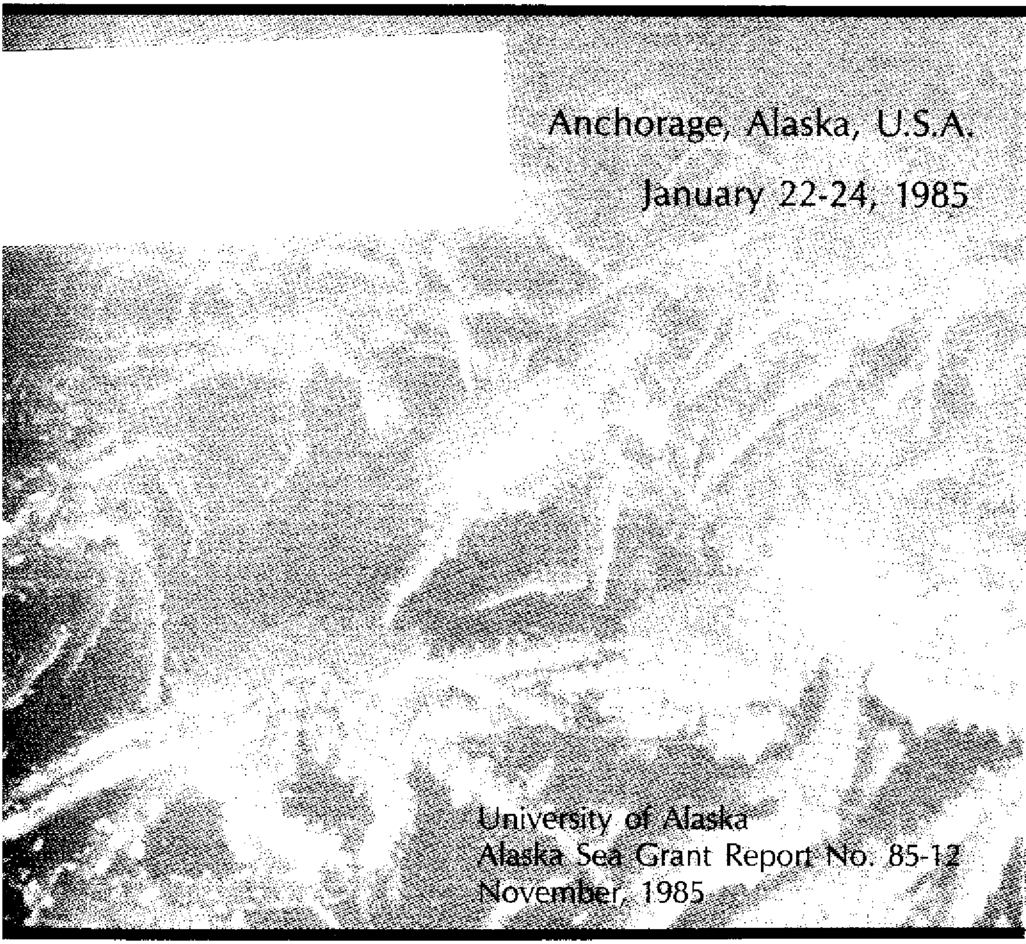
Lowell Wakefield Fisheries Symposium Series

Proceedings of the INTERNATIONAL KING CRAB SYMPOSIUM



Anchorage, Alaska, U.S.A.

January 22-24, 1985

University of Alaska
Alaska Sea Grant Report No. 85-12
November, 1985

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Symposium Coordinator
Brenda R. Melteff

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Preface

The International King Crab Symposium, the fourth in the Lowell Wakefield Fisheries Symposium Series, was planned to bring together scientists and managers working with the king crab (Lithodes and Paralithodes) resource. Participation came from Argentina, Canada, Chile, Japan, New Zealand, the Soviet Union and the United States.

The program was structured by a program planning committee whose members are:

Steven K. Davis	North Pacific Fishery Management Council
Fred Gaffney	Alaska Department of Fish and Game
Jerry McCrary	Alaska Department of Fish and Game
A. J. Paul	University of Alaska, Fairbanks
Robert S. Otto, Chairman	National Marine Fisheries Service

WELCOME AND INTRODUCTION

Welcome

Donald H. Rosenberg
University of Alaska, Fairbanks
Fairbanks, Alaska, USA

I am the director of the University of Alaska Sea Grant College Program. On behalf of the University of Alaska and the State of Alaska, I want to welcome you to the fourth in a series of conferences on commercially important fisheries resources of Alaska.

This series of symposia is named after Lowell Wakefield, one of the founders of the Alaska king crab industry. The series is designed to assist the management agencies, the scientists, and the industry in the exchange of information that is necessary to provide for sound management and wise use of these fisheries resources. This symposium, the International King Crab Symposium, is truly international. We have scientists present from Chile, Argentina, Japan, Canada and New Zealand. We are sorry that our colleagues from the Soviet Union have been unable to join us. Hopefully, in the future, conditions will allow them to more readily come and exchange information with us.

I see in reviewing the program that you have a very full few days. In talking with the session chairmen, I understand that papers are being added on, so you're going to be very busy and probably going to have to work into the evening.

I wish you well in your deliberations. I hope that this meeting is as productive as the previous Lowell Wakefield symposia have been.

Once again, I want to welcome you and I hope that, as a result of this meeting, you all leave with a little new knowledge, better ideas, and can help out this very important commercial fishery.

With that, I would like to introduce Bob Otto, of the National Marine Fisheries Service at Kodiak, who is going to give a brief introduction.

