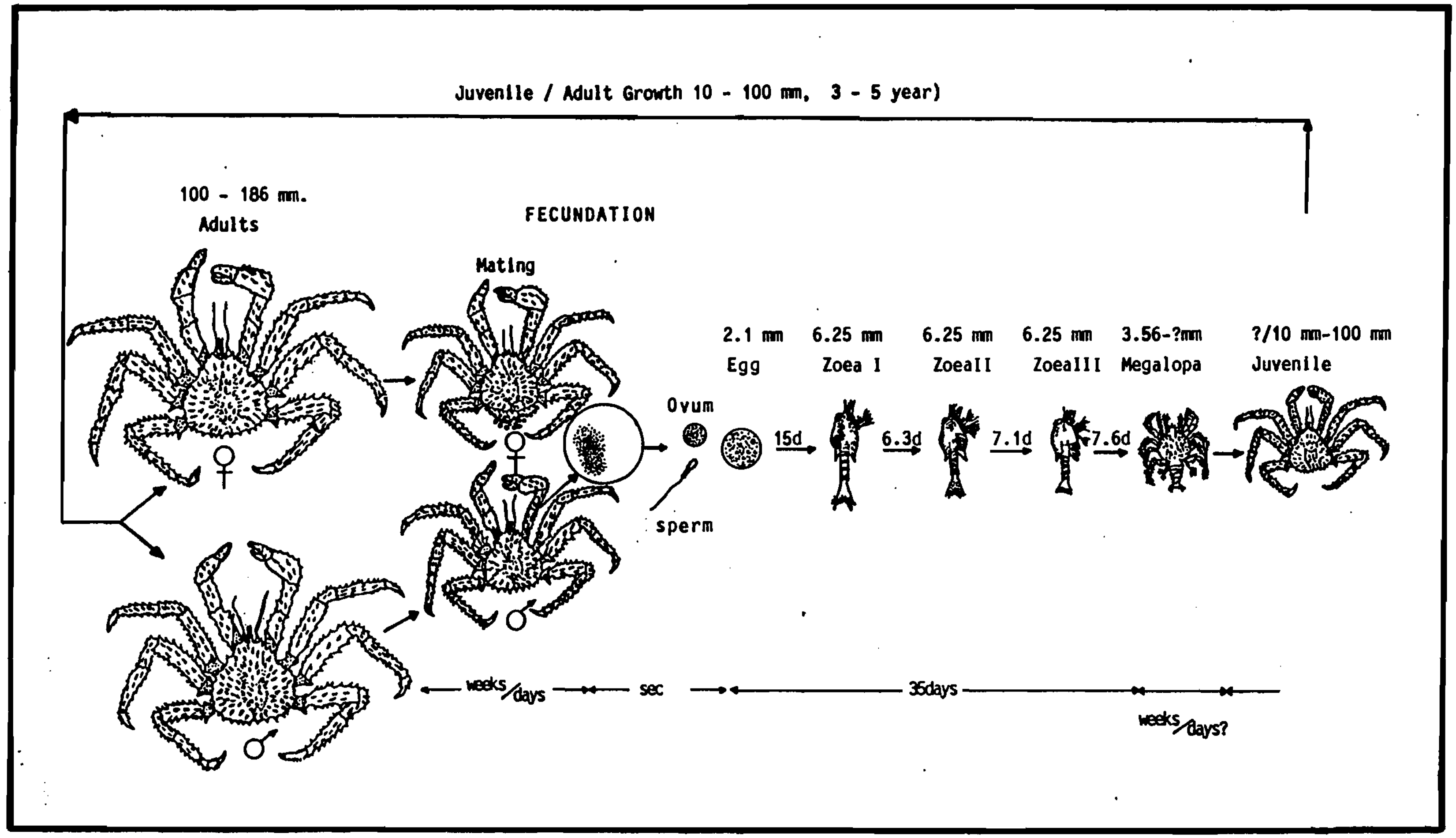


Figure 1 : Biological cycle of the southern king crab (Lithodes santolla). Stages, sizes and approximate timing of development / growth processes were compiled from several authors (Vinuesa, Campodonico, Guzman).

Campodonico (1987) has observed larval hatching in Desolada Bay and Gordon Island, he found the process to begin the first week of october, while in other areas a 50 % hatching has occurred by mid october. By the end of november most of the hatching had occurred in the Beagle Channel.

Behaviour/Ethology

Southern King crab adults show migratory movements between shallow and deep waters (Fig. 2), at the end of the spring season/summer they move up to shallower environments (10-20 m), while from mid summer/fall they move down to deeper waters (40-30 m) (Stuardo and Solis, 1963).

Wallace et. al. (1949 fide Stuardo and Solis, 1963) argues this migratory behaviour to be molting/reproduction related, he found females to migrate first than males to the shallow during the spring season. Once mating/fecundation has occurred, the individuals disperse, probably looking for food in deper waters.

This migration process appears to be very variable, in protected bays no larger migration is observed, while in unprotected areas a big dispersal pattern is encountered (Stuardo and Solis, 1963). In Argentina, on the southern patagonian coast, during the winter season, crabs can be found at depths (150-220 m), migrating northwards with along shore bottom currents (Angelescu, 1960). Stuardo and Solis (1963) reported L. santolla in Useless bay at depts of 19-54 m during december, while in january they are found at depth ranging from 18-63 m, males abundance was lower than females.

Very little is know about juvenile behaviour, however little individuals (mainly females) have been found at 3-5 metres of depth during winter (july) in the Madre de Dios archipielago (Stuardo y Solis, 1963).

Feeding Behaviour

Diet of L. santolla has been studied by Stuardo and Solis (1963), Guzmán and Ríos (1985), Vinuesa et. al., (1989) and Comoglio et. al., (1989).

In Chile, adults have been reported to feed in bryozoa and other crustacean. In Argentina, a study on 127 stomachs from individuals (ranging from 40-100 mm and living between 4 and 36 m of depth), found the major items to be: Gastropoda, foraminifera and filamentous algae; the items bryozoa and sea-urchins are seemed to be more consumed by females.

Little juveniles have been reported to be fed by adults while they are recenty molted (Vinuesa et. al., 1989).

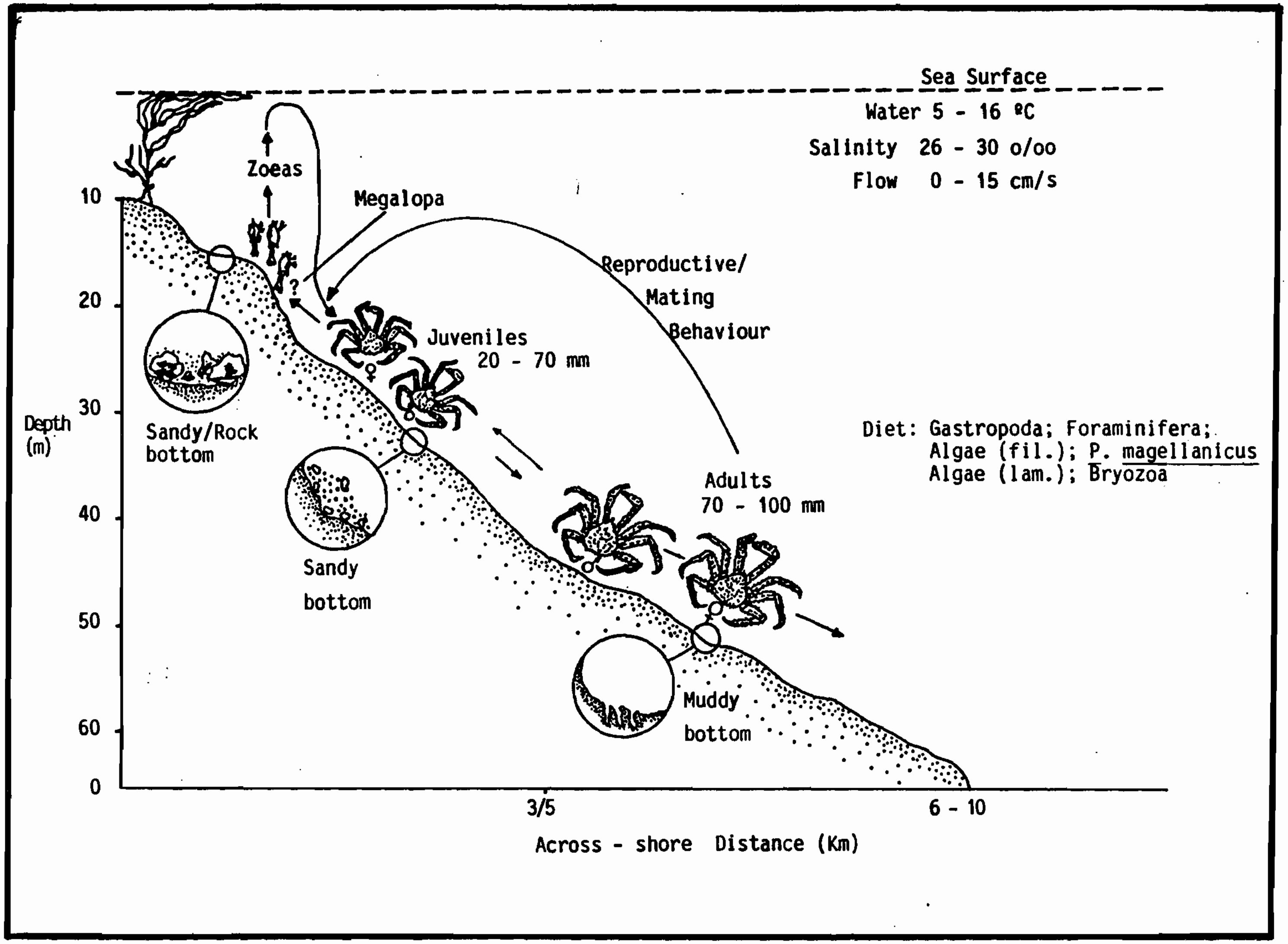


Figure 2 : Compiled habitat / behaviour of the southern King crab (Lithodes santolla). Water Characteristic, distribution of different stages, type of bottom and vertical/ horizontal scales are shown.

Population Dynamics

A sexual proportion of males/females = 2.5/1 has been reported for the Puerto Montt (42 S)-Strait of Magellan area (53 S) (Inostrosa et. al., 1982). Concerning the number and size differences between sexes, males dominate (sometimes they double the number of females). In all reported locations (Campodonico et. al., 1983) mature males are larger than mature females.

Campodonico et. al., 1983, showed a non signigicative difference between the frecuency distribution of males and females up to 80 mm; from 80 mm up, a difference is observed in individuales of 80-90 mm where females dominate; in larger animals (> 100 mm) a dominance of males occur.

A frecuency distribution study versus depth, conducted by Campodonico (1987) in three locations, showed a significative difference on the sex/size distribution, that is the individuals living between 31-60 m are bigger than the shallower ones. Campodonico (1986, 1987) has also shown a distributional gradient among egged females, where shallower egged females are fewer than the ones at depth, where all the females are found to be egged.

Growth by molting, in juveniles from the Magellan Strait sector, has been reported to be similar for males and females (Campodonico and López, 1987; Campodonico et. al., 1982a, 1982b), thus confirming the differences found in mature organism to be reproductively caused (egged females growth slower than males).

The available information in juvenile/adult growing, shows that specific growth rate decreases as the organism gets bigger (Vinuesa and Lombardo, 1982), this has been found to be an exponential decrease, when expressed as percentage of the pre-smolting size (Campodonico and López , 1987). The crabs grow year-round, as molting is observed during all seasons (Campodonico and López, 1987; Vinuesa, 1987; Vinuesa et. al., 1989).

A growth study conducted by Sanhueza (1979), found three ages group in individuals ranging from 20-80 mm, Campodonico and López (1987) assigned and age of two years at the first group, that is, 80 mm crabs would be 5 years old. On the other hand, Boschi et. al., 1984, found the 80 mm males of the Beagle Channel to be 4 years old. If all the above assumptions were correct, Campodonico and López (1987) concluded that individuals from 21 mm up to 79 mm, require 11 moltings in about three years.

Vinuesa et. al., (1989) and Campodonico and López (1987) have also shown the molting in juveniles crabs to be size-dependent:

App size (mm)	Age (year	Moltings	Obs.
	0+	6-7	
? 10	1+	4-5	
? 40	2+	3	(less frequent 2)
? 60	3+	1 female 2 males	
80	4+	1 female 1 males ?	
?	> 5+	every other year ?	

After two years, individuals skip the winter molting, while 3 years and older, females molt once a year and males do twice. The southern King crab also shows an indetermined growth, that is, not a clear terminal anecdisis is found (large adults, > 110 mm, molt every other year).

Diseases/Parasitism/Symbiosis

Weltner (1898) reported for the first time a rhizocephalan barnacle, Briarosaccus callosus, in the abdomen of Smith Channel crabs. Stuardo and Solis (1963) found the percentage of infested animals to be 0.3 % (five infested out of 1497), whether Campodonico (1987) found this value to be up to 10 %, he also reported juvenile females to have up to four barnacles. Campodonico also observed parasited females to have no eggs, while former infested females had little eggs or none.

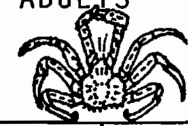
An interspecific relation between a liparid small fish (probably of the genus Careprotus) and the southern King crab has been described by Campodonico and Guzmán (1987), the fish set its eggs in the branquial chamber of the crab.

CONCLUSIONS AND DISCUSSION

The survey on available biological information of the southern King crab, Lithodes santolla, was found to be very concentrated in adults (Table 1). Little information is available for eggs, zoeas, megalopas, and small juveniles. Among areas of knowledge, most of the work has been fisheries biology and population dynamics oriented, as well as reproduction.

The lacking of information occurs among natural habitat, feeding behaviour, energetics, development, growth and ethology of the different size animals.

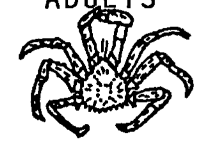
Enhancement of the crab, through cultivation practices was evaluated on the basis of the available information (Table 2). Since none of the biological successes in development/growth has been massifyied, a great deal of work is lacking if intensive/extensive cultivation are to be made. For instance, reproduction studies should consider: induction to maturity, embryogenesis, mating behaviour, fecundation, genetic handling. Development studies should be completed, if larval/juvenile rearing

	STAGE / AREA OF KNOWLEDGE	EGGS 	ZOEAS 	MEGALOPA 	JUVENILE 	ADULTS 		AUTHORS
BIOLOGY	Natural distribution	++	-	-	+	++	++	2-3-4-556-71-79
	Reproduction Maturity Fecundation	-+	*	*	*	++	++	12-15-16-18-20-23-24-25-39-40-43-71-73-75-78-79-80-82
	Development / growth (Physiology)	-	-+	-	-	++	++	1-11-18-19-25-73-75-77-78
PHYSIOLOGY	Habitat	-	-	-	-+	+	+	2-4-51-64-71
	Feeding	*	-+	-	+	+	+	31-42-71-79
	Pop. dynamics (dist./abund./growth	-+	-	-	-+	++	++	5-7-10-18-19-21-22-23-24-25- 26-27-28-37-41-59-60-64-69-71-74-78-79-80-81
	Diseases / Parasitism	-+	-	-	-+	+	+	25-71-83
ECOLOGY	Ethology / Behaviour	-	-+	-	-+	+	+	2-72-80
	Fisheries Biology	+	-	-	-	++	++	3-6-8-9-10-13-14-15-16-17-18-19-20-21-22-23-24-25-27-28-32-33-34-35-36-37-38-42-44-48-49-50-52-53-54-55-58-59-60-61-62-66-67-68-69-70-71-72-76
	General Decapods Industry	*	*	*	*	+	+	4-13-45-46-47-53-56

Note: (-) Unknown; (+) Poorly known; (++) well known; (*) Does not apply

Table 1: State of the art/biological knowledge of the southern king crab (Lithodes santolla) Information was compiled from the reference search.

Cautivation Required Knowledge

AREA OF KNOWLEDGE \ STAGES	EGGS 	ZOEAS 	MEGALOPAS 	JUVENILES 	ADULTS 
Reproduction / Parental - Induction to Maturity - Fecundation / Mating - Genetic Management	 - - -	 * * -	 * * -	 - * -	 - - -
Development (organogenesis)	-	-+	-+	-+	-+
Growth (physiology/ethology)	*	-+	-	-+	+
Feeding Behaviour (physiology, requirements)	*	-+	-	-+	-+
Parasitism / Diseases	-	-	-	-+	-+
Technologies for massive Cultivation (Hatchery)	-	-+	-	-	-
Release Studies / Hydrodinamics	-	-	-	-+	-+

Note: (-) Unknown; (+) Poorly Known; (++) Well Known; (*) Does not apply

Table 2: State of the art on the required biological knowledge of the souther king crab (Lithodes santolla) for cultivation purposes

is wanted. Growth requirements should be physiological/ ethologically oriented, while artificial feeding should be improved (in larval, and juveniles stages). Parasitism and disease studies should be conducted, as well as hydrodinamical behaviour of larvae and juveniles are required if release practices is the final objective.

Our strategy for enhancing the southern King crab is shown in figure 3, diverse experiments are on the way (among technological solutions):

1) Massive egg incubation technology
2) Massive larval rearing technology
3) Massive juvenile rearing technology
4) Growth/behaviour in captivity
5) Feeding technology in captivity
6) Larval release studies (dispersion)
7) Site selection for juvenile release practices.

Among the scientific studies we are planning:

1) Hydrodinamical/physiological behaviour of the southern King crab larvae.
2) Habitat of little juveniles (10-20 mm)
3) In vitro fecundation studies.

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REFERENCES/BIBLIOGRAPHY

1 Amin, O. y J. Vinuesa, 1991. Efectos del petroleo crudo sobre el desarrollo larval de la centolla (Lithodes santolla). In: IV Congreso Latinoamericano de Ciencias del Mar. 30 de Sep. - 4 de Oct., Coquimbo-Chile. 107 p.

2 Angelescu, V., 1960. Operación centolla en el Atlántico (*)Sur. H. 1013. Público. Secret. Marina. Serv. Hidrog. Naval. Buenos Aires.

3 Aranda, E., 1971. Pesca exploratoria de peces y crustáceos en la zona de Navarino. IFOP, Informe a SERPLAC XIIª Región. 38 p.

4 Bahamonde, N., 1963. Decápodos en la fauna preabimal de Chile. Mus. Nac. Hist. Nat., Santiago. Noticiero mensual. Nº 81.

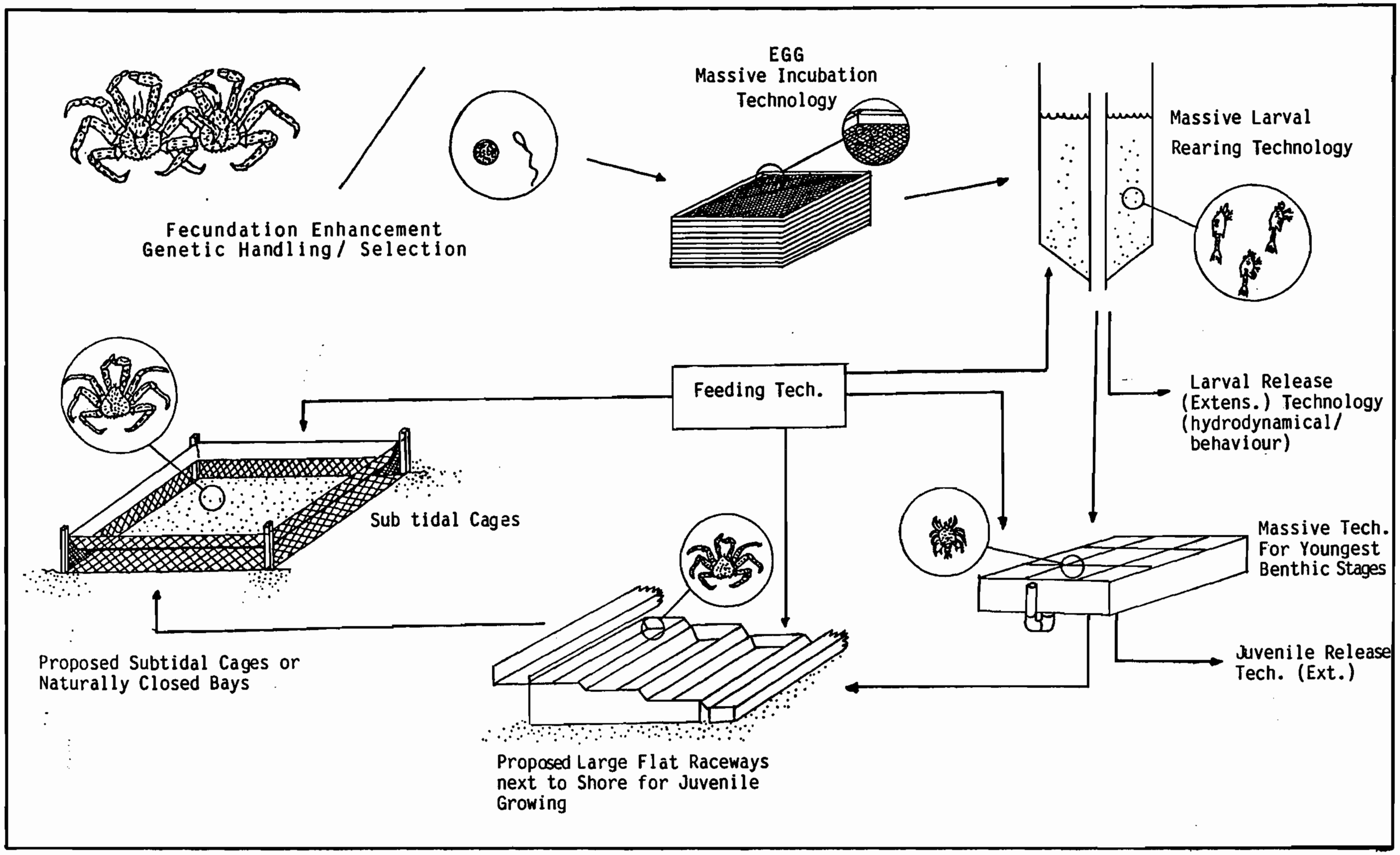


Figure 3 : Proposed studies on the enhrancement program of southern King crab (Lithodes santolla).

5 Balbontin, F., I. Campodonico y L. Guzmán, 1979. Descripción de huevos y larvas de especies de Careproctus (Pices: Liparidae) comensales de Paralomis granulosa y Lithodes antarctica (Crustacea: Lithodidae). Ans. Inst. Pat., Punta Arenas. 10: 235-243.

6 Bertuche, D.A., J.G. Wyngaard and E.E. Boschi, 1985. The fischery biology of Beagle Channel King crab (Lithodes antarcticus). Proc. Int. King Crab Symp. Jan. 22-24, Anchorage, Alaska, USA. 244-266.

7 Bertuche, D.A., J.G. Wyngaard, C.E. Fischbach and E.E. Boschi, 1989. Population structural variation of the southern King crab, Lithodes santolla, of the Beagle Channel, Argentina, from 1975 to 1989. Proc. Inst. Symp. King and Tanner Crabs, Nov. 28-30. Anchorage, Alaska, USA. 411-426.

8 Boschi, E.E., M.A. Scelzo y R. Pérez, 1975. Primer Informe de Trabajo sobre el convenio entre el Proyecto de Desarrollo Pesquero (FAO), el Territorio Nacional de Tierra del Fuego, Antártica e Islas del Atlántico Sur y el Instituto de Biología Marina de Mar del Plata, relativo al estudio biológico pesquero de la centolla. Informe mecanografiado de circulación restringida, Argentina. 15 p.

9 Boschi, E.E., M.A. Scelzo and R. Pérez, 1975/1976. Informe de trabajo relativo al estudio biológico pesquero de la centolla. Mar del Plata. Inst. Biol. Mar. I: 15 p.; II: 11 p.; III: 7 p. y IV: 6 p.

10 Boschi, E.E., D.A. Bertuche y J.G. Wyngaard, 1984. Estudio (*) bio-pesquero de la centolla (Lithodes antarcticus) del Canal Beagle, Tierra del Fuego, Argentina. INIDEP. Contribución 441, I Parte: 1-72.