Introduction

Robert S. Otto
National Marine Fisheries Service
Kodiak, Alaska, USA
and
Oscar Dyson
Commercial Fisherman
Kodiak, Alaska, USA

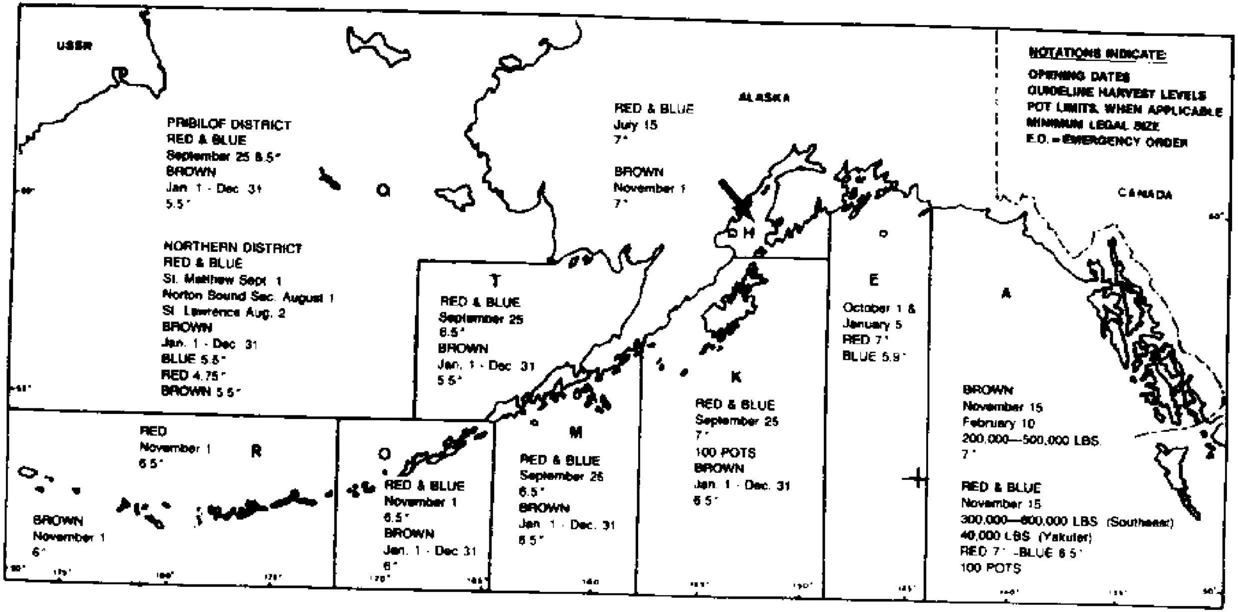
Comments of Dr. Otto

I know that many of you have traveled from afar and are perhaps not as familiar with Alaska as those of us who live here, so I'd like to start by giving you a very brief review of some areas that will be mentioned, as well as a general background on king crabs. Then I will turn the remainder of this introduction over to Captain Oscar Dyson, who has a long-term involvement in the Alaskan industry. He will give you a presentation on his experiences over the last 30 years of king crabbing.

Figure 1 shows statistical or management areas for king crabs in Alaska. You can easily locate Cook Inlet, Kodiak, the Shumigan Islands, and the Dutch Harbor or Eastern Aleutians management areas. From there north is the Bering Sea, which is divided into the Bristol Bay area (the major producer over the history of the fishery), the Pribilof Islands and the Northern Districts. Figure 1 also shows season opening dates, size limits (carapace width) and the predominant species in each area (red, *Paralithodes camtschatica*; blue, *P. platypus*; brown or golden, *Lithodes aequispina*).

Areas to the east are Prince William Sound and southeastern Alaska. Historically, some of the first U.S. king crab fisheries occurred in these areas. In recent history, however, their fisheries have been locally important but have not been major producing areas. To the west is the Adak or Western Aleutians area, which is one of the major producers.

Oceanographically, circulation in the Gulf of Alaska is dominated by the Alaska gyre. The northern edge of this countercurrent system forms the Kenai current (shown by arrows). It washes Kodiak, eventually goes through Unimak Pass, and then divides and goes east along the Alaska



KING CRAB FISHERY

Figure 1. Alaskan king crab statistical areas showing major species, season openings, guideline harvests (where applicable), minimum legal carapace widths (1" to 2.54 cm), and pot limits per vessel (where applicable).

Statistical Areas

A	Southeastern-Yakutat	O	Dutch Harbor
E	Prince William Sound	R	Adak
K	Kodiak	T	Bristol Bay
H	Cook Inlet	Q	Bering Sea
M	Alaska Peninsula		

Peninsula into Bristol Bay and north to wash the shelf edge toward the Pribilofs. In terms of interactions of various stocks, the general drift may be worth considering for the simple reason that what happens with larvae in the Kodiak area, for example, may well influence what happens to the west.

King crab stocks in Alaska are managed by the federal government and the state of Alaska. Fisheries in the Bering Sea and the Aleutians are managed by the federal government and the state. Management policy is jointly formulated and coordinated by the Alaska Board of Fisheries and the North Pacific Fishery Management Council. Historically, both Japan and the U.S.S.R. harvested king crabs off Alaska, but the fishery has been wholly domestic since 1974.

Alaskan king crab fisheries, particularly those in western Alaska, have had a substantial impact on a world-wide basis (Fig. 2). These fisheries have been dominated by landings from Kodiak and the Bering Sea. Precipitous declines in these areas coincided with declines in other areas of Alaska and led to substantial dislocations in the fishing industry. Catches in western Alaska peaked at 85,900 tons in 1980 and, due to season closures in many areas, had declined to only 5,300 tons in 1984.

Put in another perspective, Figure 3 shows the total value of king crab fisheries relative to all crab landings in the United States. This is the value of king crabs landed in the United States from all Alaskan waters, including the eastern Bering Sea and Kodiak. Again, we see a very substantial impact. Because of inflation the peak in value occurs somewhat earlier than that of landings. In 1983 U.S. dollars, the maximum was $230 million for all king crab fisheries in 1978. It has gone down ever since, and at this point in time is about $25 million.

This is some background as to the reasons why we have been interested in putting together a group of experts to talk about what happens with king crab. We feel that it would be very timely to have a document and exchange of information to help us decide where to go from here.

With that, I would like to introduce Captain Oscar Dyson, who has a long-term background in Alaskan fisheries. He came to Alaska with the Army and worked for their engineering department during the 1984s, began fishing in Cook Inlet as a gillnetter in 1946, and then was owner and operator of progressively larger vessels. He is now the captain of a 100-foot crabber/trawler which operates out of Kodiak. He has fished for salmon, halibut, shrimp and groundfish. At one time or another, Oscar has landed about anything that anyone could in Alaska, but he has a very long-term interest in king crabs. Without further ado, I'll ask Oscar to give us some background on his experiences with king crabbing over the past 30 years.

Comments of Captain Dyson

After fishing for 30 years at sea, I feel I'm much better at fishing than I am at talking about it and telling stories about it.

We have to begin back in the 1950s when I really started king crabbing. There was some fishing done prior to that, but we didn't hear much about it. We have to give a lot of credit for development of the king crab industry to Lowell Wakefield, for whom this symposium series was

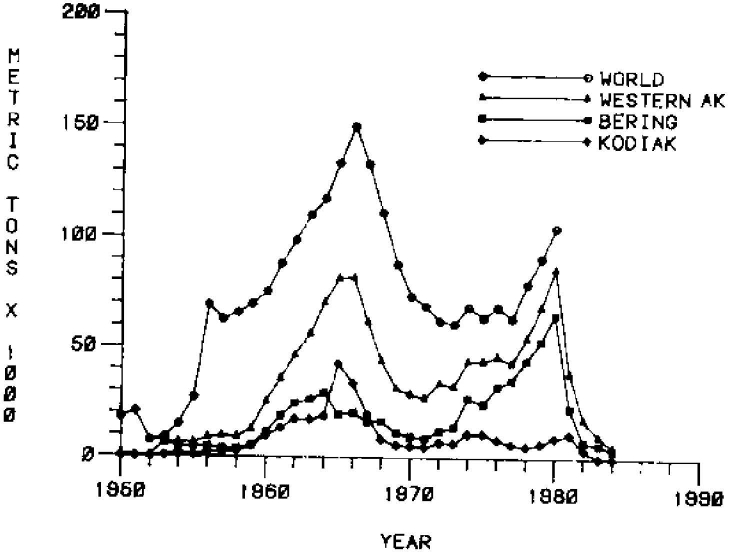


Figure 2. Landings of king crabs from western Alaska (Kodiak and west), Kodiak, and the Bering Sea (areas F and G), in comparison to world landings.

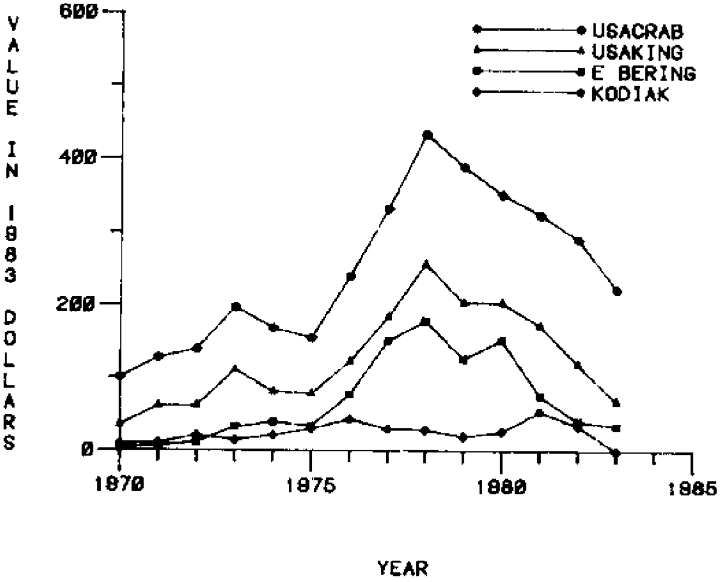


Figure 3. Value of U.S. king crab landings relative to total U.S. crab landings.

named. Lowell had done considerable work in marketing. He built a trawler, the Deep Sea, and started researching the areas and locating where the king crab were of commercial quantity. I guess he located most of the areas, because that's where we did most of our fishing over the years.

Well, to go back to the 1950s, we had a big job to do. We had to build our gear starting from scratch, and taking a lot from what the Japanese had done. We liked the tangle net gear, but it was too much work to put the tangle net gear down. When we would pull it up, we wouldn't know what was in it. We would have everything from snails to ducks, females and small crab, big crab, and by the time we got that tangle net picked out, we were lucky to have any fingers left. When you got one leg pulled out, and were working on another, the crab would get it tangled again and then he would bite you. We quit that and decided trawling might be the easiest and best way. It was for awhile, but we soon found out it was not selective. We were damaging many juveniles and females as well as other species of crab that we couldn't use, so we decided that that wasn't the way to do it. We switched to pots, which finally proved to be the best gear of all for fishing king crab. But the pot had to be designed and experimented with. Finally, we went from round pots like the Japanese used, to square pots, back to round six-foot pots, and finally settled on the pot which we're using today. It is seven feet square by three feet high, and it turned out to be an excellent and productive unit of gear.