11 Campodonico, I., 1971. Desarrollo larval de la centolla (*) Lithodes antarcticus Jacquinot en condiciones de laboratorio. Ans. Inst. Pat., Punta Arenas. 2: 181-190.

12 Campodonico, I., L. Guzmán y A. Sanhueza, 1974. Madurez sexual de los machos de la centolla Lithodes antarcticus Jacquinot, del área de Punta Arenas, Porvenir, Estrecho de Magallanes. Ans. Inst. Pat., Punta Arenas. 5: 215-222.

13 Campodonico, I., 1979. La veda de la centolla (Lithodes antarctica Jacquinot) en la Región de Magallanes. Ans. Inst. Pat., Punta Arenas. 10: 229-234.

14 Campodonico, I., 1980. Investigación, manejo y control de las pesquerías de centolla y centollón de la XII Región (año 1979). Inf. Inst. Pat., 1: 39 p.

15 Campodonico, I. y M.B. Hernández, 1981. Investigación, manejo y control de las pesquerías de centolla y centollón en la XII

Región (temporada 1980-81). Inf. Final Proy. Inst. Pat., 4: 76 p.

16 Campodonico, I., M.B. Hernández y E. Riveros, 1982. Inves(*) tigación, manejo y control de las pesquerías de centolla y centollón de la XII Región (temporada 1981-82). Inf. Inst. Pat., 9: 115 p.

17 Campodonico, I., M.B. Hernández y E. Riveros, 1982. Inves(*) tigación, manejo y control de las pesquerías de la centolla y centollón de la XII Región. I Etapa, temporada 82-83. Inf. Inst. Pat. 10: 41 p.

18 Campodonico, I., M.B. Hernández y E. Riveros, 1982. Inves tigación, manejo y control de las pesquerías de centolla y centollón de la XII Región. II Etapa, temporada 1982-83. Inf. Inst. Pat., 14: 42 p.

19 Campodonico, I., M.B. Hernández y E. Riveros, 1982. Investigación, manejo y control de las pesquerías de centolla y centollón de la XII Región. III Etapa. Temporada 1982. Inf. Inst. Pat., 16: 151 p.

20 Campodonico, I. y M.B. Hernández, 1983. Estado actual de la pesquería de la centolla (<u>Lithodes antarctica</u>) en la Región de Magallanes. In: Análisis de las pesquerías chilenas. Patricio Arana (Ed.) Escuela de Ciencias del Mar, Univ. Cat. Valp., Valparaíso, 55-76.

21 Campodonico, I., M.B. Hernández y E.Riveros, 1983. Inves tigación, manejo y control de las pesquerías de centolla y centollón de la XII Región. IV Etapa, temporada 1982. Inf. Inst. Pat., 21: 67 p.

22 Campodonico, I., M.B. Hernández y E. Riveros, 1983. Inves(*) tigación, manejo y control de la pesquería de centolla y centollón de la XII Región. Inf. Inst. Pat., 25: 97 p.

23 Campodonico, I., 1986. Estudio en poblaciones de hembras de centolla. In: Diagnóstico bio-pesquero de la centolla, XII Región, 1985. Inf. Inst. Fom. Pesq., s/n: 17 + tablas y figuras.

24 Campodonico, I., 1986. Consideraciones sobre la utilización de (*) hembras en la pesquería de la centolla (<u>Lithodes antarcticus</u>) de la XII Región. Invest. Pesq. (Chile). 33: 121-123.

25 Campodonico, I., 1987. Estudio en poblaciones de hembras, (*) 1986. In: Diagnóstico bio-pesquero de la centolla XII Región. Inf. Inst. Pat., 39: 41 p.

26 Campodonico, I. y L. Guzmán, 1987. Una relación inter(*) específica entre un pez liparido y el crustáceo <u>Lithodes antarctica</u>. Ans. Inst. Pat., 8: 389-390.

27 Campodonico, I. y J. López, 1987. Crecimiento de juveniles
(*) en cautividad. In: Diagnóstico biopesquero de la centolla, XIIª Región. Inf. Inst. Pat., 39: 24 p.

28 Campodonico, I. y López, 1988. Crecimiento de juveniles en cautividad. In: Diagnóstico biopesquero de la centolla, XIIª Región. Inf. Inst. Pat., 43: 22 p.

29 Cárdenas, J.C., J. Oporto, M. Stutzin y J. Gibbons, 1986. Impacto de la pesquería de centolla (Lithodes antarctica) sobre las poblaciones de cetáceos y pinnípedos en la Región de Magallanes, Chile. In: Resúmenes II Reuniao de rabalho de Especialistas en Mamíferos Aquáticos da América do Sul. Agot. 4-8, Río de Janeiro, Brasil. 49 p.

30 Cárdenas, J.C., J. Gibbons, J. Oporto y M. Stutzin, 1987. Impacto de la pesquería de centolla y centollón sobre las poblaciones de mamíferos marinos de Magallanes, Chile. Ambiente y Desarrollo. 3(1-2): 111-119.

31 Comoglio, L.I., J.H. Vinuesa and G.A. Lovrich, 1989. (*) Feeding habits of southern King crab, Lithodes santolla (Molina), and the false King crab, Paralomis granulosa Jacquinot, in the Beagle Channel. Proc. Int. Symp. King and Tanner Carbs, Nov. 28-30, Anchorage, Alaska, USA. 315-325.

32 CORFO, 1982. Programa de investigación de los recursos centolla, centollón y jaibas. (Extracto) Inf. Inst. Fom. Pesq. AP/82/21. 9 p.

33 CORFO, 1987. Diagnóstico bio-pesquero de la centolla, XII Región. I. Análisis de la pesquería de centolla, 1987. Inf. Inst. Fom. Pesq., Santiago. s/n: 64 p.

34 Díaz, O.P., 1987. Situación de los recursos centolla y centollón en la XII Región (Región de Magallanes). Rev. Chile Pesq. 44: 37-41.

35 Díaz, P. e I. Muzio, 1987. Análisis de la pesquería de centolla, 1986. In: Diagnóstico bio-pesquero de la centolla. XII Región, 1986. Inf. Inst. Fom. Pesq., Santiago. s/n: 58 p.

36 Geaghan, J., 1971. Observaciones biológico-pesquero sobre centolla (Lithodes antarctica Jacquinot) efectuadas en la Bahía Santa María. Inst. Fom. Pesq., Chile. 73: 8 p.

37 Geaghan, J., 1973. Resultados de las investigaciones sobre
(*) centolla, (Lithodes antarcticus Jacquinot), realizados por el Instituto de Fomento Pesquero en la Provincia de Magallanes. Inst. Fom. Pesq., 52: 41 p.

38 González, O. y M. Perugi, 1974. Pesca exploratoria para detectar la presencia de centolla entre el Estrecho de Magallanes y Puerto Natales (Sept. a Dic. de 1972). Inst. Fom. Pesq., Santiago. 55: 54 p.

39 Guzmán, L. e I. Campodonico, 1972. Fecundidad de la centolla Lithodes antarctica Jacquinot (Crustacea Decapoda, Anomura: Lithodidae). Ans Inst. Pat., Punta Arenas. 3: 249-257.

40 Guzmán, L. y A. Sanhueza, 1974. Madurez sexual de los machos de la centolla Lithodes antarctica Jacquinot, del área Punta Arenas-Porvenir, Estrecho de Magallanes. Ans. Inst. Pat. 5: 215-22.

41 Guzmán, L., C. Ríos, M.B. Hernández y P. Díaz, 1984. Investigación, manejo y control de la pesquería de centolla de la XII Región (Temporada 1983). Inf. Inst. Pat. 30: 78 p.

42 Guzmán, L. y C. Ríos, 1985. Investigación, manejo y control de
(*) la pesquería de centolla y centollón de la XII Región (1979-1983). Inf. Consol.: recurso centolla (Lithodes antarcticus Jacquinot). Inf. Inst. Pat., 34: 259 p.

43 Guzmán, L. y C. Ríos, 1986. Talla de la madurez sexual en la centolla (Lithodes antarcticus Jacquinot): Hacia la elaboración de un modelo específico. En: La pesca en Chile. Patricio Arena (Ed.) Escuela de Ciencias del Mar, UCV, Valparaíso: 89-101.

44 Guzmán, L. y C. Ríos, 1987. Alometría en Lithodes antarcticus Jacquinot, 1883 (Crustacea: Decapoda): Largo de la quela derecha versus largo del caparazon. Ans. Inst. Pat., Punta Arenas, 17: 89-98.

45 Heggem, O., 1962. Centolla industry in Tierra del Fuego. 1 March., U.S. AID. Chile.

46 Heggem, O., 1962. Centolla industry in Tierra del Fuego. 2 Sept., U.S. AID. Chile.

47 Heggem, O., 1963. Nota sobre la industria de la centolla (King crab) (Lithodes antarcticus). Punta Arenas-Porvenir, abril 1962-junio 1962. Cartilla nº 8, serie divulgación pesquera, Dept. de Pesca y Caza. 13 p.

48 Hernández, M.B., 1980. Manejo de las pesquerías de centolla y centollón de la XII Región. I Etapa, 1970. Inf. Téc. Inst. Fom. Pesq., Santiago. 37 p.

49 Hernández, M.B., 1981. Manejo de las pesquerías de la centolla y centollón de la XII Región. II Etapa, 1980. Inf. Téc. Inst. Fom. Pesq., Santiago. 45 p.

50 Hernández, M.B., I. Campodonico y P. Díaz, 1984. Investigaciones biopesqueras del recurso centolla (Lithodes antarcticus) realizadas entre 1970 y 1984 en la XII Región. Inf. Inst. Fom. Pesq., Chile. s/n: 139 p.

51 Hernández, M.B. y P. Díaz, 1984. Informe de proyecto. Manejo de la Pesquería de centolla de la XII Región. Quinta Etapa, 1983. Inst. Fom. Pesq., Santiago. s/n: 38 p.

52 Hernández, M.B. y P. Díaz, 1985. Diagnóstico bio-pesquero de la centolla XII Región. Inf. Inst. Fom. Pesq., Chile. s/n: 44 p.

53 Hernández, M.B., 1986. Situación y perspectivas de explotación del recurso centolla. In: Seminario la Pesquería de Centolla XII[a] Región. Mayo 29-30, Punta Arenas, Chile. CORFO/IFOP. 15-22.

54 Hernández, M.B., P. Díaz 1986. Análisis de la pesquería de centolla. In: Diagnóstico bio-pesquero de la centolla, XII Región, 1985. Inf. Inst. Fom. Pesq., s/n 43 + tablas.

55 IFOP, 1969. Pesca exploratoria de centolla y otras espe(*)cies de importancia comercial en la Región de Magallanes y Tierra del Fuego. Circ. Inst. Fom. Pesq., Santiago. 43: 49 p.

56 IFOP, 1969. Pesca exploratoria de centolla (Lithodes antarctica Jacquinot) y otras especies de importancia comercial en la Región de Magallanes y Tierra del Fuego (Oct. 1968- Mar. 1969). Inst. Fom. Pesq., Santiago. 43: 16 p.

57 IFOP, 1969. Elaboración de centolla congelada y en conserva (con especial referencia a Chile). Inst. Fom. Pesq., Santiago. 40: 39 p.

58 IFOP, 1971. Trabajos de pesca exploratoria y experimental realizados entre el Canal Beagle y el Cabo de Hornos, de abril a noviembre de 1970. Inst. Fom. Pesq., Santiago. 70: 32 p.

59 Inostroza, F., R. Gili y R. Salas, 1982. Programa de (*) investigación de los recursos centolla, centollón y jaibas. Inst. Fom. Pesq., s/n: 195 p.

60 Inostroza, F., R. Gili y R. Salas, 1982. Programa de investigación de los recursos centolla, centollón y jaibas. Inst. Fom. Pesq. AP/82/24. 62 p.

61 Inostroza, F., R. Gili, R. Salas y L. Vidal, 1982. Programa de investigación de los recursos centolla, centollón y jaibas. I Resumen y Conclusiones. CORFO/IFOP, Santiago. AP/82/21. 71 p.

62 Inostroza, F., R. Salas y R. Gili, 1982. Programa de investigación de los recursos centolla, centollón y jaibas. Inf. Inst. Fom. Pesq. AP/82/23. 33 p.

63 Lecaros, O. y P. Mackenney, 1981. Determinaciones preliminares de mercurio en crustáceos lithodidos y peces marinos de la Región Magallánica. Ans. Inst. Pat. 12: 295-299.

64 López, J., 1986. Investigaciones de juveniles de centolla, Lithodes antarcticus, del sector Santa María, Estrecho de Magallanes. Práctica Profesional. Inst. Prof. Osorno, Dept. de Acuicultura y Alimentos. 20 p.

65 Newsletter of the Cetacean Specialist Group, 1986. Use of dolphins for crab bait in Chile. Species Survival Commission. UICN, 2: 8 p.

66 Sanhueza, A.S., 1976. Aspectos bio-pesqueros del recurso centolla (Lithodes antarctica Jacquinot). Inf. Pesq. Inst. Fom. Pesq., Santiago. 61: 24 p.

67 Sanhueza, A., E. Aranda y G. Celedon, 1977. Resultados de experiencias de pesca de centollas con trampas. Inf. Téc. Inst. Fom. Pesq., Santiago. s/n: 31 p.

68 Sanhueza, A., 1978. Resultados exploración pesquera zona Puerto Edén-XII Región. Inf. Inst. Fom. Pesq., Santiago s/n: 32 p.

69 Sanhueza, A., 1979. Centolla Lithodes antarctica
(*) Jacquinot. Crustacea, Decapoda, Anomura, Lithododae. In: Estado actual de las principales pesquerías nacionales. Bases para un desarrollo pesquero. CORFO/IFOP, Chile. 39 p.

70 Scelzo, M.A., J.L. Fenucci y E.E. Boschi, 1974. Resultados preliminares sobre la biología pesquera de la centolla Lithodes antarcticus en el mar argentino. CARPAS, FAO, Montevideo, Doc. 6/74/Téc. 4: 33.

71 Stuardo, J. e I. Solís, 1963. Biometría y observaciones (*) generales sobre la biología de Lithodes antarcticus Jacquinot. Gayana Zool. 11: 1-58.

72 Vidal, L., 1986. Análisis económico de la pesquería de centolla. In: Seminario la Pesquería de la Centolla XII Región. Mayo 29-30, Punta Arenas, Chile. CORFO/IFOP. 71-78.

73 Vinuesa, J.H., 1982. Biología de la reproducción y el (*) desarrollo embrionario y larval de la centolla Lithodes antarcticus Jacquinot en el Canal Beagle, Tierra del Fuego. Tesis Doctoral. 155 p.

74 Vinuesa, J.H. y R. Lombardo, 1982. Observaciones sobre el
(*) crecimiento en la muda de hembras adultas de centolla Lithodes antarcticus Jacquinot. Physis (a), 40 (99): 69-74.

75 Vinuesa, J.H., 1984. Sistema reproductor, ciclo y madurez gonadal de la centolla (Lithodes antarcticus) del Canal Beagle. contr. 441, INEDEP, Mar del Plata, Argentina. 75-95.

76 Vinuesa, J.H., 1985. Differential aspects of the southern King crab (Lithodes antarcticus) in two latitudinally separated locations. Proc. Int. King Crab Symp., Jan. 22-24, Alaska, USA. 267-279.

77 Vinuesa, J.H., L. Ferrari and Lombardo, 1985. Effects of temperature and salinity on larval development of southern King crab (Lithodes antarcticus). Mar. Biol. 85: 83-87.

78 Vinuesa, J.H., 1987. Embryonary development of Lithodes (*) antarcticus Jacquinot (Crustacea, Decapoda, Lithodidae) developmental stages, growth and mortality. Physis, Buenos Aires A 45: 21-29.

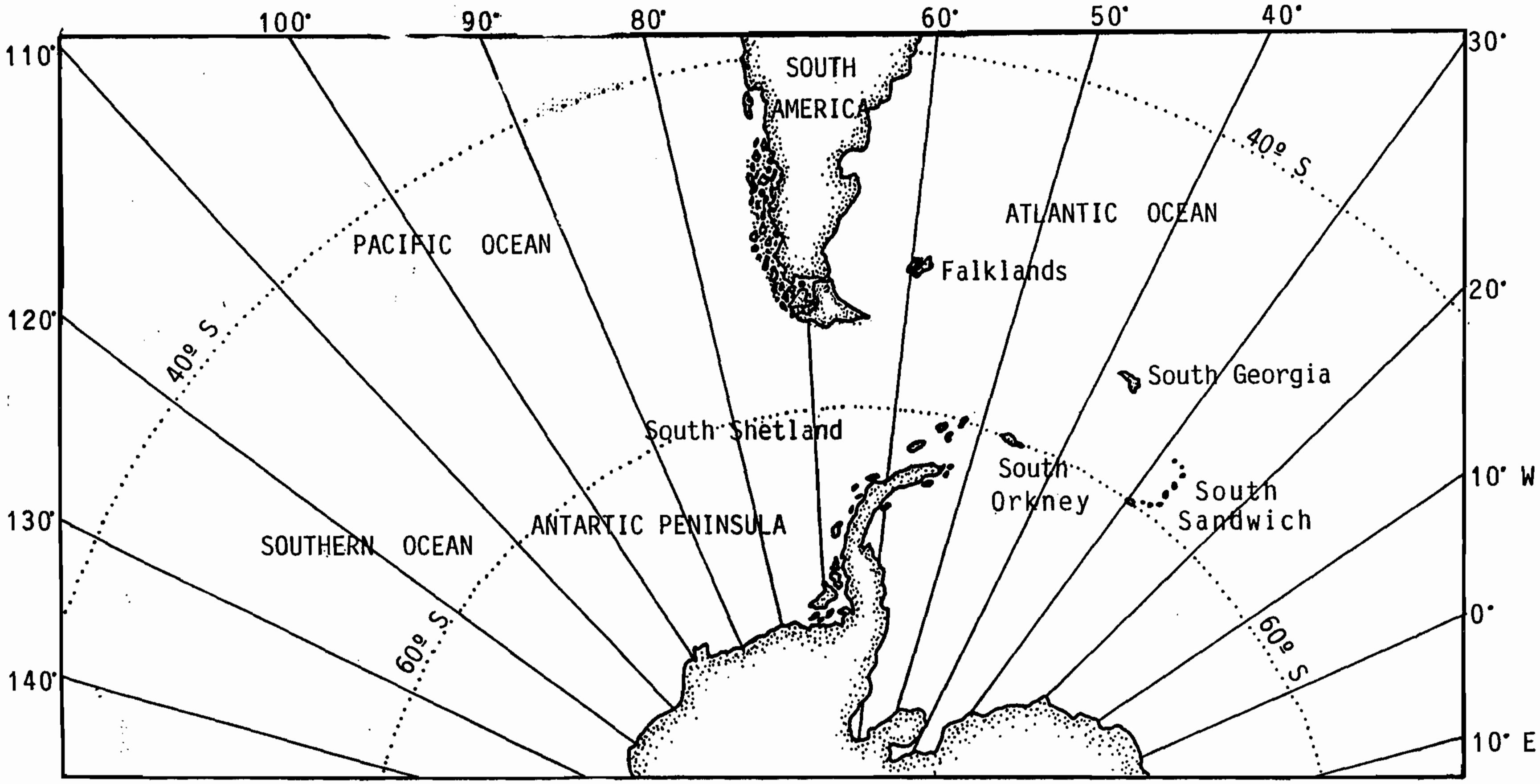
79 Vinuesa, J.H., L.I. Comoglio and G.A. Lovrich, 1989. (*) Growth of inmature southern King crab Lithodes santolla, in the Beagle Channel. Proc. Int. Symp. King and Tanner Crabs, Nov. 28-30, Anchorage, Alaska, USA. 259-271.

80 Vinuesa, J.H., G.A. Lovrich and L.I. Comoglio, 1989. Relación madurez sexual-muda en centollas hembras juveniles (Lithodes santolla). Jor. Nac. Cs. del Mar., Madryn 64 p.

81 Vinuesa, J.H., L. Comoglio y G. Lovrich, 1991. El creci(*) miento de la centolla, Lithodes santolla. In: IV Congreso Latinoamericano de Ciencias del Mar. Sep. 30-Oct. 4, Coquimbo, Chile. 150 p.

82 Vinuesa, J.H. (MS). Gametogenesis in southern King crab, Lithodes santolla in the Beagle Channel. Manuscrito.

83 Welner, W., 1998. Cirripedien. Hamburger magehaensische sammelrise. Pt. 4 Hamburg.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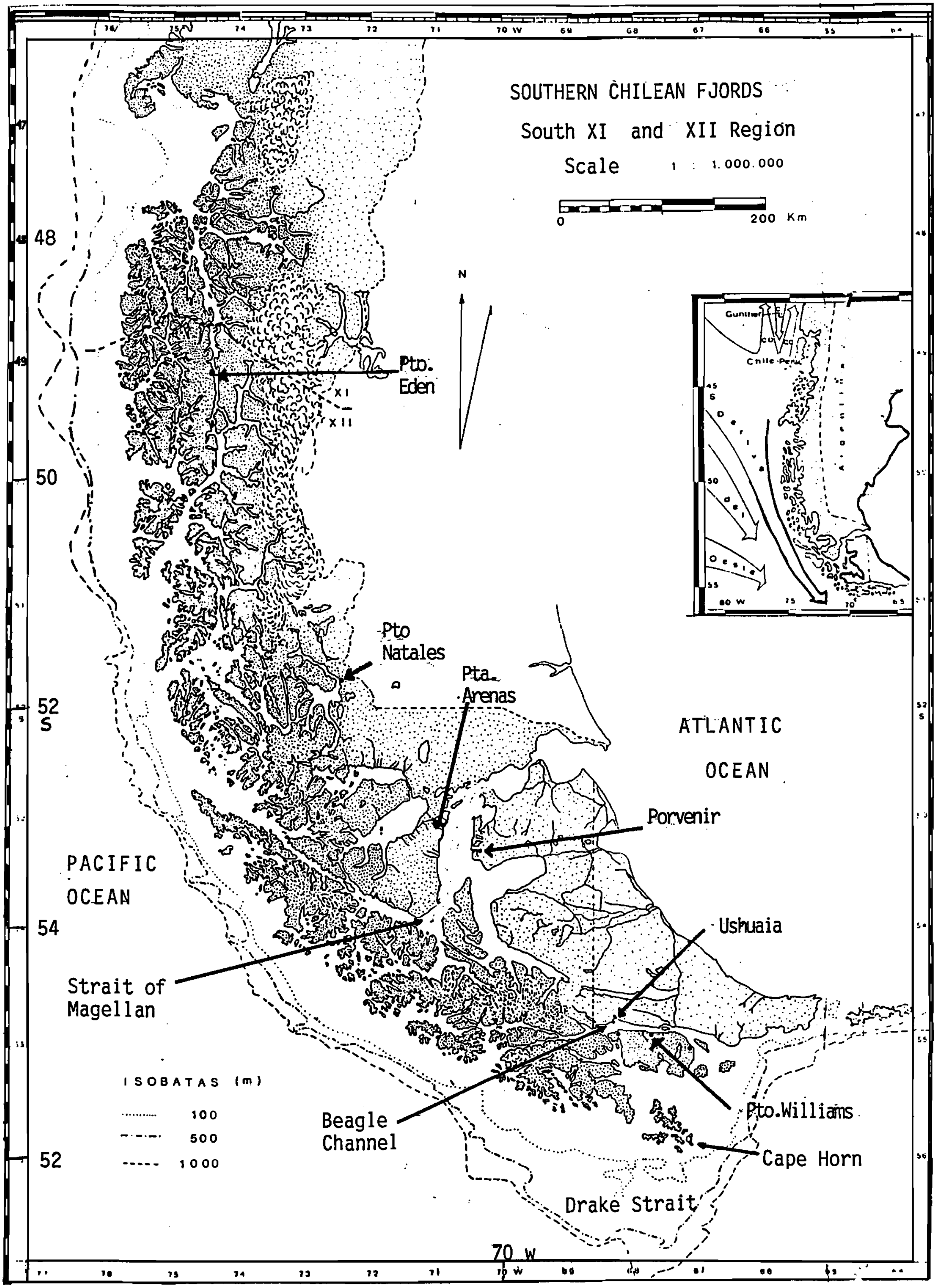
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NORWEGIAN LOBSTER ENHANCEMENT

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ABSTRACT

The private firm "Tiedemanns" started a lobster farming research program in 1978, based on the production of larvae from wild berried lobsters. In 1982 a production plant with the capacity of 120.000 one year old lobsters was finished. The locality at Kyrksæterøra was chosen because of the availability of free heated sea water from a smelting work.

The lobsters have been released at different localities mostly in western Norway , where the natural stock for the time being is at a very low level. The intention was that any effect of the the release program should easily be detected. The input on the control of effects was therefore relatively modest. However, it was discovered that the percentage of lobsters with two pincer claws increased in the release areas. These lobsters are easily detected by experienced fishermen.

In two areas in southern Norway the released lobsters contributed in 1989 more than 50 % to the lobsters recruiting to the commercial stock.

INTRODUCTION

Lobster culture has been tried in different forms since the first attempts in 1865 in France. Biological it is quite easy to raise lobsters from berried females. However, hitherto the industry has not found it commercially viable to raise lobsters to market size.

The release programs of 2 to 4 week old juvenile lobsters which were run for years in USA, Canada, France and Norway were not able to provide any good prove of beneficial effects on the lobster stocks.

An intermediate approach could be to raise the lobsters ashore to a size which probably is less susceptible to predation than the postlarvae traditionally released, and then release them in the sea either for a general stock enhancement or under a more controlled form, as sea ranching. In 1977 this idea was taken up by a cooperation project between SINTEF (Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) and a Norwegian industrial company, Tiedemanns.

In 1980 after successful experimentation with both land and sea aspects of lobster farming first at Flødevigen Marine Research Station and then at Bulandet (Fig 1), Tiedemanns decided to build a large scale production unit. This was built at Holla Smelting Works, Kyrksæterøra in mid Norway, where there is an abundant

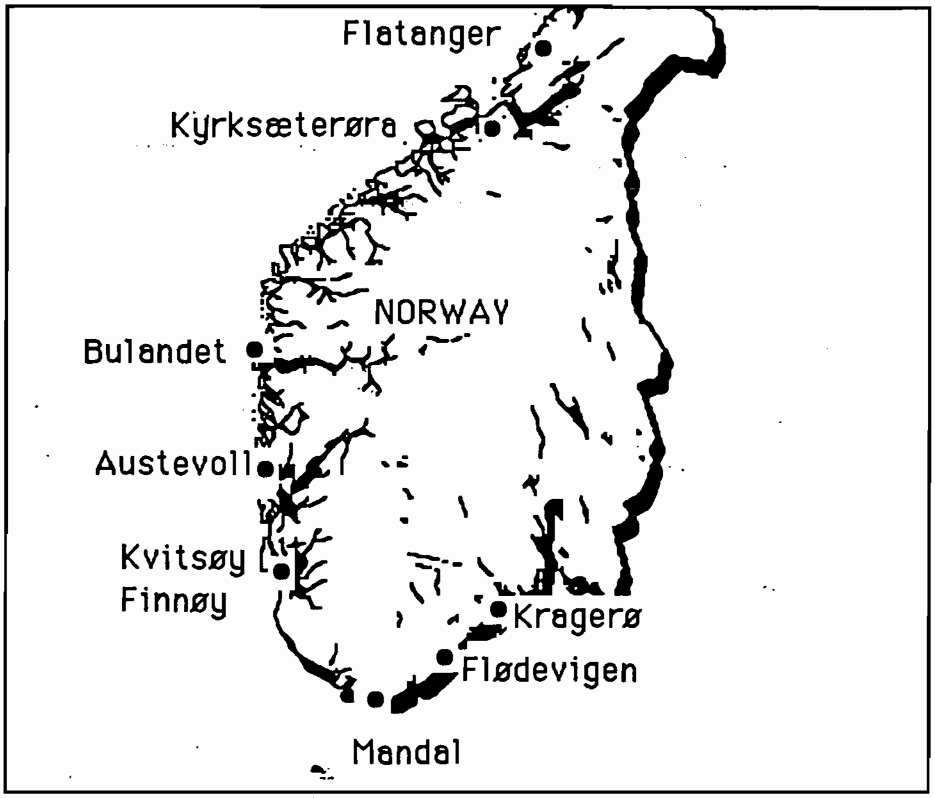


Fig. 1 Sites for production and release of one year old lobster

supply of heated sea water available. The annual production capacity of this unit is at present 120,000 one year old juveniles.

In 1989 Tiedemanns handed over the facilities at Kyrksæterøra to The Institute of Marine Research, Bergen. The intention was that under governmental administration it would be easier to enforce special legislations in the release areas. It was also felt that especially the transportation and releasing technique had to be refined through more research than Tiedemanns were willing to provide.

MATERIAL AND METHODS

The technique for producing juvenile lobsters used (Grimsen et al., 1987, Tveite and Grimsen 1992) are in principle the same as described in the literature (van Olst et al., 1980; Chang and Conklin, 1983; Beard et al., 1985).

At water temperature of 20°C a size of 8-10 gram has been reached in 11-12 months.

During the first period when the pilot plant were operating at Bulandet, the lobsters were released directly into the sea with a very short transportation distance. Here observations were made by divers both at the time of release and later on. A few sudden deaths were observed but mostly the lobsters were able to find shelter rather within seconds than minutes.

The lobsters were partly provided with artificial shelters, fed additionally with blue mussels, released in areas fenced by different methods, or released in more natural environment. It was quite early found that artificial barriers were of both economical and practical reasons inconvenient.

The lobsters were found to be quite stationary after release and lobsters confined to small areas (0.2 m^2) by net cages survived for 15 months and moulted although not at same growth-rate as free living ones.

Of 45 lobsters released in a 50 m^2 glass-fiber fenced area 12 were recaptured after two months in the sea, 4 of these having only one claw, combined with the small growth observed this shows that the density of lobsters were too high in this enclosure. 36 new lobsters were released in the area and after ten months 11 were recaptured, showing that the carrying capacity in an area like this is one lobster per 4-5 m^2. However the growth rate was again poorer than for more free living ones.

In the bigger enclosures or in areas without barriers it was difficult to recapture the lobsters in significant numbers, however, those recaptured or only observed by diving had all achieved good growth consistent with the three years to market size schedule.

After the high production of yearlings was reached at Kyrksæterøra the following method of releasing lobsters has been used for the experiments described in this paper: The lobsters are packed in cardboard or polystyrene boxes with salt water moistened wood chips cooled by frozen newspapers or freezing elements. The time from the start of packing till the last lobster has been released in the sea has been kept within 24 hours.

The one year old lobsters has been released at the surface in summertime from small boats at 2-10 m depth and a density of one juvenile per 10-20 m^2. Local fishermen have used their knowledge of the bottom conditions so the lobsters reach the bottom at the most favourable sites.

Table 1. Number of lobsters released

year	Place	Number
1979-1980	Bulandet	1000
1983	Bulandet	6600
1984	Bulandet	90000
1985	Kvitsøy	20000
	Finnøy	10000
	Mandal	7650
	Kragerø	7850
	Frøya	3150
	other	5465
1986	Kvitsøy	11000
	Flatanger	10000
	Mandal	7500
	Sula	5000
	other	5000
1987	Mandal	7500
	Sula	5000
	Risør	1500
1988	Austevoll	10800

RECAPTURES

The lobsters released in 1979 and 1980 at Bulandet have been observed in the commercial catches. As an example can be mentioned that while fishing in the area of release, the percentage of small lobsters were much higher than outside these areas (Table 2).

Table 2. Some lobsters catches in numbers at Bulandet separated in three size categories, and two areas for 1984 and 1985.

		<22 cm	22-25 cm	>25cm
1983	outside release area	3	1	83
1984	in release area	26	36	29
	outside release area	0	10	72
1985	in release area	21	50	16
	outside release area	6	10	169
1987		20	26	121
1988	fishery before season	12	4	

Detailed measurements of lobster catch are only available from the Mandal and Kragerø area.

The released lobsters are not all equally easy to detect, the easiest ones has lighter colours in addition to the two pincer claws, some has the the typical black colour of the natural population but clearly two pincer claws and finally some with the more light colour has to some extent developed a crusher claw. All has been categorised as released lobsters. Since no tagged ones has yet been recaptured we do not know if some will develop an appearance just like the natural ones. On the other hand control of lobster catches in areas without release program it was not at all observed lobsters which would have been categorised as released ones. The figures in this report must therefore be considered as minimum figures.There is no observations of behaviour among the released ones indicating differences to the natural population. Berried female has been caught at same lengths as wild ones.

In the Kragerø area 7850 lobsters were released in 1985. Until 1991 there is only one observation of recaptured lobster reported to us. No informations available about the conditions of the lobsters, the release or the transportation method can explain that this release should give other results than those in the Mandal area.

In the Mandal area 7500 lobsters were released yearly in 1985,86 and 87. The first recaptures were discovered in small numbers in 1988 (Fig.2). Most of these were below the minimum size of 22 cm total length.

In 1989 a considerable higher number were caught (Fig. 2). Below 24 cm total length the released lobsters were more numerous than the natural stock. The growth from 1988 to 1991 is shown in Fig. 3. The peak of the curves moves 2 cm, consistent with results from tagging experiments in the same area (unpublished data).

The left part of the curves on Fig 3 shows that there was no further recruitment of released lobsters in 1989, whether this

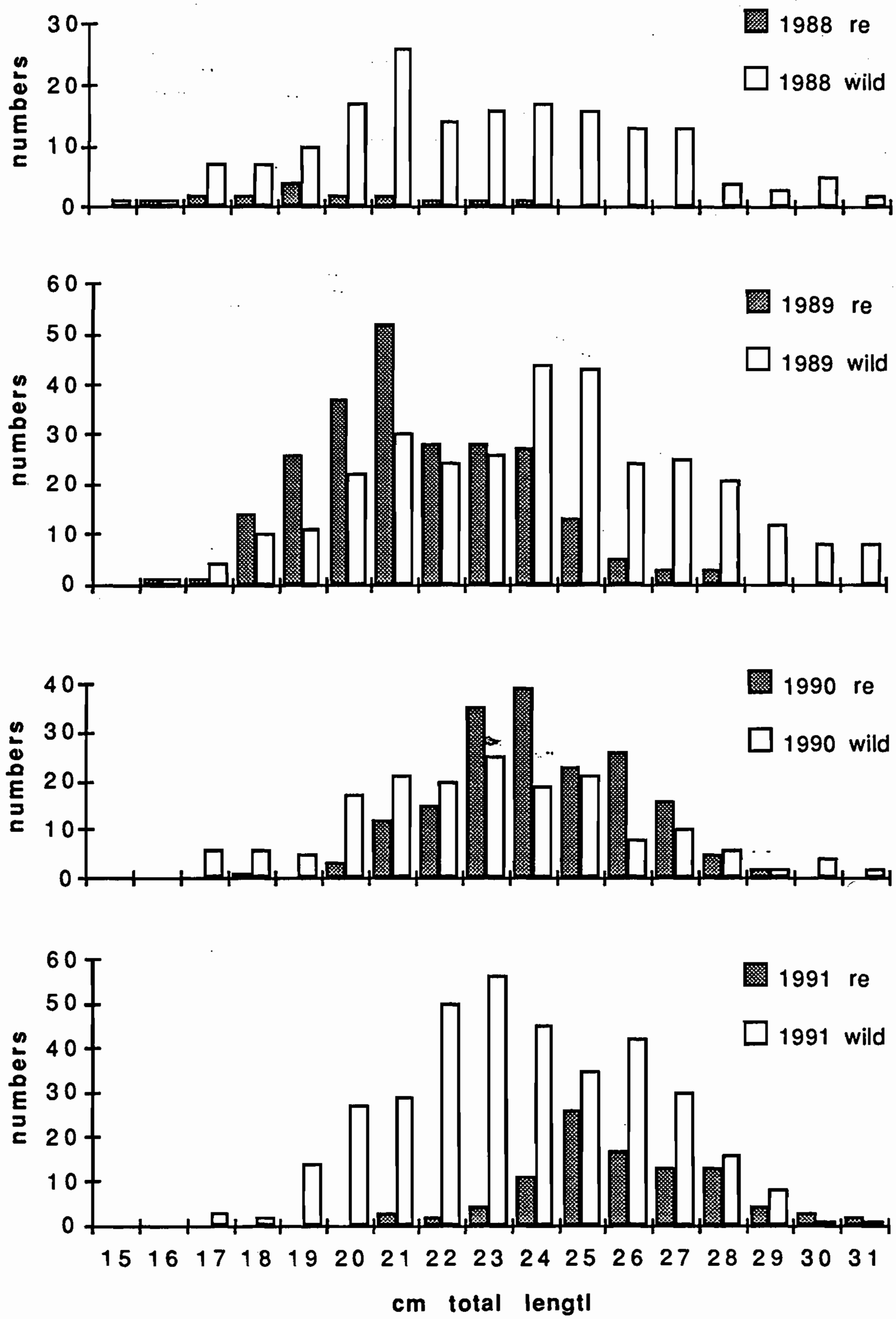


Fig. 2. Numbers of hatchery reared released and wild lobsters in the total catch for one fisherman, Mandal 1988 - 1991.

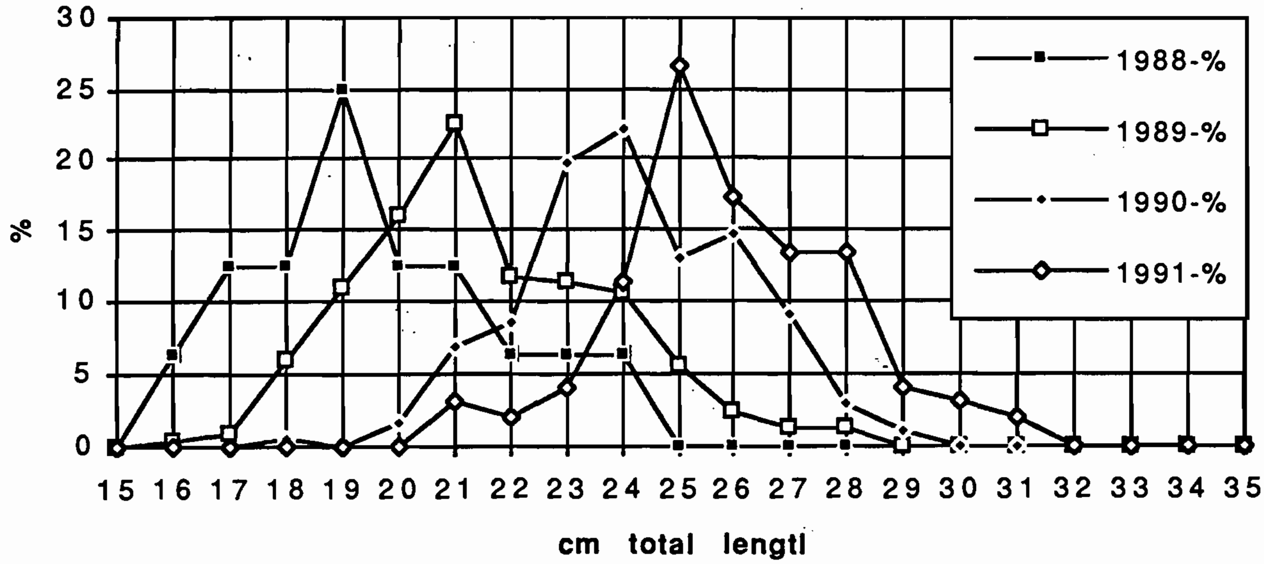
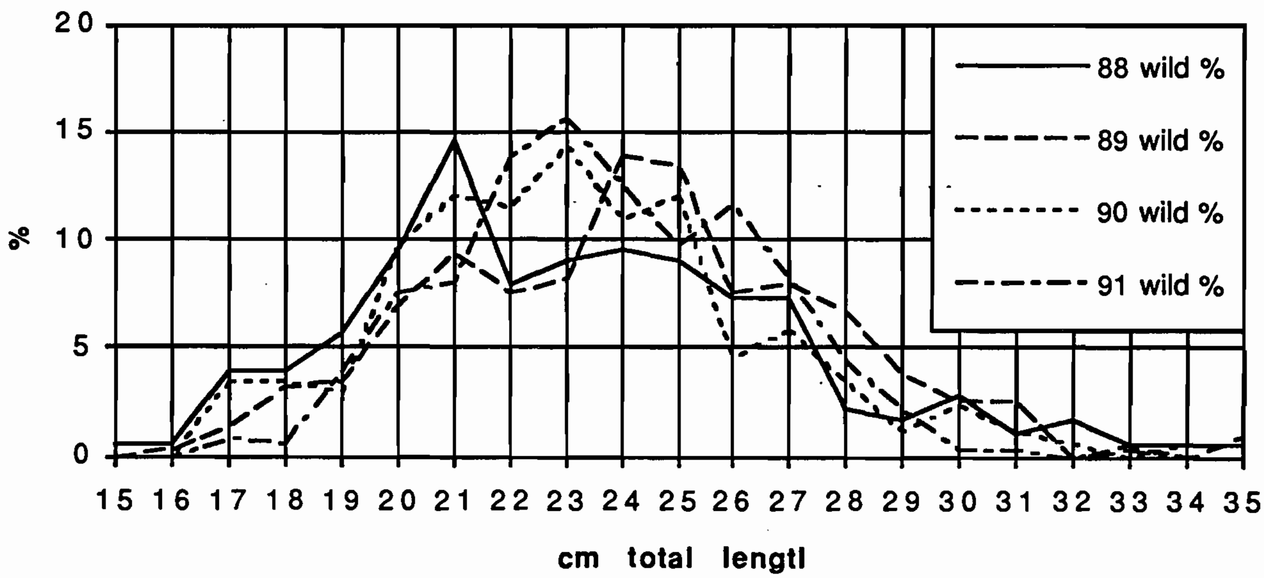


Fig. 3 % length distribution of recaptured lobsters 1988 - 1991.



group consists of one, two or three year-classes is impossible to say. Length distributions for the natural stock shows that there are new year-classes recruiting to the catches (Fig 4.)

One fisherman fishing partly in the release area got 16% hatchery reared lobsters, while the fisherman fishing completely within the release area got 43% recaptured of the total catch. The small lobsters seems therefore to be quite stationary. There are no physical barriers between the two areas.

From the other areas of release there are few informations. Until now the reported recaptures after the 90 000 released in 1984 at Bulandet are few. However, the weather conditions for fishing has been poor the last years and the lobsters are probably growing slower in this area.

In 1989 at Kvitsøy many fishermen got more than 50% in numbers of their lobster catch originating from the the release program.

DISCUSSION

Although some experiments like the one in Kragerø has been complete failures, results hitherto has proved that in small areas a release program may exceed the natural recruitment.

In the future one can expect more quantitative results since all the lobsters will be tagged. Improved release method will probably increase the survival rate (G.I.v.d Meeren et al 1990). We know that the lobster stock has been much more abundant (C.J.Rørvik and S. Tveite 1982, Tveite 1991), there should therefore be room for increased lobster populations. Whether it will be economical viable is quite another question.

REFERENCES

Beard, T.W., Richards, P.R., and Wickins, J.F. 1985. The techniques and practicability of year round production of lobsters, *Homarus gammarus* (L), in laboratory recirculation systems. MAFF Direct. Fish. Res.,Fish. Res. Tech. Rep. 79, 22 pp

Brisset, P., Versichele, D., Bossuyt, E., Ruyck, L. D., and Sorgeloos, P. 1982. High density flow through culturing of brine shrimp *Artemia* on inert feeds - preliminary results with a modified culture system. *Aquacultural Engineering* 1, 115-119.

Chang, E.S., and Conklin, D.E. 1983. Lobster (*Homarus*) hatchery techniques. In J.P. McVey (editor) CRC *Handbook of Mariculture*, Vol. I, *Crustacean Aquaculture* (CRC Press, Cleveland OH), 271-275.

Grimsen, S., Jaques, R.N., Erents and Balchen, J.G. 1987. Aspects of automation in a lobster farming plant. *Modelling, Identification and Control* 8.(1)61-68

Meeren, G.I.v.d., Svåsand, T., Grimsen, S., Kristiansen, A. and Farestveit, E. 1990. Large scale release experiment of juvenile lobsters Homarus gammarus, in Norway. (in press)

Olst, J.C.v, Carlberg, J.M. and Hughes, J.T. 1980. Aquaculture. In J.S. Cobb and B.F. Phillips (Editors), *The Biology and Management of Lobsters, Vol II* (Academic Press, New York), 333 - 384.

Perkins, H.C. 1972. Development rates at various temperatures of embryos of the Northern lobster *Homarus americanus. Fishery Bull. Natl. Oseanic and Atmos. Adm (U.S.),* 70:95 - 99.

Rørvik, C.J. and Tveite, S. 1982. A stock assessment of lobster (*Homarus gamarus*) on the Norwegian Skagerrak coast. *Flødevigen Rapportserie* No 3 1982,20 pp

Tveite, S and Grimsen, S 1992. Survival of one year old artificially raised lobsters (*Homarus gammarua)* released in southern Norway. *Rapp. P.-v. Reun. Cons. int. Explor. Mer,* (in press)

Tveite, S. 1991 Hummerbestanden i Norge med særlig vekt på Skagerrak. *Flødevigen Meldinger* 4/1991 12pp

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THE EFFICACY OF BLUE COLORMORPHIC AMERICAN LOBSTERS IN DETERMINING THE FEASIBILITY OF HATCH OR RELEASE PROGRAMS

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ABSTRACT

A multilevel culture technique is utilized that employs the use of cultured algae, brine shrimp and hatchery produced lobster larvae: (Homarus americanus) Standard bivalue hatchery technology and equipment has been adapted for the culture of lobsters from first stage to fourth stage. Brine shrimp are hatched and grown in 400 liter conical tanks for several days utilizing fresh cultured micro algae as a food source. Newly hatched lobster larval are introduced into this culture medium and maintained there with periodic changes of the algae-brine shrimp culture until fourth stage. Blue lobster larvae obtained from laboratory breeding stock were cultured to fourth stage in this system. They were then utilized in a series of laboratory tests to compare their behavior to normal-hatchery reared fourth stage lobsters on a variety of substrates and in a series of predator-prey challenges utilizing flounder, scalpin, and green crabs. Behavior experiments showed no significant differences between blue and normal lobsters. The predators showed no preference in selecting blue juvenile lobster over normal colored ones.

INTRODUCTION

The feasibility of lobster hatch and release programs is currently being evaluated by researchers at the University of Maine via the release of blue colormorphic American Lobsters, *Homarus americanus*. Presently, the efficacy of using these blue lobsters as biological markers is unknown because of the possibility of inherent behavioral differences in comparison to normal American lobsters. The basic behaviors analyzed in this study were: swimming, burrowing, walking and lack of activity. At the Ira C. Darling Center in Walpole, ME, blue and control (normal) post-larval American lobsters, ranging in carapace length (CPL) from 4.5mm to 6.5mm were recorded individually with a camcorder. Each trial lasted for a minimum of 15 minutes and none exceeded 30 minutes. Six different substrates and three approximate CPL's of 4.5 and 6mm were used. The substrates included: mud, sand, eelgrass over mud, eelgrass over sand, pebble over sand, and cobble over sand. Five trials per substrate per carapace length were attempted for both blue and control animals. During the summer of 1990, a total 76 trials were conducted, 47 with blue lobsters and 29 with controls. The data was quantified by computing the relative time the lobsters spent in each of the behaviors in each trial. Of those trials analyzed to date, no apparent behavior differences exist.

HISTORY

Between 1885 and 1920, there existed 22 lobster hatcheries in New England, the Maritimes, and Europe. The European lobster, *Homarus gammarus*, was reported to have been cultured in France in 1865, Great Britain in 1883, and Norway in 1885. The earliest attempt in the United States was in 1885 when the U.S. Fisheries Commission began hatching *Homarus americanus* eggs from "berried" females and releasing the first stage larvae. In 1902, there was a general conclusion that the release of first-stage larvae did not significantly influence the fishery, and Canadian hatcheries were closed in 1917 after an investigation into their effectiveness.