The first ten years of king crab fishing between 1950 and 1960 was more or less the development stage. We never really made much money at it. The prices were low, the markets really hadn't been developed, and the processing sector was just starting to be developed.

Finally, in 1960, things seemed to break open with the advent of radar, which gave us a chance to locate the gear and the areas; and later the advent of LORAN C, which allowed you to pinpoint your gear within 50 to 100 feet, from hundreds of miles away. You put down a pot, get your bearings on it and you can return to it night or day. One of the other big advances in the fishery was, of course, lights. Prior to lights being put on the boats, we just fished during the day because we couldn't see to pick our pots at night. When the lights came along, we would work 28 hours out of every day, if that was possible. It changed the fishery around; we put much more effort into it.

The next concern between the 1960s and the 1970s was regulations, due to the build-up in the fleet and the build-up in the processing sector. We put our heads together, all the people involved in Alaska and the group from Seattle, and proceeded to discuss, and sometimes battle over, what regulations were needed. Some of us were quite conservative. We thought the best approach would be to lower the sustained yield and to look to the future. Some wanted to catch all the crab tomorrow.

I think the state and the management people did a good job in locating the crab and determining the size, sex, seasons and quantity that was to be caught.

During the 1970s, king crab fisheries continued to develop, particularly in the Bering Sea. The Marine Design and Construction Company (MARCO) built a lot of the newer vessels up to 122 feet. Newer vessels were equipped with improved blocks, line coilers and pot launchers; and it took much of the work out of crab fishing. Before that, we had to coil by hand and when you coil 200 lines of 100 fathoms, you know you've got some work on your hands.

Well, folks, I guess that's it and thank you for listening to my story.

SESSION I

TAXONOMY AND DISTRIBUTION

Proc. Int. King Crab Symp.
Jan. 1985, Anchorage, Ak.

The disjunct distribution of blue king crab, *Paralithodes platypus,* in Alaska: some hypotheses

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Blue king crab, Paralithodes platypus, and red king crab, P. camtschatica have latitudinal ranges that, in the northeast Pacific, extend from the Bering Strait to southeast Alaska. Within their joint range, however, red king crab are nearly ubiquitous but blue king crab occur only in small isolated populations associated with either offshore islands in the eastern Bering Sea or enclosed bays and fjords in the Gulf of Alaska (Fig. 1). Although both species are found on hard and soft bottoms in relatively shallow water, each is absent or rare in areas inhabited by the other.

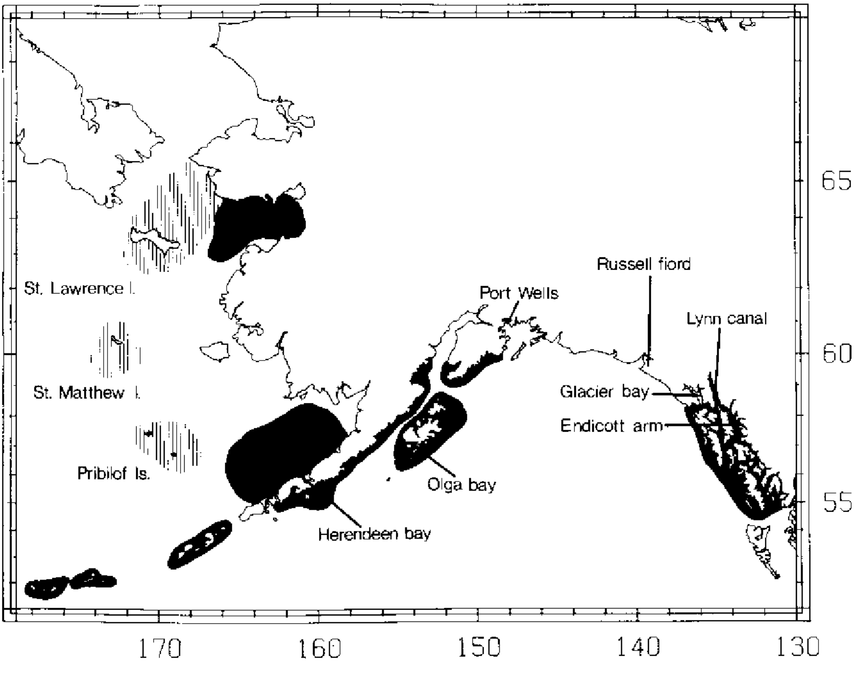
In this paper I examine the distribution of blue king crab from a biogeographic perspective starting from the premise that the isolated populations we see today are relicts from a former, broader distribution. Such relict populations are often attributed to large-scale scale environmental changes and the existence of refuges from these changes (Brown and Gibson 1983). The general rise in water temperature that has occured during the present inter-glacial period is undoubtedly such an environmental change and, in the following, will be considered the primary factor shaping the distribution of blue king crab. The effect of this increase in temperature could have been either direct, by imposing a physiological stress on blue king crab, or indirect, by allowing or intensifying the interaction with a warm-water competitor or predator. Therefore, blue king crab might occur in areas that are now either refuges from warm water or refuges from other species. In the following, I propose three mechanisms that, either singly or in concert, could have restricted the distribution of blue king crab to these isolated refuges. These mechanisms are: reproductive interference, competitive displacement and predatory exclusion.

As each of these mechanisms is examined, various biological attriattributes of blue king crab will be compared to those of its congenor, red king crab. Such comparisons will provide clues as to why each species occurs in areas uninhabited by the other and, hopefully, will indicate the applicability of each mechanism.