In spite of the 1902 conclusion, a U.S. hatchery was established at McKown's Point in Boothbay Harbor, ME in 1903-1904. The Boothbay Harbor hatchery released first-stage larvae until 1938, at which time they experimentally released fourth-stage, postlarval lobsters. This same year, the Maine State Legislature approved and constructed a lobster-rearing station adjacent to the federal hatchery at Boothbay Harbor. From 1939 to 1948, the rearing station released fourth-stage lobsters into Maine waters to enhance the natural fishery.

In 1950, the chief biologist for Maine, Clyde Taylor, wrote a review on the previous nine years of releasing fourth-stage lobsters. He said, "Lobsters-rearing in Maine is a useless expenditure of time and money and ought to be abandoned. The possibilities are...so poor that one fails to see any benefits ...even on a small, experimental scale." His criticisms included the lack of quality in techniques which inherently lead to decreased survival rate and poor data collection. He calculated a 19% survival rate in the rearing station (first to fourth stage), a 10% survival of released fourth-stage lobsters in the first year, and an impact of only 0.0015% on the fishery.

The 10% figure was obtained from the Schoodic Point experiment which was conducted in 1947 by Taylor and Baird. This experiment was designed to determine the survival of released fourth-stage lobsters in a semi-natural environment, i.e., an abandoned lobster pound in Winter Harbor, ME. They estimated a 9.9% survival rate in the first year and 4.7% survival rate in the second year. But the authors wrote in their report that "to obtain highly reliable conclusions...it would be necessary to repeat these experiments many times."

In challenging Taylor's review, especially today, one could site the many technological advances and increased knowledge of the physiological and environmental requirements of cultured lobsters. These advances have resulted in a better understanding of the proper techniques and conditions required for optimal growth and survival which were not available at the time of his review. Also, the Schoodic Point experiment was never repeated, which raises questions as to the reliability of his survival rate figures. Consequently, reliable data on the survival of released fourth- stage lobster and their impact on the fishery has never been determined.

In the late 1960's, John Hughes, of the Massachusetts State Lobster Hatchery, had the idea of using colormorphic lobsters as natural tags to determine the survival and impact of hatchery-reared lobsters on the fishery. This would enable individuals of the same size and age to be released to the fishery and thus provide a less biased estimate of the effectiveness of hatch and release programs. Dr. Anthony D'Agostino, of the New York Ocean Science Laboratory, incorporated this idea into his own broodstock maintenance and development a program using colormorphic blue lobsters. His three objectives were as follows.

1. "To Maintain a unique colony of genetically-select lobsters, e.g., true color;
2. To further develop the collection, and, by cross-breeding, produce animals with traits particularly desirable for aquaculture of the species in the wild and/or intensive culture systems;
3. To release in Fort Pond Bay broods of genetic true blue juvenile lobsters in order to evaluate the impact of the restocking program as a model for the repopulation of other depleted bays of Long Island."

In 1987, Mr. Brian Beal, of the University of Maine at Machias, along with Mr. Sam Chapman and Dr. Robert Bayer, of the University of Maine Darling Marine Center and University of Maine in Orono, respectively, wrote a proposal encompassing the use of blue lobsters to assess the feasibility of hatch and release programs in Maine. The proposal consisted of three phases:

1. the rearing and breeding of blue lobsters,
2. hatchery rearing and release of fourth-stage blue lobsters,
3. monitoring their capture.

The proposal was submitted to the U.S. Department of Agriculture, where under peer review, the major objection was the assumption that blue lobsters behave similarly to normal lobsters. The following experiment was conducted to partially answer this question raised and was funded by the Maine Aquaculture Innovation Center.

LITERATURE REVIEW

There is little information on postlarval and juvenile lobster (*Homarus americanus*) behavior. But recent interest in stock and recruitment relations have sparked researchers to focus on the interaction of larval and postlarval behavior, ocean currents, and wind direction, as well as environmental constraints.

After hatching, the American lobster passes through three larval stages over a period of 14 to 20 days at water temperatures of 18-20°C before entering metamorphosis. At this time, the lobster becomes anatomically similar to an adult lobster and also moves from a pelagic to a benthic existence.

Cobb et al. (1989) determined the pelagic to benthic transition to be two to six days into the fourth stage. Conducive to the transition is the change in response of early fourth-stage lobsters to light. Early fourth stage, and also larvae, show highly photo-positive responses. After the transition, Botero et al. (1982) determined the lobsters would have photo-negative and thigmo-positive responses. He also mentioned that the phototaxic response was a stronger force than the thigmotaxic response. However, Howard and Bennett (1979) determined phototaxis to play a lesser part during dark periods for stage VII *Homarus gammarus*. They showed that, in light, the lobsters preferred immediately available dark crevices of stones and, in darkness, the lobsters moved about on sediment surfaces sometimes choosing alternative habitats. They concluded that the lobsters will choose immediately available crevices under stressful conditions, and examine available areas under unstressful conditions.

Hudon (1987) separated lobsters according to size and activity level. She designated the postlarval stage as extending through to a CPL of about 25mm. A behavioral transition, termed "immature juvenile," occurs at CPL's of greater than 25mm. The next transition occurs at maturity, or adulthood, at approximately 76mm CPL. During Hudon's study, she determined the highest density of postlarvae and juveniles to be on rocky substrate in shallow water. She hypothesizes that the postlarvae, within rocky crevices, are given maximum protecting to quickly grow to the "highest possible size before winter." When juvenile size is reached, habitat limitation would "influence biomass, density, and size structure of lobsters found."

Lawton (1987) also makes reference to behavioral transitions. He mentions that the early postlarval stages maintain a cryptic lifestyle for their first two benthic years. Their ability to tunnel in a variety of substrates provide for both food and shelter during these two years. As the lobsters increase in size, their defensive behavior changes from abdominal reflex to the use of their claws. This is simultaneous with the transition from predominately abdominal anatomy to that of cephalothorax (Hudon, 1987). It is also simultaneous with a transition in behavior from a cryptic to sedentary lifestyle, which, in turn, is associated with the shelter-related foraging activities of juveniles, a compromise between utilizing available resources and predator avoidance (Lawton, 1987).

The first postlarval stage (stage IV) is reported to show a drop in growth factor (Hudon, 1987; Botero and Atema, 1982). This occurs due to fourth-stage, postlarvae, expending their energy while looking for appropriate habitat rather than growth. However, late fourth- and fifth-stage lobsters show high growth factors which indicate abundant food sources, possibly due to sedentary existence (Hudon, 1987). Conversely, Cobb (1989) reported that in the field they observed pelagic behavior late into the postlarval period. He states that this observation reflects the flexibility of the lobsters in choosing the time to settle due to environmental limitations or appropriate habitat availability.

The habitat preference of fourth-stage, postlarvae has been shown to be rocky bottoms. Botero and Atema (1982) reported preference for "rock garden" at 57%, mud at 25%, small pebbles at 14%, and sand at 4%. They settled most quickly, in decreasing order, on macro, algae-covered rocks ("rock garden"); rocks on sand; mud, then sand. Barshaw and Bryant-Rich (1988) reported settlement was more rapid on eelgrass and rock habitats.

Botero (1980) described a number of activity patterns over different substrates. Over sand, early fourth-stage lobsters showed a descend-walk-ascend pattern. Walking would last only a few minutes, and burrowing occurred infrequently at the corners of the aquarium. The descending-walking-ascending pattern also occurred over mud but the lobsters would eventually settle. While walking, the lobsters would occasionally poke the substrate with their chelae and/or pereiopods. Burrowing was also observed, especially under rocks in the "rock garden" substrate.

Cobb (1971) described a number of specific burrowing methods which enable postlarval lobsters to adapt to many different substrates. The lobsters loosen the substrate with their chelipeds and pleopods and by pushing the substrate through the last pair of walking legs or "backward digging." After loosening the substrate, the lobster then forms a scoop with its third maxillipeds and first and second pair of pereiopods, pushing or "bulldozing" the substrate out of the shelter.

MATERIALS AND METHODS

Lobsters

Blue colormorphic and normal (control) lobsters were hatched and reared at the Darling Marine Center in Walpole, ME. Blue lobsters were hatched on June 16, 1990 and controls were hatched on August 12, 1990. The larvae were placed in three 400 L conical tanks (approximately 1600 larvae per tank) at a water temperature of 18 to 22°C. The larvae were fed live *Artemia sp.* during the three larvae stages.

At metamorphosis, the lobsters were placed in individual compartments made of ¾" PVC cut at a height of 12.70cm with nylon netting on one side. These compartments, with lobsters, were placed in a flow-through seawater system, the water temperature ranging between 10 and 15°C. The postlarvae were fed on frozen *Artemia sp.* daily.

Aquaria

Eleven aquaria were built with 2" Amofoam insulation, ⅛" glass panes, and clear silicone caulking. For each aquarium, three pieces of Amofoam were cut: two sides at 30.48cm by 10.16cm and the bottom at a length of 40.64cm by 10.16cm. The two sides were attached to the bottom with silicone caulking. Glass panes were then attached to both sides with silicone and an outlet was placed at the top with ½" PVC piping. The inside dimensions were 35.5cm (l) by 10.2cm (w) by 31cm (h).

Five substrate scoops were constructed to deposit approximately 10.16cm of substrate into the aquaria with as little disturbance as possible. The scoops were built with ⅛" PVC plates attached with PVC glue. The outside dimensions are 29cm (l) by 10cm (w) by 10cm (h).

Substrates

The substrates used were sand, mud, eelgrass over sand, eelgrass over mud, cobble over sand and pebbles over sand. Both cobble and pebble were placed over the sand manually. All substrates were collected along the Damariscotta River in Walpole, ME. Substrates were categorized by the following grain size ranges: pebble -- 4mm to 62mm, cobble -- 62mm to 256mm, mud -- 0.001mm to 0.06mm, sand -- 0.06 to 1mm.

Filming

A Panasonic camcorder was set on a tripod at varying distances from the aquarium; distance from lens to glass on the aquarium ranged from 1.27cm to 5.08cm. Distances were varied to give the best possible view of the lobster. Two 70 watt bulbs were placed 10.16cm from the top of the aquarium, and the aquarium was set on a rotating oval plate. The CPL of each lobster was taken with calipers before each trial. After placing the lobster in the aquarium, 10 seconds elapsed before filming began. This allowed the lobster to acclimate itself to the environment. Filming lasted between 15 to 30 minutes for each trial.

The aquaria were cleaned with fresh water and soap after each trial. Fresh substrates were collected for each trial and each lobster was used for one trial only.

Analysis

The film for each trial was analyzed on a percent time basis for the following four behaviors: swimming, burrowing, walking, and lack of activity. Swimming consisted of any activity in the water column. Burrowing consisted of activities which involved the manipulation of the substrate such as: bulldozing, pleopod fanning, and backward digging. Walking consisted of roaming or investigating the substrate. Lack of activity was reported if the lobster remained still for 10 or more seconds.

For each trial the total seconds in each behavior was recorded. The percent time the lobster spent in each behavior was then calculated. The data was analyzed by using the Statistical Analysis System (SAS) with a three-way ANOVA. The data was first arcsine transformed and then ranked before running the analysis. A procedural general linear model was performed on color (blue vs. control lobsters), substrates, and carapace length. Individual CPL's were used in the analysis so to remove any effect differences in CPL may have had on the other two independent variables.

RESULTS AND CONCLUSIONS

No significant differences were found in CPL and color for all four behaviors. Swimming and burrowing among substrates did show a significant difference at alpha = 0.05. Using Duncan's Multiple Range Test (alpha = 0.05), swimming occurred significantly more often over sand than the other five substrates. Burrowing occurred significantly less often over sand than the other five substrates. Eelgrass over mud also showed significantly higher burrowing activity than eelgrass over sand, and mud. (Note: Eelgrass over mud was only performed on blue lobsters. Thus, this did not influence the results on colormorph analysis.)

Previous literature had recorded their behavioral data as the number of observations within any one behavior. This experiment is the first to quantify individual behaviors on a percent time basis, and this method appears to be adequate due to similarity in behaviors recorded in previous literature. For example, in considering approximate CPL, swimming occurred more often with lobsters between 4.0-4.9mm CPL and least often with lobsters between 6.0-6.8mm CPL. Burrowing occurred more often with the longer CPL's and less often with the shorter CPL's. The swimming/ burrowing trade-off correlates with previous literature with respect to both size and substrate (habitat availability). Walking and lack of activity also correlate with previous literature whereby the 4-4.9mm CPL were found to spend more time walking than in lack of activity. This may possibly be associated with the hypothesis that the first postlarval stage expends more energy looking for an appropriate substrate than in growth.

In comparing control (normal) to blue, postlarval lobsters within this methodology, we have found no inherent behavioral differences. More information regarding chemoreception and predator preference need to be attained before accepting colormorph lobsters as adequate tags. Both of these areas are presently being investigated. If no difference is found, the blue colormorphic lobsters could provide valuable data in determining the survival of hatchery-reared lobsters as well as their impact on the fishery.

REFERENCES

BarsBarhaw, D.E. and D.R. Bryant-Rich. 1988. A long-term study on the behavior and survival of early juvenile American lobsters, *Homarus americanus*, in three naturalistic substrates: eelgrass, mud, and rocks. Fishery Bull. 86(4): 789-796.

Botero, L. and J. Atema. 1982. Behavior and substrate selection during larval settling in the lobster *Homarus americanus*. J. Crustacean Biol. 2:59-69.

Botero L. 1980. Substrate selection and settling behavior of larval lobsters *Homarus americanus* Milne-Edwards. M.S. Thesis, Boston University.

Cobb, J.S., D. Wang, and D.B. Campbell. 1989. Timing of settlement by postlarval lobsters *(Homarus americanus)*: field and laboratory evidence. J. Crustacean Biol. 9:60-66.

Cobb, J.S., T. Gulbransen, B.F. Phillips, D. Wang, and M. Syslo. 1983. Behavior and distribution of larval and early juvenile *Homarus americanus*. Can. J. Fish. Aquat. Sci. 40:2184-2188.

Cobb, J.S. 1971. The shelter-related behavior of the lobster, *Homarus americanus*. Ecology 52:108-115.

D'Agostino, A. 1980-81. The American lobster: Broodstock Maintenance and Development-Summary. Per comm. to Dr. Bayer of the University of Maine.

Dow, R.L. 1970. Marine and Estuarine Culture in Maine. Fisheries Circular #24, Dept. of Sea and Shore Fisheries.

Dow, R.L. 1971. Management and Culture of Commercial Marine Organisms in Maine. In a paper given to Atlantic Fisheries Society meeting, Portland, ME.

Hedgecock, D. 1983. Maturation and Spawning of the American Lobster, *Homarus americanus*. In J.P. McVey, ed. Handbook of Mariculture, Vol. i, Crustacean Aquaculture, p. 261-270.

Howard, A.E. and D.B. Bennett. 1979. The substrate preference and burrowing behavior of juvenile lobsters *(Homarus gammarus)*. J. Nat. Hist. 13:433-438.

Hudon, C. 1987. Ecology and growth of postlarval and juvenile lobsters. *Homarus americanus*, off lles de la Madeleine (Quebec). Can. J. Fish. Aquat. Sci. 44:1855-1869.

Johns, P.M. and K.H. Mann. 1987. An experimental investigation of juvenile lobster habitat preference and mortality among habitats of varying structural complexity. J. Exp. Mar. Biol. Ecol. 109:275-285.

Lawton, P. 1987. Diel activity and foraging behavior of juvenile American lobsters, *Homarus americanus*. Can. J. Fish. Aquat. Sci. 44:1195-1205.

Pottle, R.A. and R.W. Elner. 1982. Substrate preference behavior of juvenile American lobsters, *Homarus americanus*, in gravel and silt-clay sediments. Can. J. Fish. Aquat. Sci. 39:928-932.

Taylor, C.C. and F.T. Baird Jr. 1949. Schoodic lobster planting experiments, Supplement #1. Maine Dept. of Sea and Shore Fisheries.

Taylor, C.C. 1950. A review of lobster rearing in Maine. Research Bulletin #5. Dept. of Sea and Shore Fisheries.

Van Olst, J.C., J.M. Carlberg, and J.T. Hughes. 1980. Aquaculture. In J.S. Cobb and B.F. Phillips, ed. The Biology and Management of Lobsters. Vol ii, p. 333-384.

Proc. Int. Crab Rehab. & Enh. Symp.
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USE OF INTERTIDAL OYSTER SHELL TO ENHANCE 0+ DUNGENESS CRAB PRODUCTION IN GRAYS HARBOR ESTUARY (WA)

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ABSTRACT

Juvenile 0+ dungeness crab (Cancer magister) are dependent on intertidal shell as refuge from predators following settlement in late spring. There is virtually no survival of subtidal and intertidal recruits on open substrate, and the preponderance of this age class is found in Mya and Crassostrea shell deposits, and in ongoing oyster culture beds. Annual dredging by the Corps of Engineers (COE), and particularly an extensive effort to widen and deepen the Grays Harbor navigation channel has focused attention on the impact of such activity to crab resources. In addition to changes in dredging schedules and gear as means to attenuate impact, research has been directed toward mitigation based on construction of intertidal shell habitat to increase 0+ production. This year COE will place 8 hectares of oyster shell at two locations in Grays Harbor as means to offset an estimated loss of 160,000 2+ crab during extensive dredging in 1990. We will study population dynamics of the '92 year class, and also a variety of predator-prey issues associated with this habitat manipulation.

INTRODUCTION

Since the late 1800's, Grays Harbor has been a major west coast port for exporting wood products, and is dependent on maintenance dredging and occasional improvement of the navigation channel by the U.S. Army Corps of Engineers (COE). The most recent construction project began in April, 1990 and involved widening and deepening (W&D) the channel from the Grays Harbor Bar up to Aberdeen (Fig. 1) by removal of about 8.5 million cubic yards (cy) of sediment to accommodate passage of large log ships. Planning and coordination for the present W&D project began about 20 years ago. From the beginning of the planning process, one species of concern to agencies and fishermen has been the Dungeness crab (Cancer magister), which is entrained during dredging operations. COE funded several studies in response to questions raised about potential adverse impacts on crab; among those were entrainment studies (Armstrong et al. 1982; Dinnel et al. 1986; Dumbauld et al. 1988; McGraw et al. 1988); population and ecological studies (Gunderson et al. 1990); an impact model (Armstrong et al. 1987; Wainwright et al. 1992); pilot shell mitigation studies (Armstrong et al. 1991; Dumbauld et al. in press); and contaminant and

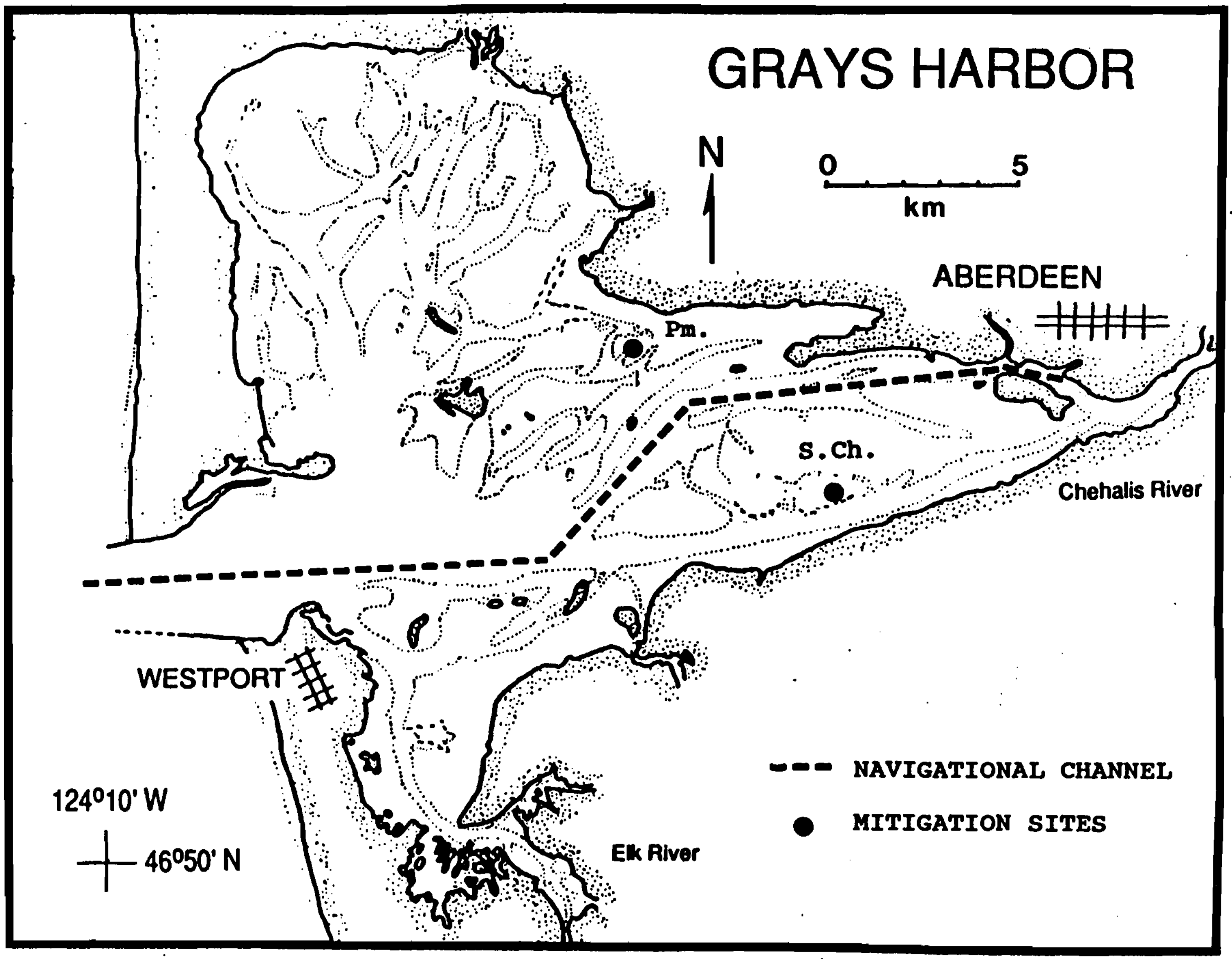

Figure 1: Grays harbor estuary showing the navigation channel which was widened in 1990, and two intertidal shell mitigation plots at South Channel (about 6 ha) and "Pacman" (about 3 ha) constructed during spring, 1992.

sediment disposal studies (Pearson and Woodruff 1987; Pearson et al. 1987).

The approach to crab mitigation was developed over several years through coordination with resource agencies, biologists, and crab fishermen, and is also based on the results of the field studies listed above, conducted by the University of Washington, COE, and Battelle Northwest Marine Laboratory. Mitigation proposed in the 1982 Environmental Impact Statement (EIS) (U.S. Army Corps of Engineers 1982) for loss of Dungeness crab caused by the present project focused on avoidance of entrainment by modification of dredging equipment. Because this method was unsuccessful in field tests, a combination of other approaches was considered based on a Dredge Impact Model (DIM; Armstrong et al. 1987; Wainwright et al. 1992) used to calculate theoretical crab loss under different scenarios of seasonal and spatial abundance, and COE dredging programs. Those estimates were used to adjust project plans to minimize adverse impacts to crab by: 1) scheduling dredging, to the extent practicable, to avoid times and areas of high crab densities; 2) locating offshore disposal sites to avoid high concentrations of crab and interference with the crab fishery; and 3) using clamshell dredges instead of hopper dredges to reduce crab entrainment wherever it was cost-effective.

Although these actions were implemented in the project schedule, some unavoidable crab losses occurred during construction dredging in 1990, and will continue to occur annually during maintenance dredging. In order to assess real-time impacts from construction dredging, Dinnel et al. (1991) monitored actual crab densities in the navigation channel (Fig. 1) during the period of construction dredging from April through December 1990. Estimated crab losses (by size, sex, month and location) together with dredging data (amounts dredged, gear type, location, and time) were integrated into the existing DIM to calculate total project crab losses, which were about 161,500 crab, normalized to age 2+.

Because the creation of intertidal oyster shell habitat for 0+ crab has been shown to be an effective and feasible technique for increasing the abundance of this age class (Armstrong et al. 1991; Dumbauld et al. in press), it was chosen as the primary method to mitigate for loss of crab in the dredged channels. A mitigation plan was devised based on estimated crab losses and data from the pilot shell habitat study (U.S. Army Corps of Engineers 1989), to be implemented with the initiation of construction dredging in 1990. A total of 14 ha (35 acres) of intertidal shell habitat was to be constructed the first year after W&D the channel. However, due to time constraints, uncertainty about shell retention and deployment techniques, and some controversy regarding site selection, shell placement in 1990 was reduced to only four experimental sites of 0.4 ha each. Results of the 1990 shell plot studies (Armstrong et al. 1991) emphasized the need to find intertidal locations in Grays Harbor which had substrate qualities that promote shell retention, since shell at three of the four experimental sites essentially disappeared due to sinkage and/or burial by sediments. Additionally, placement of mitigation plots has been severely constrained by private ownership of tide lands, alleged pollution of the inner harbor by pulp mill effluents, agency concerns about impacts to eelgrass (Zostera marina), and the possibility that imported oyster shell may contain seeds of cord grass (Spartina spp.). As a consequence, additional small-scale test plots were constructed in 1991 in areas with little or no eelgrass and generally removed from pulp mill pollution sources instead of full mitigation shell placement in 1991.

SHELL AS HABITAT

Since 1984 we have collected data form the intertidal of Grays Harbor that reoccuringly demonstrate higher density of 0+, young-of-the-year Dungeness crab in shell than found on open unprotected tidal flats. Our initial samples focused on naturally occurring beds of eastern softshell clams (Mya arenaria) which cover extensive regions of the intertidal in Grays Harbor. Based on this observation and preliminary samples from commercial oyster culture operations, we suggested that construction of artificial shell habitat might be used as a means to mitigate for subtidal crab loss caused by annual dredging programs conducted by the Army Corps of Engineers. Through a series of studies since 1986, we have elucidated aspects of ecology and population dynamics of several categories of animals that come to occupy artificially constructed shell habitat. As predicted, the density of 0+ Dungeness crab is routinely high during spring and summer following arrival of megalopae to the estuary. Density at first benthic instar (J1) may exceed $200/m^2$ and density of older instars range between $50\text{-}100/m^2$ through the summer (Fig. 2). Although COE always attempts to construct shell habitat as a layer of uniform depth on tidal flats, depth in fact varies substantially within and between different mitigation sites. We have measured crab density as a function of shell depth (Fig. 3) and find no relationship between abundance and the thickness of the shell layer. This indicates to us that the habitat is of primary importance as cover for 0+ crab at the sediment interface where they are still dependent on moist sand and mud for residency during periods of low tide and aerial exposure. During flood tide we assume that crabs move and forage through the three dimensional matrices of the shell where abundance of certain prey such as gammarid amphipods, is positively correlated with depth of the shell (Fig. 3). A schematic shown in Figure 4 portrays a conceptualized distribution of crab and various prey taxa in the shell.

Each spring between mid April through June megalopae arrive to the estuary and settle to the shell habitat, molt and grow for approximately 2-3 months and move from this intertidal refuge when they reach a size of about 25 mm CW (J5-J6 instar). The primary function of shell habitat seems to be one of refuge from several major predators as well as source of abundant food. Predators of small instars that settle directly to open tideflats or move from the protection of shell include staghorn sculpin (Leptocottus

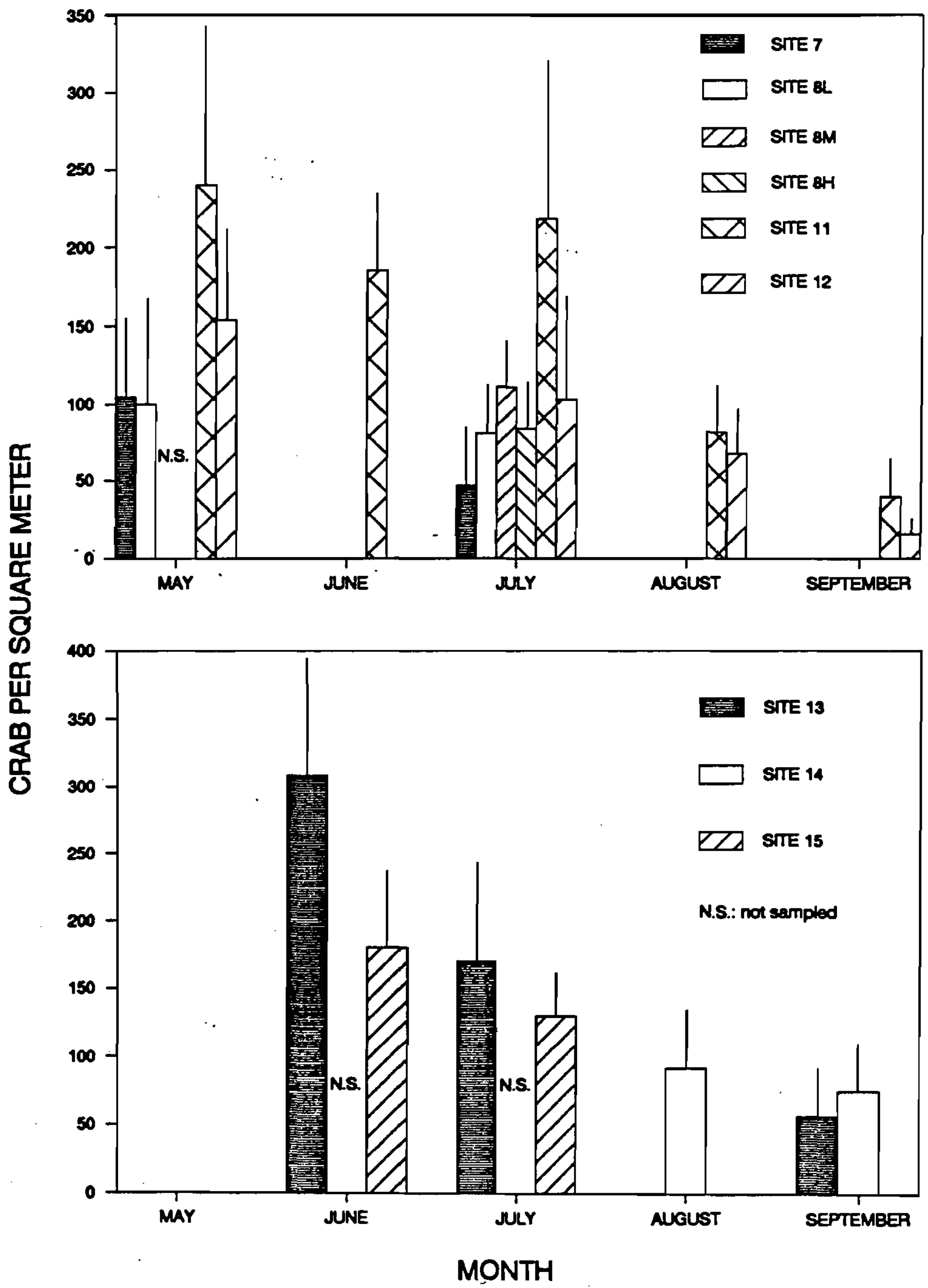

Figure 2: Representative data on density of 0+ Dungeness crab in intertidal shell mitigative habitat sampled in 1991. Crab were a mix of J1 through J5 instar (about 7-30 mm CW) from May to September. Sites 11 and 15 are at "Pacman", sites 12, 13 and 14 are at South Channel (see Fig. 1).

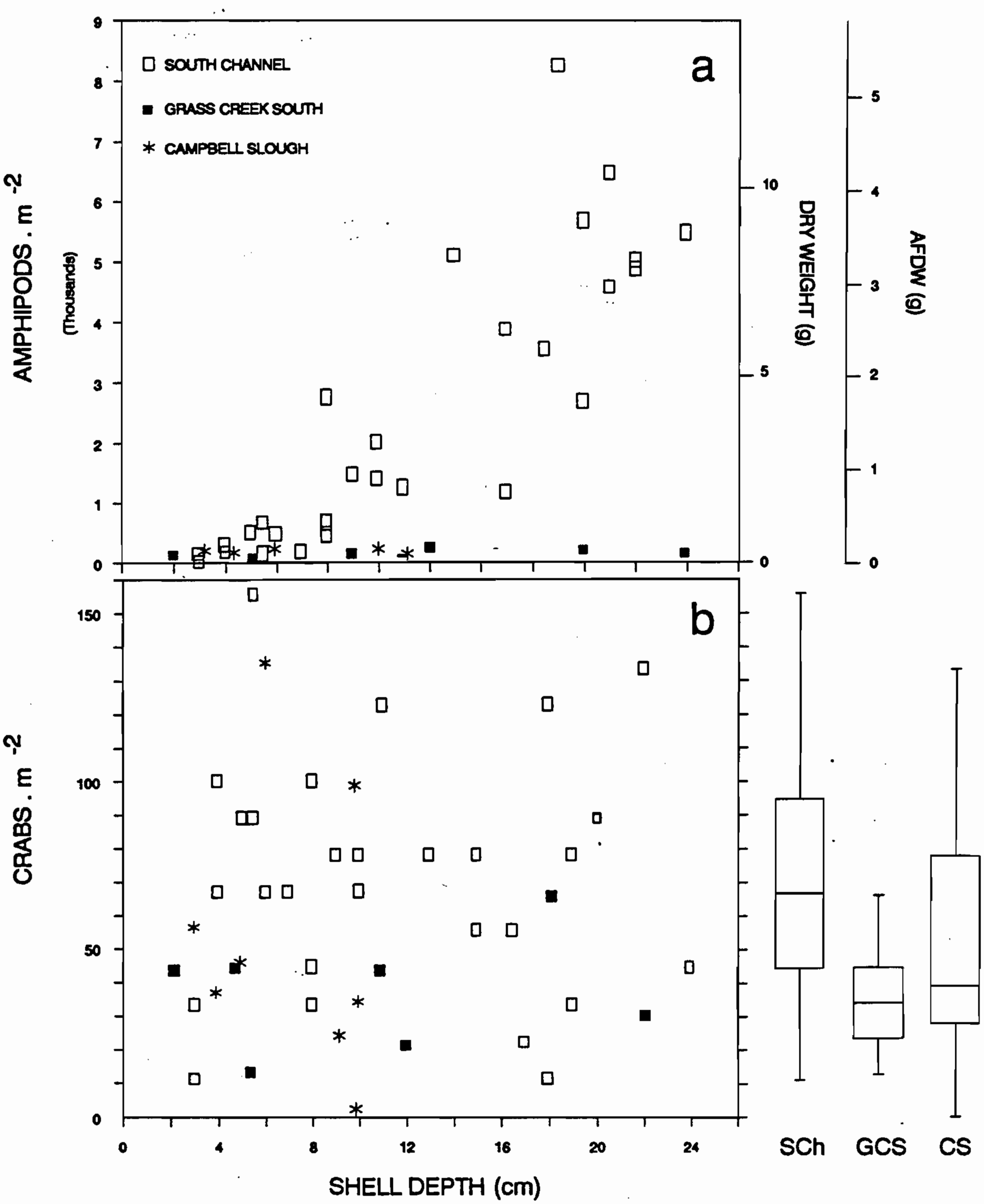

Figure 3: Density of 0+ Dungeness crab and the amphipod <u>Eogammarus confervicolus</u> as a function of intertidal oyster shell depth in mitigation habitat. Note strong positive correlation between amphipod density/weight and shell depth at South Channel.

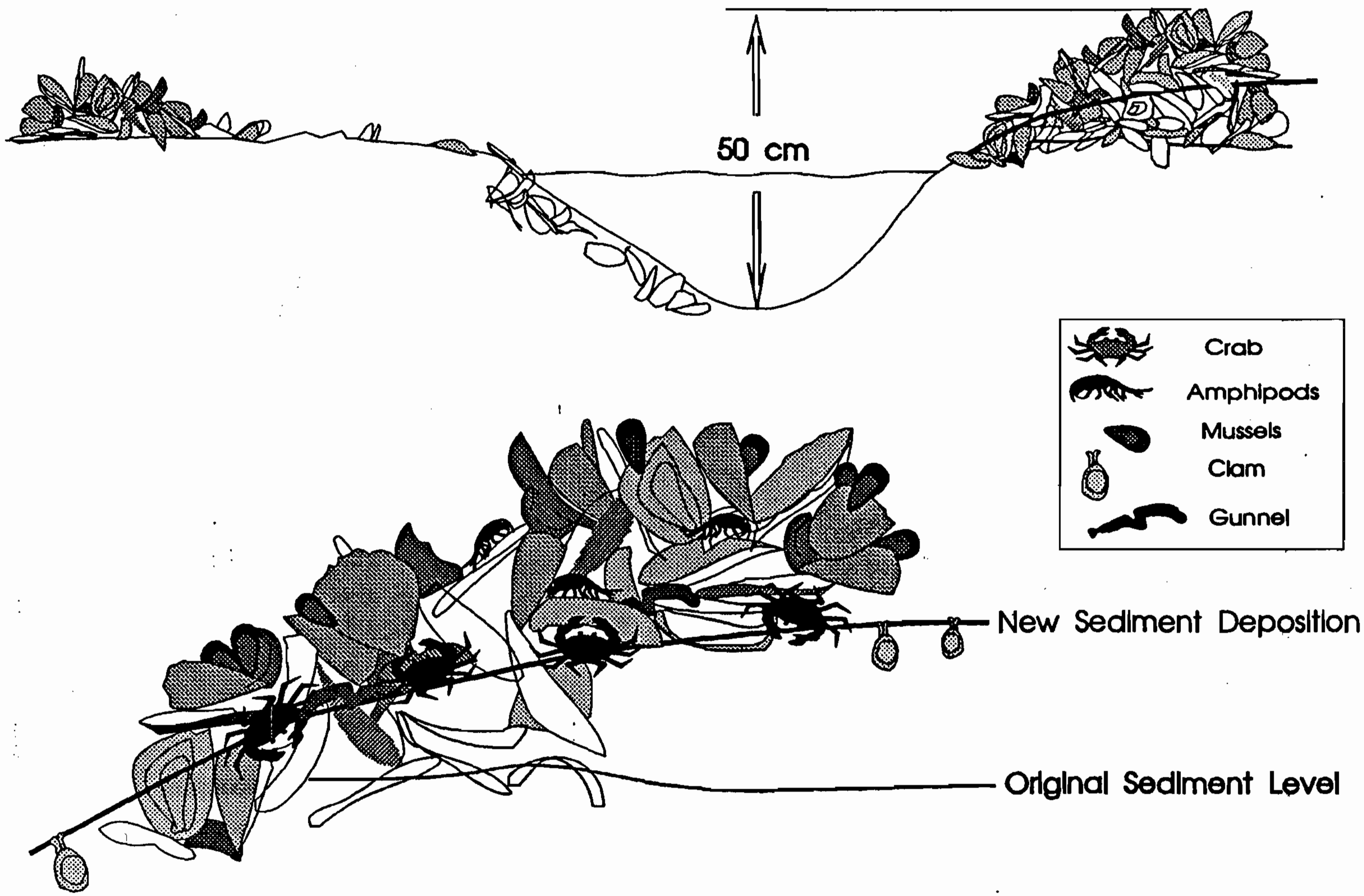

Figure 4: Schematic portrayal of intertidal shell habitat and several major faunal groups. 0+ crab prey heavily on amphipods, clams and polychaetes. Note increase in sediment elevation within the shell habitat after construction.

armatus, Armstrong 1991), several species of birds and older, conspecific 1+ and 2+ crab which move on to intertidal flats at flood tide to feed (see Stevens et al. 1982 for evidence of cannibalism). There is essentially no survival of 0+ crab on open intertidal flats or even those areas that contain sparse eelgrass, and we estimate that a significant portion of the age class eventually found in the subtidal toward the end of summer originates from intertidal refuge habitat such as shell (Gunderson et al. 1990; Jamieson and Armstrong 1991).

OTHER FAUNA

In addition to 0+ crab, several other taxa recruit to shell and occupy it year around. Notably abundant in comparison to open tideflats are fish such as gunnels (Pholis sp.) the amphipod Eogammarus confervicolus, hermit crabs and several species of bivalves (Fig. 5). Small bivalves including Macoma and Mya clams, as well as gammarid amphipods are important prey items for 0+ Dungeness crab. Amphipod density may reach 6,000/m^2 at an ash-free dry weight of 4-5 grams/m^2 (Fig. 3). In addition, our preliminary data also indicate that 0+ crab within the shell are highly cannibalistic and that successive cohorts which recruit on new or full moon spring tides impact each other through predation. High densities of 0+ crab resident in shell through summer are supported by several taxa whose own abundance and biomass is greater in the shell than on open tideflats characteristic of much of the estuary. However, through intense predation during summer, density of some taxa such as bivalves may eventually be lower than found in surrounding tideflats. Changes in mobile prey such as amphipods are less conspicuous because of their ability to constantly repopulate areas of shell where crab predation is high.

LOSS OF SHELL HABITAT

Our original expectations were that shell habitat, once constructed, would endure for a number of years, this based on the existence of extensive piles of Mya shell found throughout the estuary. However, preliminary small scale plots of oyster shell in certain instances were quickly lost, either by transport off the site or sedimentation to the extent that 0+ crab were no longer able to find refuge spaces within the shell. We assumed that differences in rates of sedimentation would be reflected in different regions of the estuary, but have found no pronounced difference in either sediment loads or current velocities through tide cycles in a variety of locations. Rather, the most significant data collected to date as reason for loss of shell habitat has to do with concurrent density of two species of burrowing shrimp (Upogebia and Callianassa) which can occur in high abundance on intertidal flats. These same species impact commercial oyster culture when their densities are such that the substrate is rendered too porous and oyster clutch sinks or individuals are smothered by high burrowing activity and

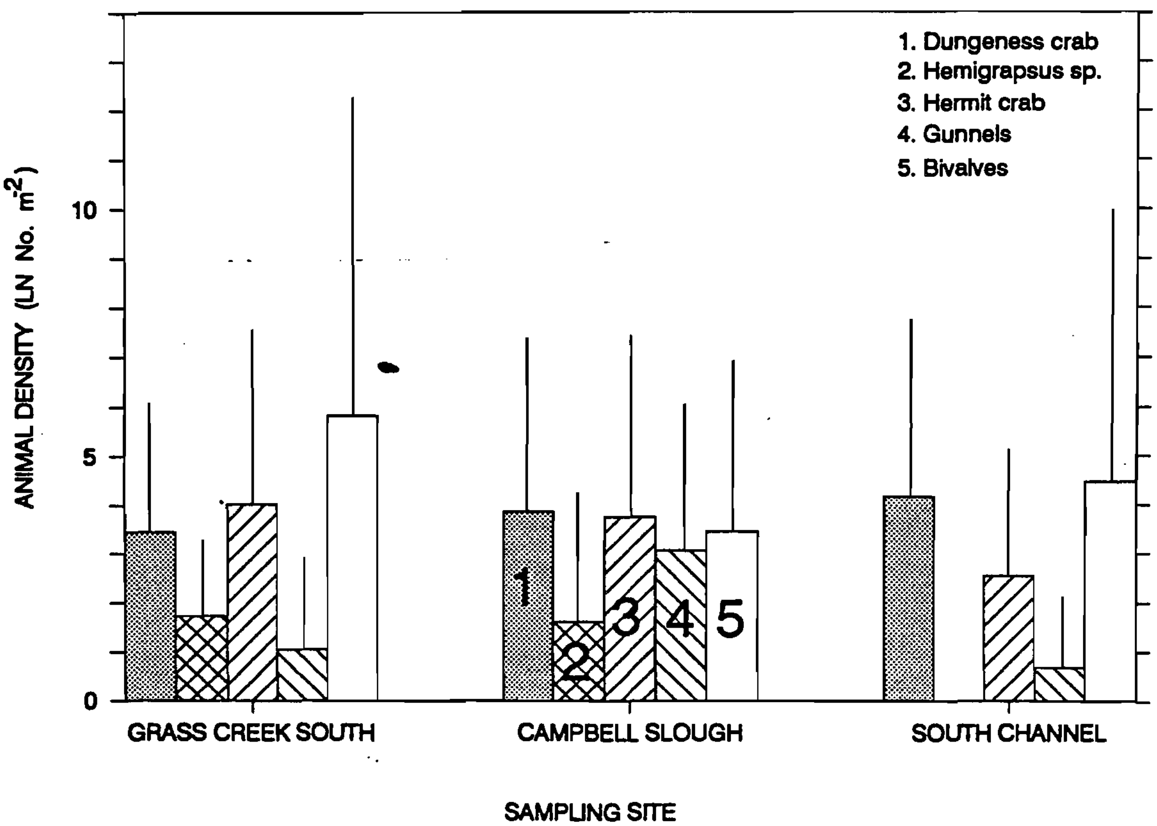

Figure 5: Density of several taxa in intertidal shell habitat at three representative sites in Grays Harbor.

resuspension of the sediment by these shrimp. For over 25 years commercial oyster growers in Washington State have used the insecticide carbaryl sprayed at low tide on selected tide flats to kill the shrimp which subsequently firms oyster ground for plantings. Our own data indicate the same fate of oyster shell habitat in the Grays Harbor estuary. Since there is direct correspondence between increasing density of shrimp (burrows/m^2), and percent of shell cover (habitat) still available some months after construction (Fig. 6), we have found that most loss of shell habitat occurs from sinkage (subsidence) into the unconsolidated mud substrate where shrimp density is high. In certain instances, experimental plots of 0.5 ha have vanished in as little time as a month due to sinkage and the upper boundary of the shell layer may be anywhere from 5-30 cm below the surrounding tideflat gradient (Fig. 7). Two exemplary sites (sites 6 and 11) are shown as isopleth maps of shell elevation above the surrounding grade in June and September of the year they were constructed. Site 6 in the northern part of the bay was deemed unsuitable for broad scale shell mitigation since much of that experimental plot had sunk out of sight and was completely unusable by 0+ crab. In contrast, a reasonable amount of the shell at Site 11 at South Channel was still above grade and usable as crab habitat into September. A critical part of the shell mitigation program has been determination of those areas of the intertidal firm enough to support the weight of shell and thus guarantee reasonably long durability for a couple of years of crab recruitment.

LESSONS FOR KING CRAB ENHANCEMENT

Several aspects of the intertidal shell mitigation program adversely impacted the overall success of the project. Some were anticipated in terms of physical limitations regarding retention or durability of viable shell habitat. Others were politically and economically driven and contentious for a number of years. If king crab enhancement is attempted *in situ*, it is important to recall that expansion from technically feasible small scale pilot studies to large scale enhancement programs can be difficult. Well run experimental designs executed on a scale of meters may often indicate technical feasibility of an enhancement concept which is difficult to sample and quantify. At the same time we all recognize that the value of an experimental demonstration program is not contained solely in the commercial dollar return to a fishery, but also in technological development and a variety of experimental results that might be obtained in hatchery and lab investigations. To an extent, the Dungeness crab program has been successful in this regard since most of the present knowledge concerning estuarine early life history, ecology, and population dynamics is derived from these studies in Grays Harbor.