Preliminary Note

In several instances I will cite my personal observations as evidence for a particular statement. These observations were obtained in Olga Bay, Akaska, where I spent approximately 35 hours underwater observing both adult and juvenile blue and red king crabs under natural conditions. The study consisted of four diving trips made at three month intervals, beginning in March, 1980. During each trip, individual dives were made during the day and at night, in soft-bottom and in hard-bottom habitats. Although the observations are qualitative, often subjective, and posibly not applicable in other areas, they are, to my knowledge, the only information on some aspects of king crab biology that is available.

Figure 1. The locations of blue king crab populations in Alaska are indicated with names and, in the eastern Bering Sea, with parallel lines. The more wide-spread distribution of red king crab is shown with dark shading.



The Mechanisms

Mechanism 1: reproductive interference

If blue king crab were physiologically adapted to colder water than red king crab, then an increase in water temperature could have restricted blue king crab to cold water refuges and allowed red king crab to expand into the vacated habitat. In other words, the distribution of each species could be determined solely by temperature tolerances and habitat availability.

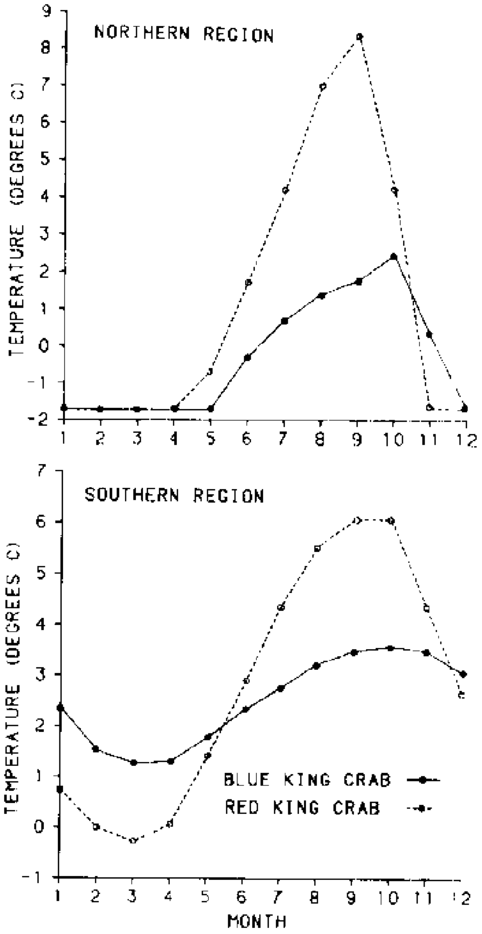
If this hypothesis were true, then blue and red king crabs should now be found in areas with different temperature regimes. The annual fluctuation in bottom temperature is shown in Fig. 2 for two pairs of adjacent blue and red king crab populations in the eastern Bering Sea: 1) Pribilof Island blue king crab and Bristol Bay red king crab (southern region) and 2) St. Lawrence Island blue king crab and Norton Sound red king crab (northern region). In both the southern and northern regions, the mean annual temperatures within the blue and red king crab areas are not significantly different (paired t test: southern area, P=.54; northern region, P=.06), however red king crab areas are warmer throughout much of the spring and summer. In areas outside the eastern Bering Sea, it is also likely that red king crab experience higher summer temperatures than blue king crab because the bays and fjords inhabited by blue king crab probably have sufficient fresh water input to create stratified two-layer systems, and such stratification would tend to restrict summer warming to depths shallower than those inhabited by king crab (In Olga Bay there is a distinct thermocline that gradually increases in depth during the summer. Adult blue and red king crab were never found shallower than this thermocline, but often immediately below it; per. ob.).

Temperature undoubtedly influences many aspects of the biology of red and blue king crabs which limit their distribution, but its effect on the reproductive cycle could be the most important. Red king crab have an annual ovarian cycle and a 12 month embryonic period whereas blue king crab have a biennial ovarian cycle and a 14 month embryonic period (Somerton and MacIntosh, in press). Since the rates of ovarian and embryonic development vary with temperature (Wear 1974), one interpretation of the more protracted reproductive cycle of blue king crab is that it represents an adaptation for reproducing in cold water. If this is true, then the optimum temperature for reproduction could differ between species, and each species should therefore be restricted to areas having the appropriate temperatures.

Mechanism 2: competitive displacement

An increase in temperature could have allowed a warm-water competitor to expand its range and displace blue king crab from its preferred habitat. This mechanism, however, would produce the disjunct distribution of blue king crab only if the following were true: First, the competitor must, either directly (contest competition) or indirectly (scramble competition), be competitively dominant, that is, it must be capable of excluding blue king crab from its preferred habitat. Second, blue king crab refuges must exist in which the competitor cannot live successfully.

Figure 2. Annual temperature fluctuation for nearby blue and red king crab populations in the eastern Bering Sea. The upper panel (northern region) compares St. Lawrence Island blue king crab with Norton Sound red king crab and the lower panel (southern region) compares Pribilof Island blue king crab with Bristol Bay red king crab. In both cases, long-term (1953-1982) averaged monthly temperature data for 24x24 nautical mile squares was obtained from Ingraham (1983) and averaged over the geographic area of each population as defined in Otto (1981).



Two lines of evidence suggest that red king crab is a potential competitor of blue king crab. First, red and blue king crabs are similar not only with respect to size and shape but also with respect to chela morphology and foraging behavior. Both species have chela adapted for crushing mollusc and urchin shells, both feed on hard and soft bottoms (per. obs), and, when feeding on a soft bottom, both species excavate large pits (per. obs.). Second, blue and red king crabs have adjacent, but nonoverlapping, distributions, and this is often interpreted as an indication that two species are potential competitors (Brown and Gibson 1983).