The most negative aspect of the Dungeness program has been a variety of controversies at the forefront in discussions between various regulatory agencies, commercial fishermen and university scientists. Once the dredging program was authorized, it would

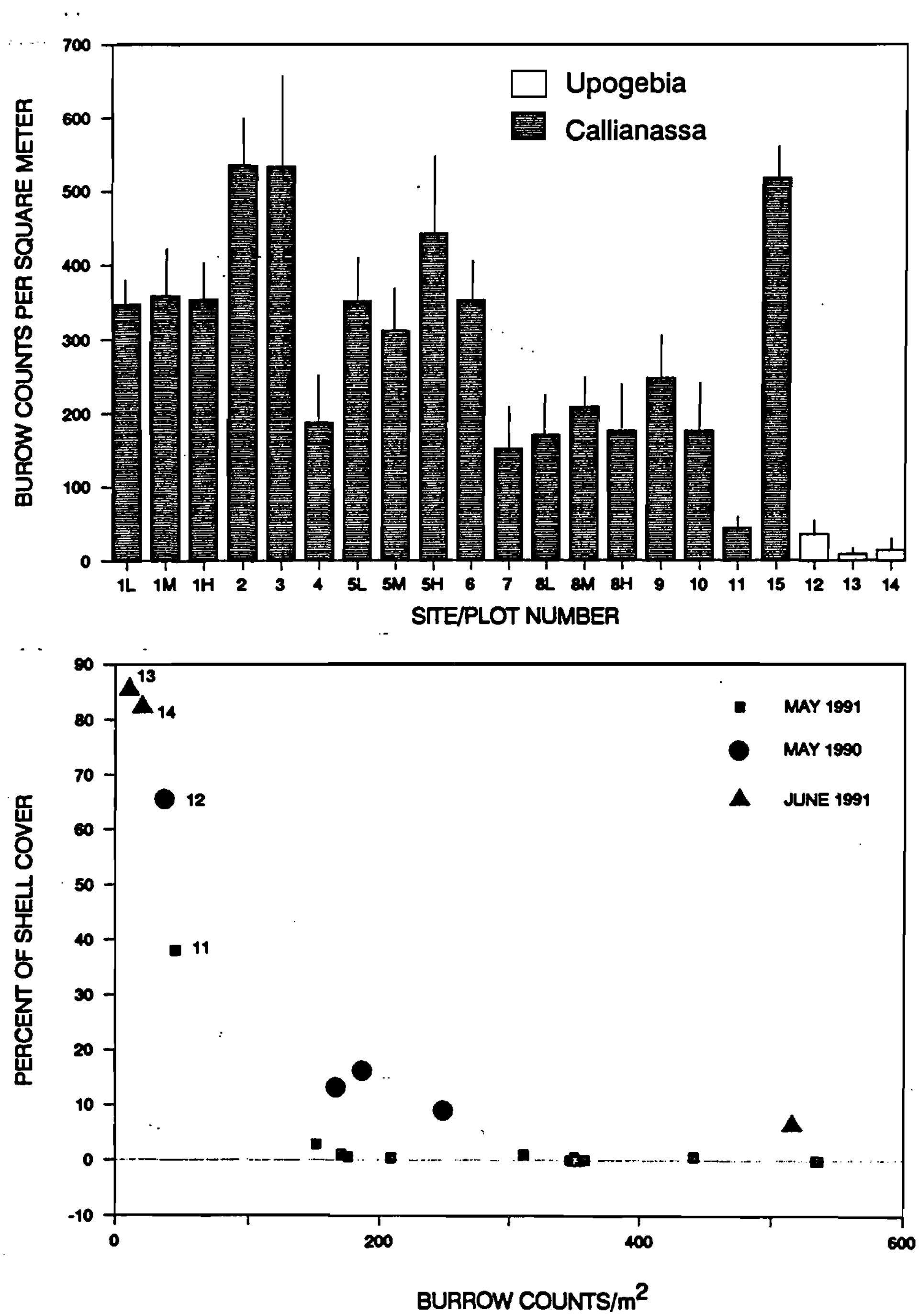

Figure 6: Effect of infaunal shrimps (Upogebia and Callianassa spp.) on intertidal shell habitat. Upper panel gives burrow count per m^2 at a number of test sites (number 11 and 12 were selected for full scale mitigation; see Fig. 1). Lower panel shows percent of original shell cover (100%) remaining on test plots in September, 1991, that were constructed in the months shown in the upper right (e.g. some plots constructed in June, 1991, had only about 10% of shell still visible three months later).

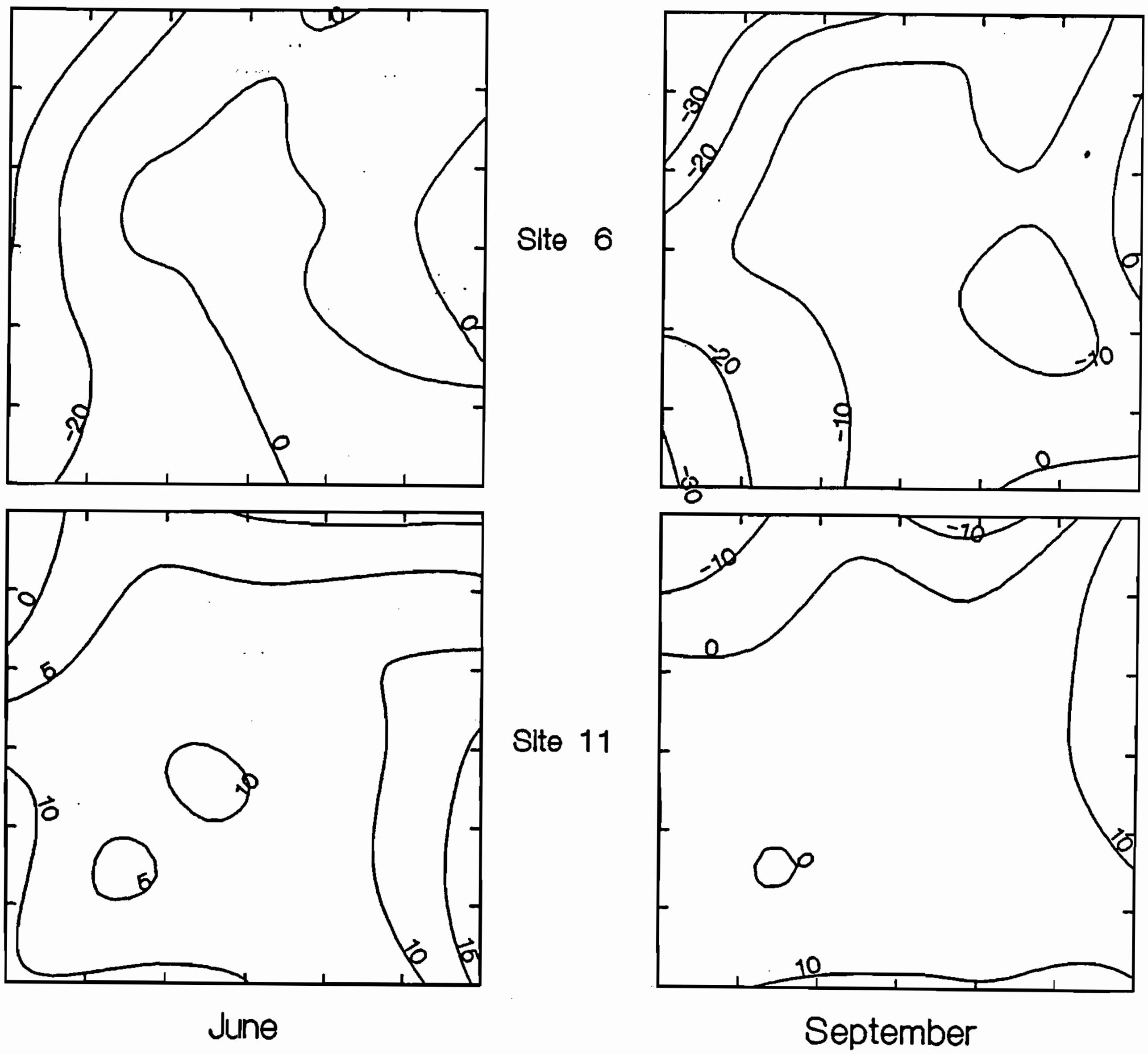

Figure 7: Depth isopleths of representative intertidal shell mitigation habitat constructed in April 1991. Values are depth (cm) of the shell surface relative to the surrounding grade of tideflats at two and five months after construction. Most shell at site 6 (high shrimp burrow count) was sunk 10 to 30 cm below grade by September, but most shell at site 11 ("Pacman") was still visible and functional as crab habitat.

definitely result in certain impacts to the estuarine population of crabs. After various negative consequences were eliminated or attenuated to the extent possible (timing, area, gear), construction of shell habitat was never embraced wholeheartedly by the full spectrum of participants in the agencies charged with protecting the resource. Some individuals were firm supporters of the shell mitigation program, others listed a variety of possible environmental consequences that, from their perspective, required a number of studies over seven years that caused costs to escalate tremendously. Among some of the environmental issues of concern were possible damage to eelgrass by intertidal shell, proximity of certain (and best) mitigation sites to upcurrent industrial pollution, and possible spread of exotic Spartina cordgrass with shell imported from other estuaries to Grays Harbor. Although seemingly important as concepts, these environmental issues were generally not important in reality. Eelgrass is tremendously sparse throughout the Grays Harbor estuary and in no case were perspective mitigation sites associated with high densities of this important vegetation. No studies were conducted to measure sediment or body burdens of various toxicants at perspective mitigation sites in comparison to alternative areas elsewhere in the estuary. [As an interesting aside, the greatest toxicant issue was directed toward dioxin and fear that small 0+ crab in residence for two to three months on certain intertidal mitigation sites, might obtain body burdens that are conceptually retained through life to adulthood. When caught in commercial fisheries offshore four years later, body burdens acquired as small juveniles would then pose some sort of health hazard to consumers. At the same time, individuals who raised this issue never questioned the possibility of consumer risk arising from extensive oyster culture in place at adjacent intertidal sites in the immediate vicinity where oysters require three years to market size.] Proliferation of Spartina seemed a legitimate concern since most of the shell was to be imported form Willapa Bay where this species of exotic vegetation is prolific. Measures were taken to ensure that shell brought into Grays Harbor was relatively free of seeds, but the estuary is by no means completely free of this plant.

Participants in deliberations concerning means to enhance king crab are right to consider a broad spectrum of pros and cons associated with the concept. The species has a complicated reproductive cycle and it will be difficult to rear *en masse* in the laboratory and out-planted to the wild as augmentation of natural production. There is little chance of assessing how such efforts translate into increased commercial landings. However, much can be gained along the way through committee efforts to best focus on practical plans and then select those few with greatest promise. Once done, participants should support a program at legislative and scientific levels in a grace period long enough to test feasibility of the research approaches adopted.

ACKNOWLEDGEMENTS

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REFERENCES

Armstrong, J. 1991. Food habits of staghorn sculpin and their role as crab predators in Grays Harbor estuary, Washington. Masters Thesis, University of Washington. 88p.

Armstrong, D.A., B.G. Stevens and J.C. Hoeman. 1982. Distribution and abundance of Dungeness crab and Crangon shrimp, and dredging-related mortality of invertebrates and fish in Grays Harbor, Washington. Tech. Rpt. for Washington Department of Fisheries and U.S. Army Corps of Engineers, Seattle District by School of Fisheries, University of Washington, Seattle. 349 pp.

Armstrong, D.A., T.C. Wainwright, J. Orensanz, P.A. Dinnel and B.R. Dumbauld. 1987. Model of dredging impact on Dungeness crab in Grays Harbor, Washington. Final Report to Battelle Pacific Northwest Laboratories and U.S. Army Corps of Engineers, Seattle District Office. Univ. Washington, School of Fisheries, Fish. Res. Inst., Seattle. FRI-UW-8702:167 pp.

Armstrong, D.A., O. Iribarne, K.A. McGraw and R. Palacios. 1991. Intertidal shell mitigation and community composition in Grays Harbor Estuary, 1990. Chapter 2, pp. 21-35 in Construction Dredging Impacts on Dungeness Crab, Cancer magister, in Grays Harbor, Washington and Mitigation of Losses by Development of Intertidal Shell Habitat, D. A. Armstrong, et al., Principal Investigators. Final Report by School of Fisheries, Univ. Wash. for Seattle District, U. S. Army Corps of Engineers. FRI-UW-9110:63 pp.

Dinnel, P.A., D.A. Armstrong and B.R. Dumbauld. 1986. Impact of dredging and dredged material disposal on Dungeness crab, Cancer magister, in Grays Harbor, Washington during October, 1985. Final Report to the U.S. Army Corps of Engineers, Seattle District Office. Univ. Washington, School of Fisheries, Fish. Res. Inst., Seattle. FRI-UW-8606:30 pp.

Dinnel, P.A., D.A. Armstrong, A. Whiley, T.C. Wainwright and K.A. McGraw. 1991. Impact of 1990 Grays Harbor construction dredging on Dungeness crab, Cancer magister. Chapter 1, pp. 3-20 in Construction Dredging Impacts on Dungeness Crab, Cancer magister, in Grays Harbor, Washington and Mitigation of Losses by Development of Intertidal Shell Habitat, D. A. Armstrong, et al., Principal Investigators. Final Report by School of Fisheries, Univ. Wash. for Seattle District, U. S. Army Corps of Engineers. FRI-UW-9110: 63 pp.

Dumbauld, B., D. Armstrong, P. Dinnel and T. Wainwright. 1988. Impact of dredging on Dungeness crab, Cancer magister, in Grays Harbor, Washington, during August 1987. Final Report to U.S. Army Corps of Engineers, Seattle District Office by Univ. Washington, School of Fisheries, Seattle. FRI-UW-8820:25 pp.

Dumbauld, B., D. Armstrong and T. McDonald. 1992. Use of intertidal oyster shell as habitat enhancement to mitigate loss of subtidal juvenile Dungeness crab (Cancer magister) caused by dredging. Can. J. Fish. Aquat. Sci. (in press)

Gunderson, D.R. and I.E. Ellis. 1986. Development of a plumb staff beam trawl for sampling demersal fauna. Fish. Res. 4:35-41.

Jamieson, G. S. and D. A. Armstrong. 1991. Spatial and temporal recruitment patterns of Dungeness crab in the Northeast Pacific. Memoirs of the Queensland Museum 31: 365-381.

McGraw, K.A., L.L. Conquest, J.O. Waller, P.A. Dinnel and D.A. Armstrong. 1988. Entrainment of Dungeness crab, Cancer magister Dana by hopper dredge in Grays Harbor, Washington. J. Shellfish Res. 7(2):219-231.

Pearson, W.H. and D.L. Woodruff. 1987. Effects of dredged materials from Grays Harbor on bait odor response in Dungeness crab (Cancer magister). Final Report for U.S. Army Corps of Engineers, Seattle District by Battelle Marine Research Laboratory, Sequim, WA. 48 pp.

Pearson, W.H., D.L. Woodruff, P. Wilkinson and J.S. Young. 1987. Data report for the 1984-1985 ocean surveys to investigate potential ocean disposal sites off Grays Harbor, Washington. Final Report for U.S. Army Corps of Engineers, Seattle District by Battelle Marine Research Laboratory, Sequim, WA. 183 pp.

Stevens, B., D. Armstrong and R. Cusimano. 1982. Feeding habits of the Dungeness crab Cancer magister as determined by the index of relative importance. Mar. Biol. 72: 135-145.

U.S. Army Corps of Engineers. 1982. Interim Feasibility Report and Final Environmental Impact Statement, Grays Harbor, Chehalis, and Hoquiam Rivers, Washington, Channel Improvements for Navigation. Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. 800 pp.

U.S. Army Corps of Engineers. 1989. Final Environment Impact Statement Supplement. Grays Harbor, Grays Harbor Navigation Improvement Project. Seattle District, U.S. Army Corps of Engineers. Seattle, WA. 115 pp.

Wainwright, T.C., D.A. Armstrong, P.A. Dinnel, J.M. Orensanz and K.A. McGraw. 1992. Predicting effect of dredging on a crab population: an equivalent adult loss approach. Fish. Bull. (U.S.) 90: 171-182.

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DUNGENESS CRAB ENHANCEMENT: A MARICULTURE PERSPECTIVE

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ABSTRACT

Most hypotheses relating to the collapse of the central California Dungeness crab population focuses on losses early in the life cycle. Consequently, protection of early stages in a hatchery environment followed by reseeding is thought to be an attractive way to help in the restoration of this fishery. The challenges, however, of developing hatchery technology for this crustacean are formidable. Little information is available on key components of the biology of Dungeness crabs which are necessary to have reliable and cost-effective hatchery programs. In addition to a lack of knowledge relating to larval rearing, a variety of other problems such as limited broodstock availability strongly hampers further research. These problems of developing hatchery programs for Dungeness crab as well as potential solutions are examined within the context of commercial crustacean aquaculture.

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A Review of Rehabilitation and Enhancement Strategies Utilized in Atlantic Canada Snow Crab (Chionoecetes opilio) Fisheries

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INTRODUCTION

The snow crab (Chionoecetes opilio) was first harvested commercially in the Gulf of St. Lawrence in 1966 and on the east coast of Newfoundland in 1968 (Taylor and O'Keefe 1981, Elner and Bailey 1986). The fisheries and the roll of the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) in providing advice for their prudent management have been well described by Elner (1982) and Bailey and Elner (1989), however, we will provide a brief summary of the recent history of the fishery in order to place this overview in its proper context.

Until the mid-1980's both the Newfoundland and southwestern Gulf of St. Lawrence fisheries (Fig. 1) were largely regulated by market demand and resource abundance. While both areas had in place "pre-emptive TAC's", these served solely as precautionary tools which would allow resource managers to close a fishery rapidly in the event it was determined that a fishery's viability was in jeopardy. It was felt that a 50-60% exploitation rate, minimum size limit, limited entry, pot limits, prohibition of soft-shell landings, and a male only fishery would safeguard the resource, at least from a biological perspective. Under this management regime landings rose in Newfoundland to 13,000 t in 1981 and reached 32,000 t in the

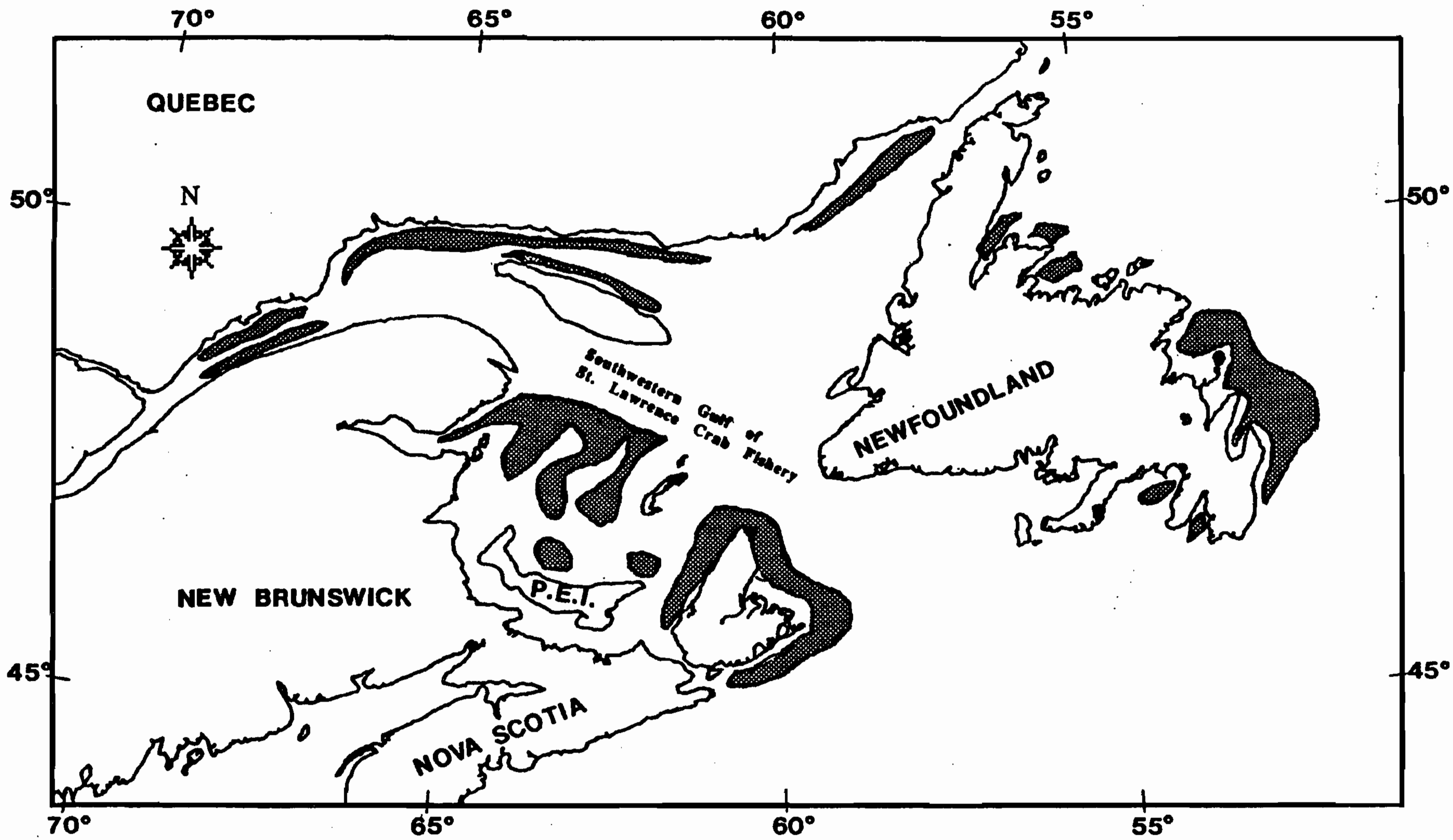

Figure 1. Distribution of snow crab, Chionoecetes opilio stocks (hatched zones) exploited in eastern Canada. (Adapted from Elner, 1982).

Gulf of St. Lawrence in 1982 (Fig.2). Following this peak, Newfoundland landings began to decline precipitously due to a combination of adverse environmental factors probably interfering with the normal molt cycle (Taylor et al. 1990) and excessive fishing effort. Catch rates in some management areas became so low that fishing activity virtually ceased. In the southwestern Gulf of St. Lawrence landings were stable at 24,000-26,000 t from 1983 to 1986. Between 1984 and 1987, fishery managers had set a quota level at 25,000 t which had not been based on scientific information. In addition, this quota being merely pre-emptive, had no real signification of catch limitation. In 1987-88, landings dropped drastically to 12,000 t, the lowest level since 1978 probably due to a combination of overfishing of hard-shelled commercial-sized crab and a high mortality of soft-shelled discards. In 1989, the landings further decreased to 7,900 t due to the premature closure of the fishery as a result of a high incidence of newly molted soft-shelled crabs in the catches.

Biology of Snow Crab

The description of a terminal molt in male crab (Conan and Comeau 1986) has been accepted by many snow crab researchers and, as a result, has generated a new interpretation of the life cycle of the species. The existence of a terminal molt phase in male crab has important management implications for the snow crab stocks. The key issue of biological factors relative to terminal molt influencing stock assessment techniques and management strategy are the following:

(1) Large-clawed males falling in the upper cloud of chela height-carapace width relationship do not molt at all (terminal molt) during the rest of their life cycle or have an extremely long intermolt period compared to their longevity.

(2) Small-clawed males falling in the lower cloud of chela height-carapace width relationship may molt once a year or every other year.

(3) Molting season of pre-recruit size crab occurs between February and May and the commercial fishing season starts as soon as the ice disappears (April-May). It takes several months for post-molt crabs to harden their carapace and reach commercially acceptable meat yield levels (Taylor et al. 1989). Therefore, in intensively fished areas where the season is of short duration crabs which molt in the spring may not be commercially acceptable until the following year.

In Atlantic Canada, the crab industry relies on hard-shelled males which preferably have molted one year or more prior to exploitation. During the developmental stage of the fishery, most individuals captured were probably in the large claw group which had accumulated over a period of years. As the fishery developed, old large claw males were fished out and the proportion of

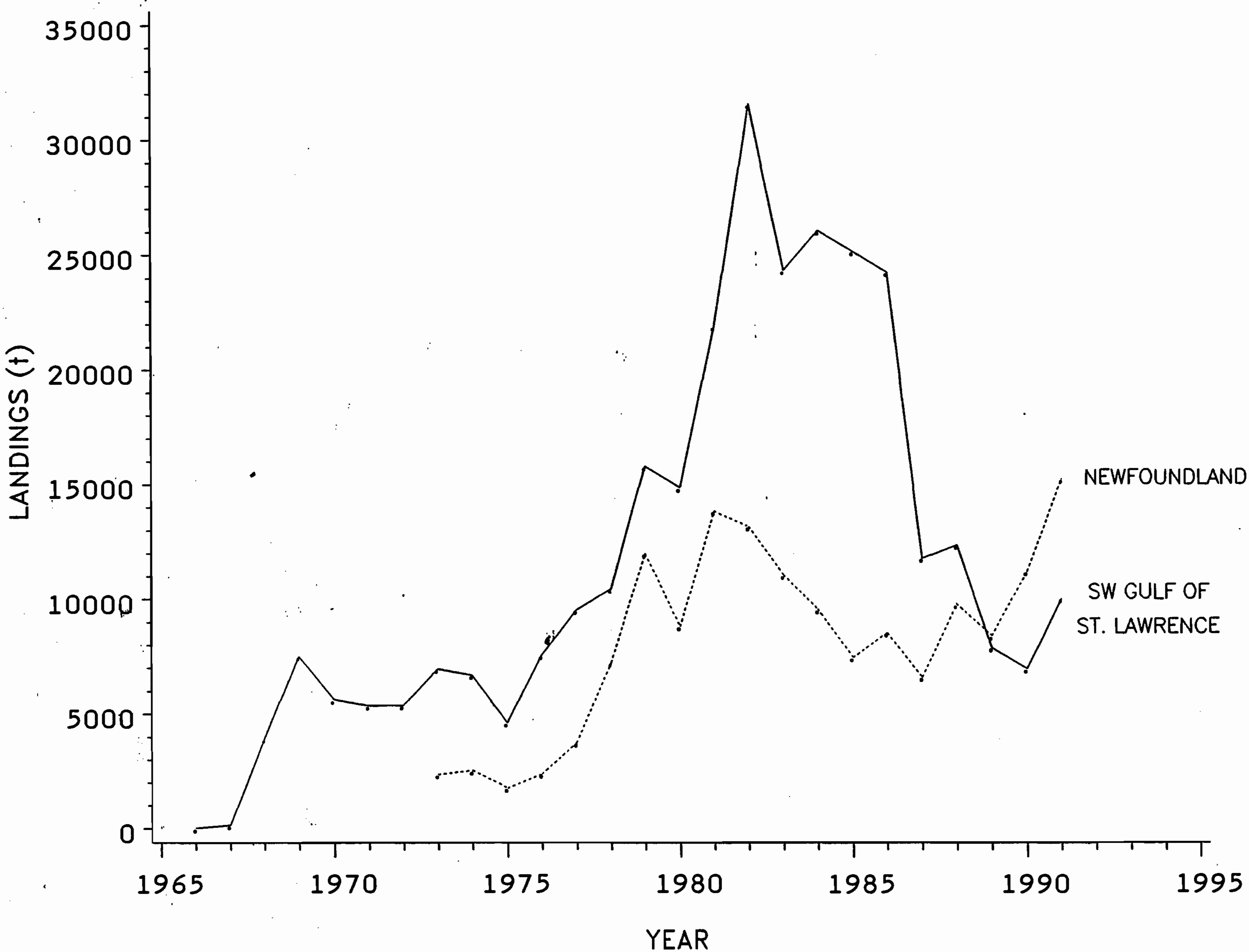

Figure 2. Summary of combined landings for the southwestern Gulf of St. Lawrence and Newfoundland 1966-1991.

individuals which had molted immediately prior to the fishing season increased in the commercial catch. These recently recruited soft-shelled crabs have a low commercial value and are discarded at sea with a subsequent high fishery induced mortality. This creates a dependency on annual recruitment to the fishery, which can translate into fluctuations in landings reflecting changes in recruitment levels.

Stock Assessment Tools

In the southwestern Gulf of St. Lawrence the principle assessment tool is a post-season biomass survey using a Nephrops bottom trawl. This survey covers all of the southwestern Gulf of St. Lawrence snow crab fishing areas (150 stations over the total surface of 30,000 km.) and has provided, for the first time in eastern Canada, a direct estimate of the abundance of exploitable and pre-recruit snow crab. The catch data sorted by sex, size, and morphometric characteristics are analyzed by geostatistic techniques known as Kriging (Conan et al. 1988). The technique of Kriging consists of analyzing and modelling the covariance between sampling units as a function of distance between their locations and calculating optimal weights to be attributed to each sampling unit for calculating a predicted average characteristic of a given region to be assessed. This technique provides an estimate of the average density and a variance over the whole area, therefore estimating the total number of crab and the variance present within the area surveyed. The numbers are then converted to biomass by calculating an average weight by size class from the size frequency distribution and the carapace weight-width relationship. An annual quota level can therefore be set based on the results of biomass estimation. Also, maps of isodensity contours of a given category of crab, such as commercially exploitable crab and potential molters, visualizing the areas of crab concentration provide useful tools for enhancement of stock management strategy and provide fishermen means of avoiding areas which are likely to experience a high proportion of soft shell crab in the following year (Fig. 3). Within-season monitoring of the commercial fishery by trained observers placed on commercial vessels provides information on the proportion of soft-shelled crabs in the catch at sea on a weekly basis and allows independent confirmation of catch rates reported by fishermen in their logbooks. The determination of soft-shelled crab is based on a durometer (Foyle et al. 1989) reading equal to or less than 68. This information is used to ensure the protection of new recruits to the fishery.

In Newfoundland, the large number of management areas (Fig. 4) spread over the entire Island preclude a yearly cruise that could provide a productive areal survey. Many of the deep-water bays have bottom topography unsuitable for effective bottom trawling. While such tools as retrospective Leslie analyses have been discontinued, a combination of detailed logbook analyses, at-sea observers, port sampling, consultations with fishermen and fisheries officers and several time-series trapping surveys are carried out in order to obtain an overview of the status of the

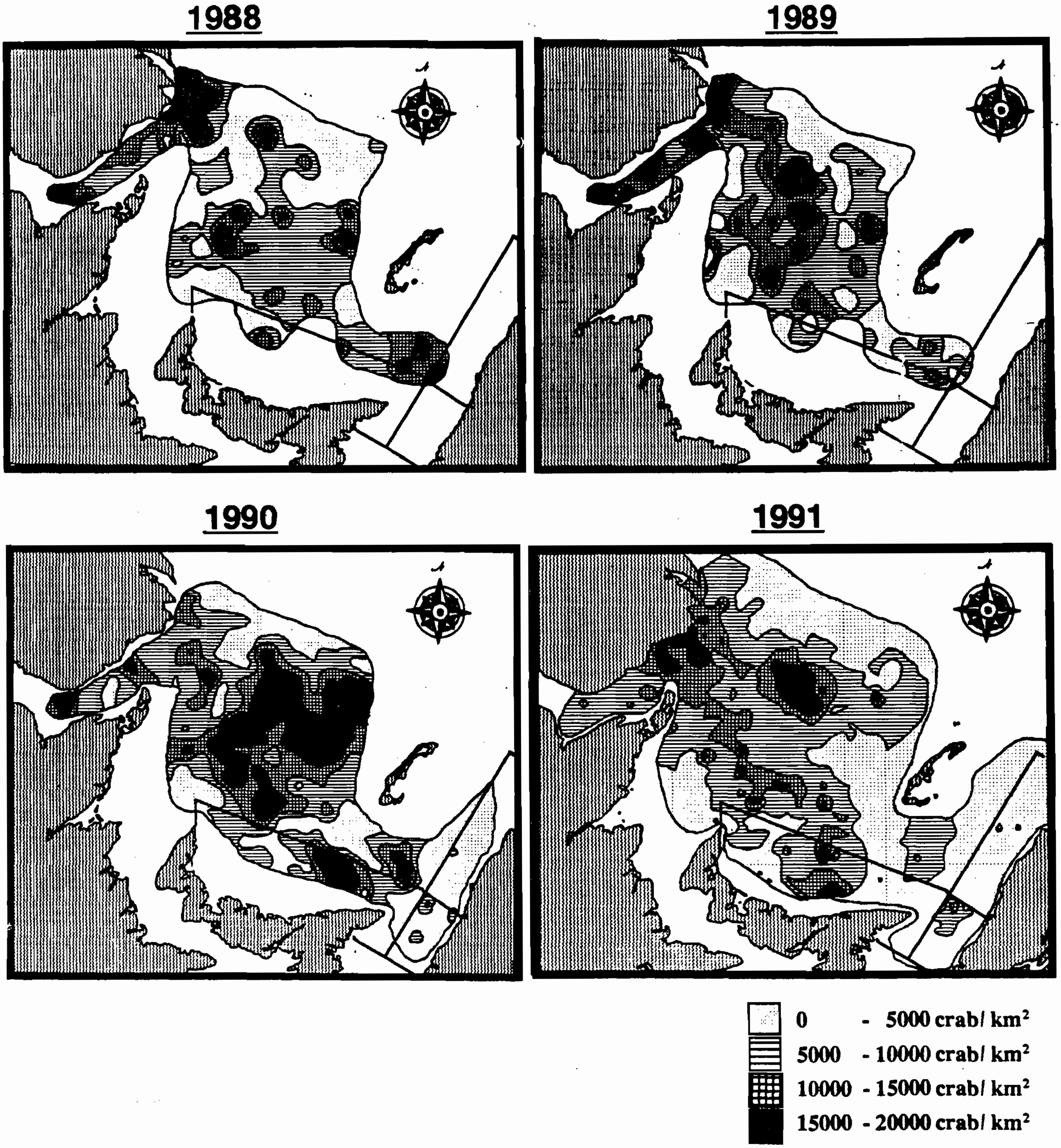

Figure 3. Isodensity contours of concentrations of potential male molters (small claw males) for four fishing seasons (1989-1991) seasons estimated based on the fall trawl survey (1988-1991) data.

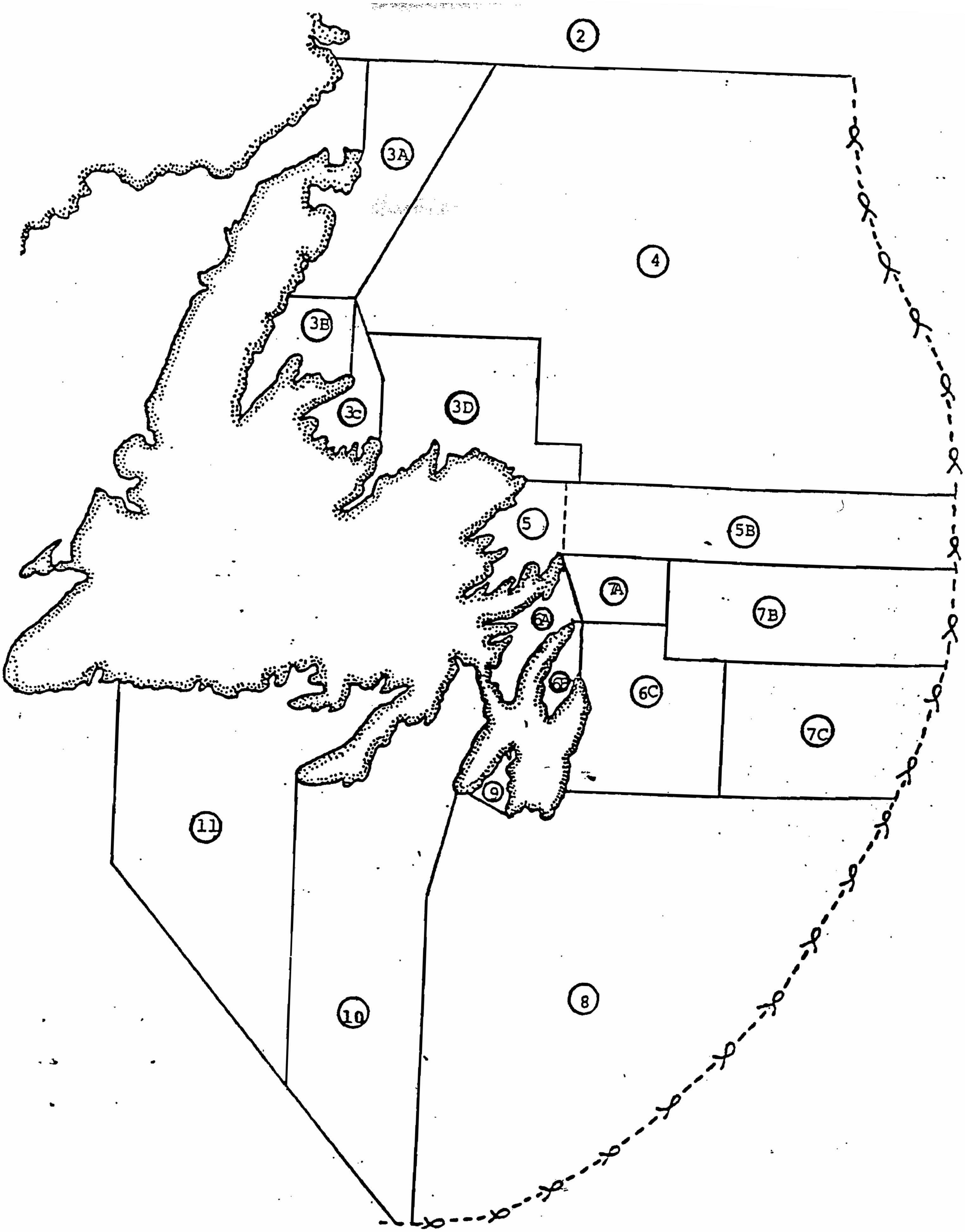

Figure 4. Newfoundland snow crab management areas.

snow crab resource in all areas. Quotas are not scientifically based in any strict sense of the word but rather, are assigned to individual areas based on the previous year's landings and how the crab population reacted to that level of exploitation. While quotas are assigned by resource managers this is rarely done without thorough discussion with area Crab Advisory Committees.

New Management Strategies

The snow crab fishery cannot be managed efficiently by the traditional manner of setting the annual catch limit representing half of the initial biomass. In addition, the biomass estimates traditionally used (Leslie analyses) did not exclude the biomass of potential molters from the commercially acceptable biomass, which leads to an overestimation of exploitable biomass (Mallet et al. 1990). Two principles or main management measures are in use in rebuilding the collapsed snow crab stock of the southwestern Gulf of St. Lawrence:

(1) limitations on the harvest of the accumulated part of the stock in order to avoid overfishing and;

(2) eliminating the premature exploitation of the newly molted crab in order to diminish the fishery induced mortality of discards and to accelerate the growth of the stock.

For the 1990 season, fishery managers set a quota level for the first time in the history of the southwestern Gulf of St. Lawrence fishery based on the predictive biomass estimation. The quota level was determined by taking conservative measures and setting the total quota level at 70% of the lower limit of biomass estimated (9800 t), i.e. 7,000 t. A new management measure was also added in order to protect soft-shelled crab by closing the season when a high incidence of such crab occurred in the commercial catches. The decision of seasonal closure is made either when the quota level is reached or when the incidence of soft-shelled crab on the fishing grounds exceeds 20%. For the 1991 season, the quota level was increased by 43% from 7,000 t to 10,000 t because of the increase in the biomass estimate. There was no problem of soft-shelled crab in the 1990 and 1991 seasons, mainly due to the conservative quota level. The exploitable biomass estimate has been increased over three consecutive years (8,700 t in 1989, 21,748 t in 1990, 23,444 t in 1991, and 29,433 t in 1992).

There is no scientific basis for setting quota levels based on biomass estimates. However, two years of experience in the southwestern Gulf of St. Lawrence crab fishery seems to indicate that an exploitation rate around 35-50% allows the population to grow slowly while ensuring the survival of the commercial fishery.

In Newfoundland, the emphasis in recent years has been on rebuilding depleted populations in almost all management areas. This has involved severe quota cuts initially often with painful economic consequences for fishermen and processing plant workers.

In some areas zonal (based on NAFO divisions) quota reductions were attempted but failed to have desired results as fishermen concentrated efforts on nearshore areas in order to minimize expenses. Only when management areas (Fig. 4) were handled individually did expected increases in CPUE occur. While the effect of changing recruitment patterns in determining the success of a fishery cannot be ignored, apparent increases in commercial abundance have occurred in almost all areas governed by this new management regime. Figure 5 demonstrates the apparent recovery of the fishable population subsequent to the introduction of quota management by individual management area. A one year lag effect has been imposed on the plot of CPUE vs Landings in order to better illustrate the direct effect quota manipulation appears to have on CPUE. A summary of the varying degrees of success of this practice in several management areas is provided in Table 1.

As a potential management strategy for all snow crab fishing areas, a rotation of the fishing grounds based on the estimation of the geographic concentrations of both commercially exploitable crab and potential molters may be more efficient in enhancing the protection of new recruits and the rapid growth of the exploitable part of the stock (Moriyasu and Conan 1991).

Snow Crab Rehabilitation and Enhancement Efforts

The recently formed aquaculture division of the Quebec Region has identified research on snow crab as a future priority due to its high commercial value and availability. However, culturing this species through its complete life cycle is currently considered impossible due to low survival rates to the settlement stage and the long time period between settlement and attainment of commercial size (probably up to 9 years). In addition, the high cost associated with feeding and maintaining in near-natural conditions (0-1°C and 28-30 ppt salinity), would make such an enterprise unprofitable. Instead, initiation of small-scale holding ("livestocking") projects aimed at improving crab quality in order to sell to a specialized market outside the normal snow crab harvesting period thereby commanding a premium price has begun.

Three steps in "livestocking" can be considered: first, maintaining commercial-sized hard-shelled crabs alive without feeding or with a minimum sustaining treatment; second, conditioning commercial-sized soft-shelled crabs normally discarded during the fishery by feeding until they recover to commercial acceptability; finally, manipulating the molt cycle of "immature" hard-shelled legal-sized crabs in order to accelerate their molt frequency. Since the gain in weight at molt is substantial, a comparable increase in value could be achieved through this procedure. Research plans are thus geared to these steps, proceeding from the elementary to the more complex stages and in the process gaining information that might eventually be transferred to rearing snow crab commercially from the egg stage.

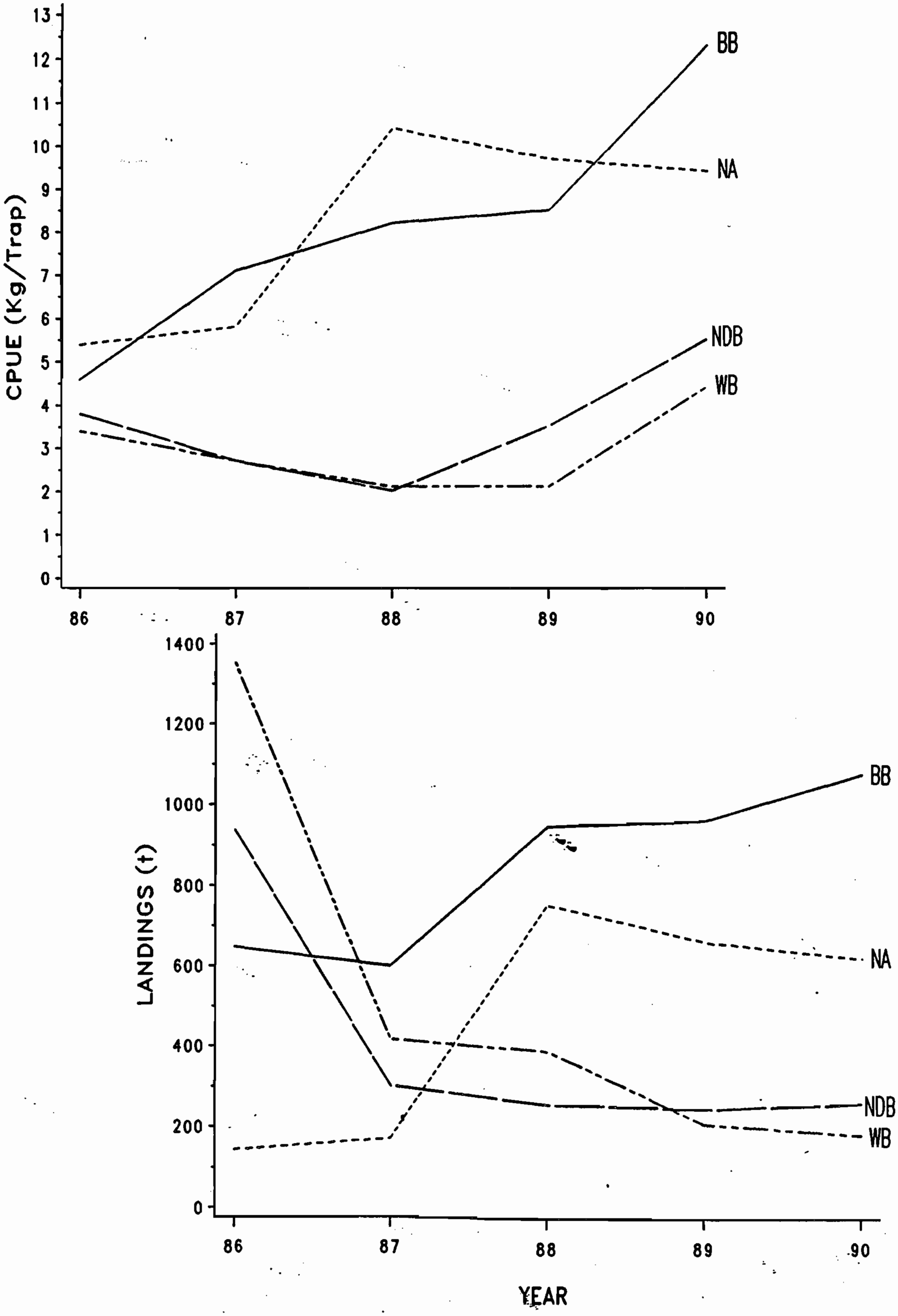

Figure 5. Apparent effect of quota (landings) manipulation on CPUE in four Newfoundland snow crab management areas illustrated in figure 4. A lag effect of one year is employed to better illustrate this effect.
'BB' = Bonavista Bay (Management Area 5, Fig. 4)
'NA' = Northeast Avalon (Management Area 6C, Fig. 4)
'NDB' = Notre Dame Bay (Management Area 3C, Fig. 4)
'WB' = White Bay (Management Area 3B, Fig. 4)

Table 1. Summary of apparent effects on CPUE of quota manipulation in four snow crab *Chionoecetes opilio* fisheries.

Year	Landings (t)	Quota (t)	Change (%)	Mean CPUE (kg/trap)	Change (%)
			WHITE BAY		
1988	387	300	-	2.1	-
1989	206	200	-33.3	2.1	0
1990	182	150	-25.0	4.4	+110.0
			NOTRE DAME BAY		
1988	255	400	-	2.0	-
1989	243	200	-50.0	3.5	+75.0
1990	260	180	-10.0	5.5	+57.0
			BONAVISTA BAY		
1985	1015	-	-	2.9	-
1986	648	500	-	4.6	+58.6
1987	602	500	0	7.1	+54.3
1988	944	700	+40.0	8.2	+15.5
1989	959	900	+28.6	8.5	+03.7
1990	1072	900	0	12.3	+44.7
			NORTHEAST AVALON		
1988	751	300	-	10.4	-
1989	661	400	+33.3	9.7	-6.7
1990	619	600	+50.0	9.4	-3.1

At the time snow crab were selected for this project the only indicator of the potential value of "livestocked" snow crab was the within-season price paid to fishermen. In spite of market uncertainties, 500 kg of crabs were kept unfed in pens from June to September 1991. Some weeks after the commercial fishery had ended the crabs were sold live to the restaurant market for twice the usual within-season price. A market study is planned in 1992 in order to evaluate the full potential of this type of operation.

A study of snow crab tolerance limits to changes in temperature and salinity was conducted on the hard-shelled and soft-shelled snow crabs. Soft-shelled crabs were included in view of a possible supplemental advantage that might occur by holding them. If kept for culture, they would escape an increased probability of mortality from at-sea discarding during the commercial fishery. A joint project has been conducted by DFO Fisheries Research Branch, University du Quebec, Rimouski, and DFO Division of Aquaculture on the mortality and tolerance limits of the soft-shelled crab.