If red king crab were competitively dominant over blue king crab then some mechanism must exclude it from areas inhabited by blue king crab. There are two possible ways this exclusion could occur. First, competitive dominance may be a function of temperature, that is, red king crab may be dominant in warm water and blue king crab may be dominant in cold water. Second, since blue king crab areas tend to be geographically and hydrographically isolated, a species should exist in these areas only if it could reproduce there, and red king crab may not be able to reproduce sucessfully at the lower temperatures found within blue king crab areas.

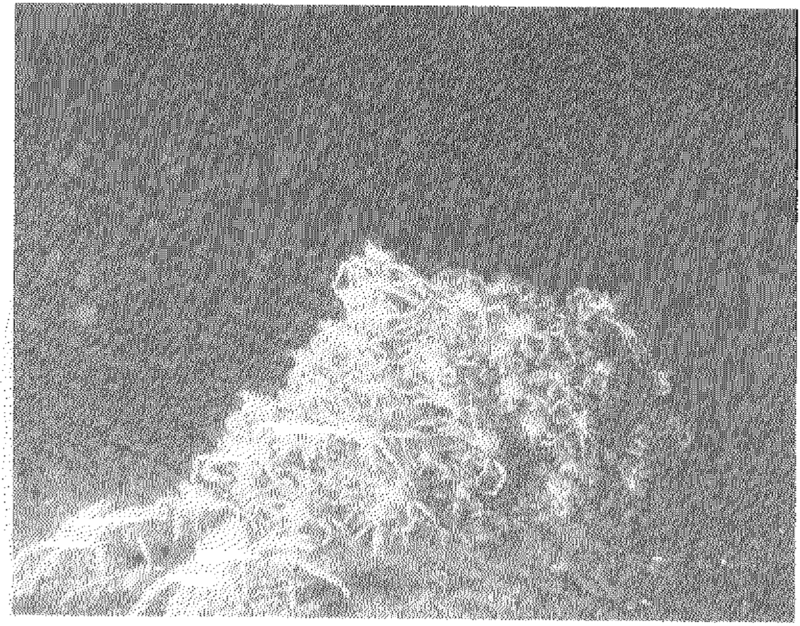
Mechanism 3: predatory exclusion

An increase in temperature could have also allowed a warmwater predator of king crab to expand its range and exclude blue king crab from its preferred habitat. Again, however, this mechanism would produce the disjunct distribution of blue king crab only if the following were true. First, blue and red king crabs must, at some stage in their lives, be differentially vulnerable to the predator so that blue king crabs, but not red king crabs, are excluded from an area. Second, blue king crab refuges must exist in which the predator cannot live sucessfully.

Although adult red and blue king crabs are similar with respect to size, shape and behavior (per. obs.), juveniles differ markedly, and these differences reflect different mechanisms for predator avoidance. Juvenile red king crab are bright red or orange, which is conspicuous at the shallow depths in which they occur (per. obs.), whereas juvenile blue king crab are cryptically colored and vary from blue-grey to white depending on Substrate type. Juvenile red king crab form large aggregations (Fig. 3), or pods, and are diurnally active whereas juvenile blue king crab are solitary and nocturnal (per. obs.). Juvenile red king crab have relatively long spines compared to adults whereas juvenile blue king crab have spines which are proportionately the same length as those of adults (Fig. 4). Since all of these features can be interpreted as mechanisms for avoiding predation, it is likely that each species is adapted to avoid its own unique suite of predators. Presumably, the defenses of blue king crab are adapted for cold water predators and those of red king crab are adapted for warm water predators. If this is true, then blue king crab could have been increasingly exposed to a warm-water predator for whom its defenses, but not those of red king crab, were ineffective.

If a predator could exclude blue king crab from its preferred habitat, then some mechanism must exist to exclude not only the predator, but also red king crab, from blue king crab areas. The simplist, consistent explanation is that both the predator and red king crab either avoid cold water, or are unable to reproduce in cold water.

Figure 3. Juvenile red king crab typically form aggregations or pods like the one shown in the above photo taken by Guy C. Powell near Kodiak, Alaska.