Preliminary results suggest that soft-shelled crabs generally survive being fished and returned to the water if they are undamaged (R. Dufour, pers. comm.). In the tolerance study, soft-shelled and hard-shelled crabs kept at 4°C and 28 ppt salinity were directly transferred to various temperatures up to 20°C or to a series of lower salinities down to 7 ppt. 100% survival was achieved after 4 days exposure to a temperature regime ranging from 4°C to 16°C and in salinities ranging from 28 to 21 ppt. Soft-shelled and hard-shelled crabs had very similar survival rates. These results indicate that both soft-shelled and hard-shelled crabs, are somewhat physiologically robust they can tolerate surface and coastal fluctuations in salinity and temperature that are characteristic of the maritime estuary and Gulf of St. Lawrence. Within as yet undetermined limits, a higher optimal temperature can also be envisioned that would allow accelerated conditioning in the soft-shelled crab.

Proposed Areas of Study

Additional research projects on the life cycle of snow crab were begun in 1990. Researchers in Atlantic Canada have initiated monthly trawl surveys on an exploited population, studies on larval and post-larval recruitment mechanisms and population dynamics in an unexploited population, carapace ageing by means of radioisotopic techniques and epibiont densities, year round observations in aquaria, biochemical analysis of the characteristics of the molting hormones and change in ratio estimators of the effect of commercial exploitation on snow crab populations. The results from these projects together with the annual biomass and time-series trapping surveys will shed new light on the long-term fluctuation of snow crab abundance. This information will be utilized in designing Atlantic Canada snow crab management strategies geared towards assuring long-term optimal exploitation of the stock.

In terms of 'livestocking' projects, further research will be required in order to determine the optimal stocking conditions of hard-shelled crab within identified tolerance limits. Future studies are planned on determination of optimal conditions for muscular growth, control of density related physical and biological parameters such as oxygen limitation, excess in nitrogen and other waste compounds and hierarchial effects. A project investigating the possibility of controlling the molting process by manipulating various phenomena associated with molting is also being considered.

REFERENCES

Bailey, R. F. J., and R. W. Elner. 1989. Northwest Atlantic snow crab fisheries: lessons in research and management. In J. F. Caddy, Ed. Marine invertebrate fisheries: their assessment and management. John Wiley and Sons, New York, 1989, 261-280.

Conan, G. Y., and M. Comeau. 1986. Functional maturity and terminal molt of male snow crab, Chionoecetes opilio. Canadian Journal of Fisheries and Aquatic Sciences 43: 1710-1719.

Conan, G. Y., M. Moriyasu, E. Wade, and M. Comeau. 1988. Assessment and spatial distribution surveys of snow crab stocks by geostatistics. ICES Shellfish Committee. C.M.1988/K:10.12 p.

Elner, R. W. 1982. Overview of the snow crab, Chionoecetes opilio, fishery in Atlantic Canada. pp. 3-18. In: Proceedings of the International Symposium on the Genus Chionoecetes. Lowell Wakefield Symposia Series, Alaska Sea Grant Report 82-10.

Elner, R. W. and R. F. J. Bailey. 1986. Differential susceptibility of Atlantic snow crab, Chionoecetes opilio, stocks to management. Canadian Special Publication of Fisheries and Aquatic Sciences 92:335-346.

Foyle, T. P., G. V. Hurley, and D. M. Taylor. 1989. Field testing shell hardness gauges for the snow crab fishery. Canadian Industry Report of Fisheries and Aquatic Sciences 193.

Mallet, P., E. Wade, M. Moriyasu, and G. Y. Conan. 1990. La pecheau crabe des neiges (Chionoecetes opilio) dans le sud-ouest du golfe Saint-Laurent en 1989: L'etat de la resource et l'estimation de la biomasse. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document 90/93, Dartmouth.

Moriyasu, M., and G. Y. Conan. 1991. An alternative stock management for snow crab, Chionoecetes opilio Brachyura, Majidae), based on the presence of a terminal moult. Memoir of the Queensland Museum. 31: 461.

Taylor, D. M. and P. G. O'Keefe. 1981. Assessment of snow crab (Chionoecetes opilio) stocks in Newfoundland, 1979. Canadian Atlantic Fisheries Scientific Advisory Committee 81/57, Dartmouth.

Taylor, D. M., G. W. Marshall and P. G. O'Keefe. 1989. Shell hardening in snow crabs Chionoecetes opilio tagged in soft-shelled condition. North American Journal of Fisheries Management 9:504-508.

Taylor, D. M., P. G. O'Keefe and C. Fitzpatrick. 1990. A snow crab, Chionoecetes opilio, fishery collapse in Newfoundland. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document 90/63, Dartmouth.

Yamazaki, A., and A. Kuwahara. 1991. The terminal molt of snow crab in the Japan Sea. Nippon Suisan Gakkaishi 57(10): 1839-1844.

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AN INTRODUCTION TO IMPLANTABLE PASSIVE INTEGRATED TRANSPONDER (PIT) TAG TECHNOLOGY AS APPLIED TO RED KING CRAB IN BRISTOL BAY, ALASKA

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INTRODUCTION

An intensive study utilizing non-visible, implantable PIT tags in conjunction with external tags (Floy tags) was conducted by the Alaska Department of Fish and Game (ADF&G) in 1990 and 1991 on legal and pre-recruit male red king crabs, *Paralithodes camtschaticus*, in Bristol Bay, Alaska. The primary objectives of the study were to determine the feasibility of using PIT tags in a large-scale, commercial crab fishery application and to improve the accuracy of the estimated exploitation rate of legal male red king crab in Bristol Bay during the summer of 1990 through tag recovery analysis. Data gathered from subsequent tagging surveys will be used to refine annual population estimates from trawl survey data and to provide information on natural mortality, growth, migration, and the effects of fishing mortality on the Bristol Bay red king crab population.

The Bristol Bay red king crab fishery has historically been one of Alaska's most valuable shellfish fisheries, with a record landed catch in 1980 of 129.9 million pounds (58.9 million tonnes) worth an estimated 117 million dollars ex-vessel (ADF&G 1990). The abundance of Bristol Bay red king crab has been assessed annually since 1969 from trawl surveys conducted in the eastern Bering Sea by the National Marine Fisheries Service (Stevens and MacIntosh 1990). Over the course of the fishery and its assessment, many unanswered questions concerning stock status and the dynamics of the Bristol Bay red king crab population have arisen. For example, trawl surveys in recent years have shown major differences in legal population numbers while the catch-per-unit-effort (CPUE) from the fishery has been relatively constant. Low precision and unknown biases in the trawl survey may be contributing factors in this apparent discrepancy.

To-date, attempts to address these questions through supplemental tagging efforts by NMFS has yielded little additional information due to insufficient and inconsistent tag returns (R.S. Otto, National Marine Fisheries Service, Kodiak, personal communication). Further, tagging studies conducted on Kodiak Island red king crab populations during the early 1980s were compromised by a high degree of non-cooperation from fishermen in returning externally-marked crabs, which also resulted in deficiencies in collected tag data (ADF&G 1982). High loss rates of externally-marked (i.e., Floy-tagged) juvenile red king crab in the Kodiak area suggests at-sea tag losses may be a significant factor in the rate of visible tags recovered from the fishery (B. Dew, National Marine Fisheries Service, Kodiak, personal communications). The need for a tagging program capable of providing tag returns unbiased by factors associated with visible tags is clearly evident.

Implantable tags have been field-tested in several commercially-important crustaceans. The use of injected ferromagnetic or coded-wire tags in the snow crab, *Chionoecetes opilio* by Bailey and Dufour (1987) and the spot prawn, *Pandalus platyceros* by Prentice and Rensel (1977) has been tested with some success. Preliminary testing of PIT tags on small numbers of several other crustaceans, the dungeness crab, *Cancer magister* (Prentice 1986) and red king crab (W.E. Donaldson, Alaska Department of Fish and Game, Kodiak, personal communication) indicated that these tags were retained through molting and could be detected without sacrificing the tagged animal.

TAGGING EQUIPMENT AND PROCEDURES

Two different tagging systems were tested in the 1990 and 1991 studies and both were demonstrated. The first system was developed by Destron-Identification Devices, Inc. (2545 Central Ave, Boulder, CO 80301) and consisted of TX1400L 125 kHz PIT tags 10 mm in length and 2.1 mm in diameter. The electronic components of the tag are encapsulated in glass and are uniquely coded. The tag, when excited with an external power source provided by an HS5102L 125 kHz portable detector-reader, transmits its unique code which is then captured, displayed and stored by the reader. Tags were implanted into red king crab using a model I-300 automatic PIT tag injector developed by NMFS. The second system, distributed by InfoPet Identification Systems, Inc. (517 W. Travelers Trail, Burnsville, MN 55337) consisted of a Trovan model ID 100 128 kHz PIT tag 12 mm in length and 2.2 mm in diameter. As with the Destron system, the Trovan tag is glass-encapsulated. The tag is excited by the Trovan Model - LID 500 hand-held reader and its unique code is subsequently captured, displayed and stored by the reader. The two systems are incompatible due to the different operating frequencies of the tags and readers.

The proximal segment of the fifth, right leg was chosen as the site for tag implantation. As this leg is not processed because of its small size the possibility of product contamination is avoided. The fifth leg normally remains attached to the abdomen of the crab and not broken during processing. The tagging needle was inserted through the articulation membrane and the tag released longitudinally into the leg muscle. Tag orientation within the leg is shown in Figure 1.

REFERENCE

ADF&G (Alaska Department of Fish and Game). 1982. Westward region shellfish report to the Alaska Board of Fisheries.

ADF&G. 1990. Westward region shellfish report to the Alaska Board of Fisheries.

Bailey, R.F.J., and R. Dufour. 1987. Field use of an injected ferromagnetic tag on the snow crab (*Chionoecetes opilio* O. Fab.) J. Cons. int. Explor. Mer. 43:237-244.

Prentice, E.P. 1986. A new internal telemetry tag for fish and crustaceans. *In* A.K. Sparks, editor. Marine farming and enhancement; proceedings of the fifteenth U.S.-Japan meeting on aquaculture, Kyoto, Japan, October 22-23, 1986.

Prentice, E.F., and J.E. Rensel. 1977. Tag retention of the spot prawn, *Pandalus platyceros*, injected with coded wire tags. J. Fish. Res. Board Can. 34:2199-2203.

Stevens, B.G., and R.A. MacIntosh. 1990. Report to industry on the 1990 eastern Bering Sea crab survey. Ak. Fish. Sci. Cen. Proc. Rep. 90-09.

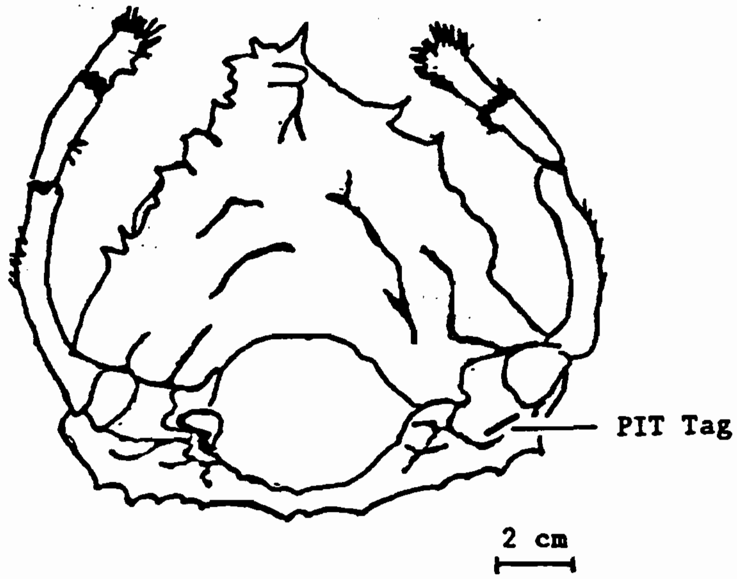

Figure 1. Ventral aspect of a red king crab abdomen showing the placement of the PIT tag in the proximal segment of the right, fifth leg.

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GENETIC STRUCTURE OF RED KING CRAB POPULATIONS IN ALASKA FACILITIES FISHERIES MANAGEMENT

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ABSTRACT

Horizontal starch-gel electrophoresis of proteins for genetic stock identification (GSI) has proven to be a powerful tool for the management of many marine species. This technique provides data on the genetic relationships of reproductively isolated populations, thereby permitting the individual management of these self-recruiting stocks. Additionally, when large genetic differences are found between populations, collections from unknown origin may be genetically screened and unambiguously classified. Finally, in the context of hatchery evaluation, the frequency of one or more of these markers can be modified in the enhancement stock (a process termed genetic marking). Thus, standard GSI and Peterson mark/recapture formulae can be used to evaluate the success of such a release program.

The Alaska Department of Fish and Game is currently screening genetic marks for stock management and unknown stock identification. We have examined collections of red king crab from fifteen localities in Southeast Alaska, the Aleutian Islands, and the eastern Bering Sea for genetic variation at 42 protein coding loci. Two highly polymorphic loci, PGDH (Phosphogluconate dehydrogenase) and ALP (Alkaline phosphatase), are useful for discriminating population differences between major geographic areas. The eastern Bering Sea collections from Bristol Bay and Norton Sound were very different from all other collections. Further, Southeast Alaska collections appear to form a population unit discrete from the Kenai, Alaska Peninsula, and Aleutian collections. Additional polymorphic loci appear to be useful in further differentiating populations, and we are continuing our study.

In January, 1989, we analyzed 89 red king crab samples of unknown origin. These samples were from a boatload of crabs allegedly caught near Adak Island in the Aleutian Islands. Enforcement personnel from Alaska Department of Public Safety and biologists from Alaska Department of Fish and Game believed that the crabs were actually caught in Bristol Bay during an area closure. Our data clearly showed that the crabs could not have come from Adak Island and that they probably originated from the Norton Sound/Bristol Bay population. Based on these genetic data, the vessel owner and the skipper pled "No Contest" in court and agreed to pay the state $565,000 in penalties for fishing violations.

We believe that these genetic data should be of considerable use in the harvest management of Alaskan red king crab. Additionally, the knowledge by fishermen that unknown samples may be identified to population of origin maydeter illegal fishing and improve the quality of catch statistics used to manage crab fisheries.

As part of this genetics study, we have identified seven naturally occurring genetic markers that may be suitable for hatchery evaluation. For example, the proposed Kodiak area hatchery enhancement would consist of collecting (each year) approximately 100 gravid females from wild stock. These will be spawned in order to produce approximately 25,000,000 larvae for hatchery production. The hatchery stock could be genetically marked by selecting these females from more than 1,000 which could easily be captured in Alitak Bay during late February and early March. The captured females would be tagged with an externally visible tag, and

muscle biopsies will be collected and delivered to the FRED genetics laboratory in Anchorage for genotyping. The genetic data could be collected within two weeks, prior to the spawning of the crab. The females will then be selected for hatchery production based upon their carrying one or more identifiable genetic markers which will be passed on to their progeny. These enhancement progeny will be distinguishable from native crab based upon their unique genotype frequencies.

The contribution of the enhancement crabs to local production could then be monitored by periodic samplings from early development through commercial harvest. The selection effort of one crab spawned per ten crabs genotyped (above) will permit accurate identification of enhancement crab in the mark recapture analysis (standard errors of less than 5% in samples of approximately 300 individuals).

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FORUM

International Crab Rehabilitation and Enhancement Symposium Panel Discussion

Lorne White, Alaska Department of Fish and Game, asked the panel of speakers the following three questions:

1. What are the research gaps or needs.
2. What should be the restoration strategy and/or technology.
3. What are the limiting factors and priorities.

Lorne showed a video of Tom Kron asking the speakers to consider:

1. situation in Alaska
2. state of technology available
3. what their recommendations are on what can be done in Alaska

Hiroyasu Kahata, Japan Sea Farming Association: They started 20 years ago and are beginning to know more about rising king crabs now, producing 200,000 king crabs with a goal of 1,000,000. Need to insure culturing and mass production of seeds. They still need better knowledge of young king crab. Advises long-term prospect - not short-term. Technology and development with a long-term plan, and need facilities.

Funding sources most important - fishermen should help with the cost. In the research and development stages, the federal/state should fund projects. Federal/state should also fund building a facility. When the results are good and when these would benefit fishermen, then they should defer the cost. It is important that the fishermen have the right attitude to support the government.

A.J. Paul, University of Alaska: It would need to be a long-term program, Alaska has a history of short-term programs. He was not sure if politics would support a long-term plan. Alaska knows nothing about enhancement so it would be difficult to answer that question. No one is funded to work on the problems (life history, recruitment), conserve stock that we have now, don't waste it.

D.M. Taylor, Department of Fisheries and Oceans, Canada: Establish project to look at recruitment of crab, defining mechanisms from cradle to grave. Not sure of building something like Japan until we know whether its worth it (settling areas). There are gaps in knowledge. Could do vertical movement of crab to encourage maintenance of them. Would suggest a pilot project using king crab settling stage collectors at optimal locations as a type of enhancement strategy at a modest cost.

Tom Shirley, University of Alaska: Alaska can not invest money as Japan has. Cost effectiveness of program should be looked at. Management through hatchery situation should be looked at. Would there be opportunities to attract research money to the state? Is it going to be cost effective to enhance the return of king crab.

Christine Brodersen, National Marine Fisheries Service: Alaska does not know what is preventing king crab from coming back naturally, so putting out lots of larvae is unlikely to help, and it carries the risk of causing serious genetic, ecological, or disease problems. Alaska needs to look at a research facility first, with no more than a small experimental hatchery.

Sergio Andrade, University of Magellan, Chile: Look at the broader perspective - support scientific work, 10 - 15 good scientist are needed. Would want a longer-term program with large scale research statewide involving size selection and genetic work. Would recommend lateral funding. Internal technology - not much is done in Alaska. Develop massive protocols on the successful projects that they all ready have. Need a training program for handling, etc. king crab. Must look at political issues, the whole process is longer than in Chile, need sensitivity from politics, and fishermen involvement and enthusiasm.

Doug Conklin, University of California: Regarding the use of collectors..., what would happen if you put 100,000 small king crab in a bay? Would you want hatchery on a large scale? You would have to culture algae and food. Would recommend collecting animals on small scale first.

Dana Schmidt, Alaska Department of Fish and Game: Should we go forward, when so far it has not been cost effective? Research and development as to why the king crab collapsed should be done. We are just trying to get the culture back, not enhance it. It could be considered cost effective because of what you learn. We need a marked animal whether in a hatchery or bay. Large scale production has proved not to work, and there are major questions that we can't answer.

Sam Chapman, University of Maine: Manifold program - culturing clams in large numbers. It takes a long time to research and get clear answers. A research hatchery is a good idea. Techniques developed elsewhere can be used, but need background of good scientists. Follow seeds in defined areas to research where they will grow. Conditions of survival from bay to bay are different.

Braxton Dew, National Marine Fisheries Service: Use of collectors may be most practical. Would need a lab to raise larvae - need a fundamental sampling program. Learn more about their movements - mostly assessments of what happened. Need to know the life history of the king crab. Shift focus on to research.

Dave Armstrong, University of Washington: He is against large scale production facilities, feels there is a need for a comprehensive, long-term plan. Timing is important for public support, opportunity. Need saltwater facility.

Stein Tveite, Flodevigen Biological Station: Should study side effects of crustaceans. Need a facility and public interest and support. Their lobster program has not be cost effective and probably will not be.

Masaru Fujiya, Overseas Fishery Cooperative Foundation, Japan: Seed production, clean water, environmental conditions, and fishermen support are all important. Studies on ecosystem changes, replacing king crab, and contaminants in water are also important.

Takashi Nakanishi, National Research Institute, Japan: Man should get value out of natural resources. Fishermen need to have a definite idea of what they want to do with the resource. Their attitude on what they want to do with it is important. There needs to be cooperative spirits between researchers, scientists, and fishermen.

Canada is more successful than Japan or Alaska at managing fishing resources. Japan scientists were criticized when they started seed production. They did not displace the natural production of resources. By planning and implementing king crab research, it shows we care about the management of this resource. Seed production is stable in Japan, the next step is release, etc. Japan has the technology on culturing.

Jeff Stevens, United Fishermens Marketing Association: Laymen are ready to support something being done to help with king crab population. It has to be creditable. There is a bottleneck in population and abundance of king crab. Broaden scope of research to include an enhancement/rehabilitation effort. Also, study physical oceanographic factors.

Guy Powell, retired crab biologist of the Alaska Department of Fish and Game: Habitat is good, in the 30's and 40's there was hardly any king crabs, nature went from low to high to low stock. There has to be balance between nature and introduced king crabs.

Unidentified audience member: Should concentrate on research and development.

Brad Stevens, National Marine Fisheries Service: Should king crab culture and enhancement be done? Adding organisms into the environment could be dangerous. Study all potential fishery resources so we can adapt to new resources. Enhance existing habitat some, but let nature take its course.

Unidentified audience member: Temperature factor - low temperature is better for egg production while larvae do better with higher temperatures. There are low temperatures one year, high temperatures the next year in ocean. Hatchery situation can control this. Star fish is the favorite food of king crabs. This may be one factor as to why king crabs have not come back. Star fish can be controlled in a hatchery.

Dave Osterback, Sandpoint Fisherman: Lots of changes in fishery from 60's to now. Can not understand what happened to king crab, the same thing happened to shrimp, they have not come back either. In the early 1990's there were lots of cod, in the 30's they disappeared, now they are back. Also, in the early days there was no jelly fish, now there are lots of them.

Hiroyasu Kahata, Japan Sea Farming Association: Japan's goal is one million seeds for production to be released, probably a minimal number needed for tracking. Advises a need for experimental facilities, more data on marking, and aging of adult king crab (no one has a method). Important to do larvae culture in a lab and trace them as far as possible. To be commercial, they would need to be much larger sized.

<u>Research Gaps or Needs</u> (Identified by Forum Panel)

Recruitment, time, method
Identify and define limiting factors & reason for decline
Marking and sampling
Incorporate research questions & management with plan
Oceanographic model
Adult tagging

<u>Restoration Strategy and/or Technology</u>

Protect critical habitat
Import known technology and develop research
Maintain genetic integrity, management, restoration
Habitat/competition
Set goals

<u>Limiting Factors/Priorities</u>

Long-term funding commitment
Habitat/competition changes

<u>Recommendations</u>

Long-term plan, facilities, funding
Public support, involvement, and education
Habitat enhancement
Identify sub-components
Recognize spin-off benefits - public, political, research
Wait for nature and ecosystem approach
Review this meeting and make plans

EXECUTIVE SUMMARY OF FORUM DISCUSSION - LORNE WHITE

The purpose of this symposium and forum was to evaluate Japanese and other national and international efforts on rehabilitation of king crab and other related shellfish species. This was proposed as a first, foundational step before undertaking any process of restoring the depleted natural stocks of king crab.

Half of the experts believed massive culturing of king crab for rehabilitation purposes is economically and biologically infeasible. The other half, particularly the Japanese scientists (who have the most experience), felt that culturing king crab for rehabilitation purposes was an achievable goal but needed to be started on a small scale basis with fundamental questions on public and fishermen support and evaluation questions solved at the onset of the program.

The next step in this program is to start a pilot program culturing small king crab to a point in their life history where they can be marked for identification. This step is of significant importance to evaluate the projects success. The Japanese program can be used as a model, with modifications that include evaluation, for a pilot project. The major challenge is finding the public and fishermens support to build a saltwater culture facility to carry out the work.

Instead of a massive statewide crab hatchery program, a localized demonstration project is needed to test the feasibility and success of king crab enhancement efforts. The concept of the project is to hold and rear young king crab in net pens; a process which takes twelve months. Protecting tiny crabs at a much higher rate than nature can is one key component to the success of this project. Recently, technological developments by the Japanese have accomplished this task for king crabs. The second part of the project is to mark and take the newly settled king crabs and "seed" them onto favorable marine habitats, then monitor their success rate to adulthood to see if the project is cost-effective.

This project would be carried out in a cooperative manner by two divisions of the Alaska Department of Fish and Game. The Fisheries Rehabilitation and Development (FRED) Division would have lead responsibilities on the project; focusing on juvenile crab rearing. The Division of Commercial Fisheries would take the settled tiny crabs, which they currently catch by the hundreds in their index equipment, and transfer them into our proposed net pen culture facility.

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