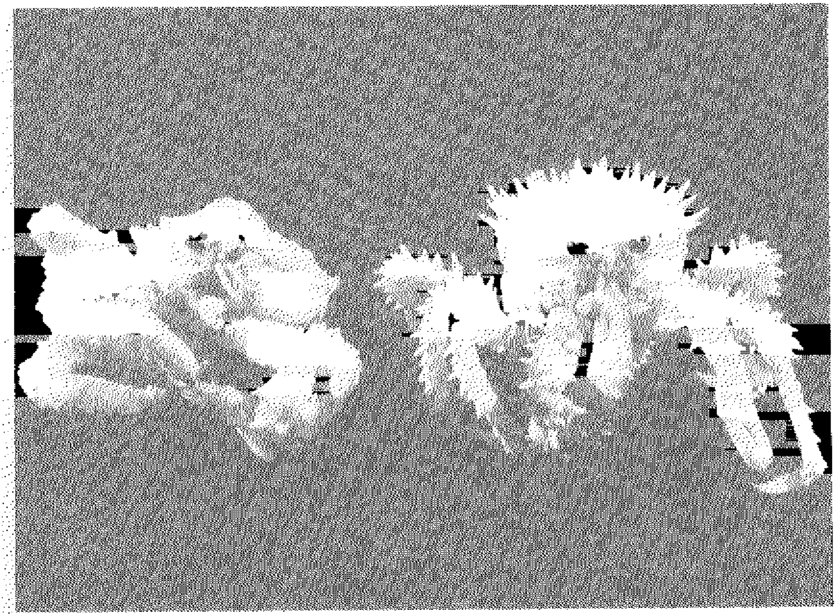


Discussion

To provide a sufficient explanation of the disjunct distribution of blue king crab, a mechanism must answer two questions : 1) what excludes blue king crab from areas, with otherwise suitable habitat, that lie between the extant populations? and, 2) why are red king crab absent or rare within blue king crab areas? The three mechanisms proposed here differ primarily in their answer to the first question. The first assumes that the distribution on blue king crab is solely determined by the distribution of refuges from warm water whereas the second and third assume that temperature alone is insufficient and that the distribution is largely determined by interaction with either a competitor or a predator. Although each explanation is plausible and is supported by many examples in the ecological literature, each has its own weaknesses.

The first mechanism assumes that the biennial reproductive cycle of blue king crab is an adaptation for reproducing in cold water, and, based on this, proposes that temperature limits the distribution of blue king crab through its influence on reproduction. However, there are two reasons why the biennial reproductive cycle may not represent an adaptation to cold water. First, *Chionoecetes opilio* lives within many of the same areas of the eastern Bering Sea as blue king crab, but, like its warm water congenor, *C. bairdi*, *C. opilio* has an annual reproductive cycle (Somerton 1981). Second, biennial reproduction in other animals has been interpreted as a strategy for increasing the energetic efficiency of reproduction (Bull and Shine 1979) rather than an adaptation to cold water.

Figure 4. Juvenile red king crab (right) have spines on their exoskeleton which are much longer than those of a similar sized blue king crab (left). Photo taken by J. Bowerman.



The second mechanism assumes that red king crab is a dominant food competitor of blue king crab. However, competing species often display strong habitat partitioning in areas where they are sympatric, but, within Olga Bay, there were no conspicuous differences in when, where and how adult red and blue king crab foraged (per. obs.).

The third mechanism assumes that red king crab and a warm water predator have sympatric distributions and that blue king crab is excluded from red king crab areas because its defenses are ineffective against this predator. However, no predator appears to be associated with one species of king crab but not the other. Furthermore the differences in shape, color and behavior of juvenile red and blue king crabs could be viewed as a mechanism for habitat partitioning rather than for predator avoidance. For example, the aggregating behavior of juvenile red king crab should allow them to avoid predation on soft bottoms and therefore to exploit these areas more effectively than blue king crab. Although juvenile habitat partitioning could explain the distribution of the two species within the eastern Bering Sea (inshore areas of Bristol Bay and Norton Sound are sandy whereas Pribilof Islands, St. Mathew Island, and St. Lawrence Island are rocky), it could not explain the distributions in the Gulf of Alaska.

With respect to the second question, all three mechanisms assume that red king crabs either avoid cold water (seek warm water) or are unable to reproduce in cold water and therefore do not occur within the colder blue king crab areas. However, red king crab do occur in at least three blue king crab areas (Pribilof Is., Olga Bay and Prince William Sound) and, within these areas, nearly all adult females are found with embryos that appear to be developing normally (per. obs.). To the extent that 1) these females were resident within the areas and not recent immigrants from nearby red king crab areas, and 2) the embryos carried by these females would have hatched at the appropriate time for good larval survival, then these observations suggest that red king crab can reproduce within blue king crab areas. If red king crab are fully capable of living and reproducing within blue king crab areas then the only consistent explanation for their absence from these areas is that they are excluded by blue king crab.

Although the true mechanism that is responsible for the disjunct distribution of blue king crab in Alaska remains equivocal, many of the questions could be answered with field sampling and experimentation. Monthly temperature data from both blue and red king crab areas outside of the Bering Sea would allow a better characterization of the temperature preferences of each species. In addition, maintaining adult females of both species at a variety of temperatures would allow a better understanding of the effect of temperature on the timing of egg extrusion and embryo hatch, and would help determine the role of biennial spawning in the reproductive strategy of blue king crab.

Acknowledgements

I thank A. Kimker and T. Koeneman for providing information on the distribution of red and blue king crab in Prince William Sound and southeast Alaska, N. Pola for reviewing the manuscript and R. Otto for many stimulating discussions about why blue king crab have a disjunct distribution in Alaska.

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Jan. 1985, Anchorage, Ak.

Overview and comparison of the major red king crab *(Paralithodes camtschatica)* surveys and fisheries in western Alaska 1969-1984

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Abstract

The Alaska Department of Fish and Game (ADF&G) and National Marine Fisheries Service (NMFS) have studied the population structure and dynamics of the red king crab (Paralithodes camtschatica) and its relationship to commercial fishing. Surveys conducted in the Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet king crab management areas are the focus of this paper. Trawl surveys were conducted by NMFS in Bristol Bay and their results since 1969 are examined. The remaining four areas were surveyed by ADF&G using crab pots starting in Kodiak in 1972. The survey catch of male and female red king crab including their length frequencies are given for each area. The total number of legal males tagged throughout each area's survey history is summarized. The commercial king crab fishing effort, catch, exploitation rate and population estimates are given for each area by survey year.

Surveys have proven useful in tracking size-age classes of king crab. The high commercial catches in the 1979-1981 seasons were the result of excellent region-wide recruitment of small crab (70 to 105 mm carapace length) evident from the 1974-1977 surveys. These crab were progeny from the 1970-1971 parent years. The dramatic commercial catch decline between 1980 and 1982 was the result of sharp declines in recruitment to legal size. Currently only the Bristol Bay area appears to have an above average population of sublegal crab which could substantially increase commercial harvests there by 1988. Record low levels of king crab found on the 1983 and/or 1984 surveys of Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet indicate no hope for any substantive increase in legal males, or commercial harvest, for at least four more years.

Introduction

The red king crab, *Paralithodes camtschatica*, has been the singlemost valuable commercial invertebrate species along the west coast of North America since the 1960's. Almost all of the commercial harvest comes from Alaska. Both the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) conduct surveys of king crab in Alaska to forecast the abundance of legal males, assess the reproductive condition of females and to study the population dynamics of the species over time.

The major focus of this paper is to compare the commercial and survey catches of red king crab since 1969 in the following five contiguous management areas in western Alaska: Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet. These management areas are located approximately between 54°-59° N latitude and 149°-171° W. longitude and comprise the major red king crab producing areas that have been consistently surveyed (Fig. 1). An overview of the historical red king crab catch for the above five areas from 1950-1984 is given.

The remaining king crab management areas in Alaska (Bering Sea, Adak and Southeastern Alaska) have been excluded from this paper since they have had either lesser catches and/or fewer surveys. Hereafter in this paper king crab refers only to red king crab.

Historical Catch Overview

The 1930's and 1940's are considered the exploratory period for king crab fishing in Alaska as both markets and gear types were being developed. The developed phase of the fishery did not begin until the 1950's. The Bureau of Commercial Fisheries (now NMFS) managed the king crab fishery prior to 1959 when Alaska gained statehood. In 1949 the Bureau increased the minimum legal size limit from 5½" to 6½" carapace width on the males only fishery. That size limit has remained in effect for all five management areas except for Kodiak and Cook Inlet which increased their minimum size to 7" in 1963. There also were some size limit changes in Bristol Bay ranging from 5½" to 7" between 1966 and 1972 (Otto 1981).

The commercial catch of king crab during the 35 year developed phase of the fishery (1950-1984) reveals two major peak periods (1963-1967 and 1978-1980) followed by two major declines (1968-1971 and 1982-1984) for the combined catches from the Bristol Bay, Kodiak, Dutch Harbor, Alaska Peninsula and Cook Inlet management areas (Fig. 2) (ADF&G 1985). The peak single season catches occurred in 1966 and again in 1980. Each of these single season peaks was followed by a marked decline in catch just two years later. The second major peak and decline was more dramatic than the first. The reasons for this latter decline will be explained later in this paper.

From 1950-1984 Bristol Bay was the greatest commercial producer of king crab. The total catch during this period was over one billion pounds, almost equal to the combined catch of the other four management areas (Table 1). Japan and the U.S.S.R. were the major harvesters of the

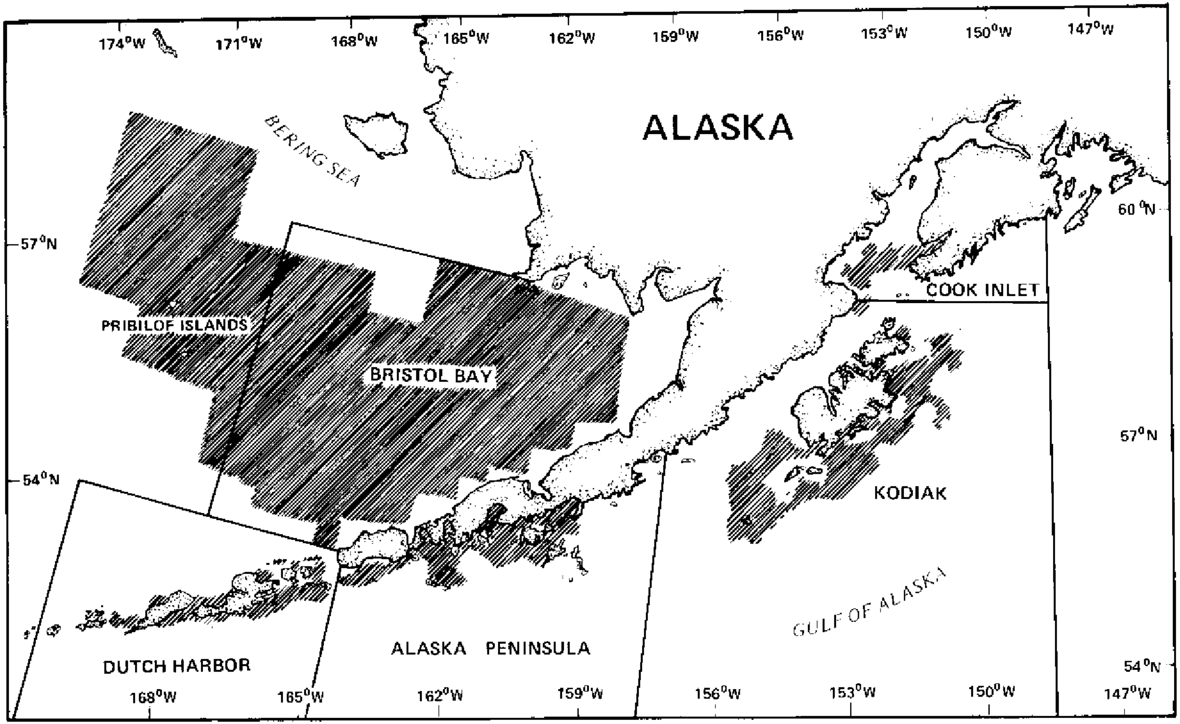


Figure 1.--Location of five king crab management areas: Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet. Diagonal shading shows extent of areas surveyed 1969 to 1984 by NMFS (Bristol Bay) and ADF&G (remaining four areas).

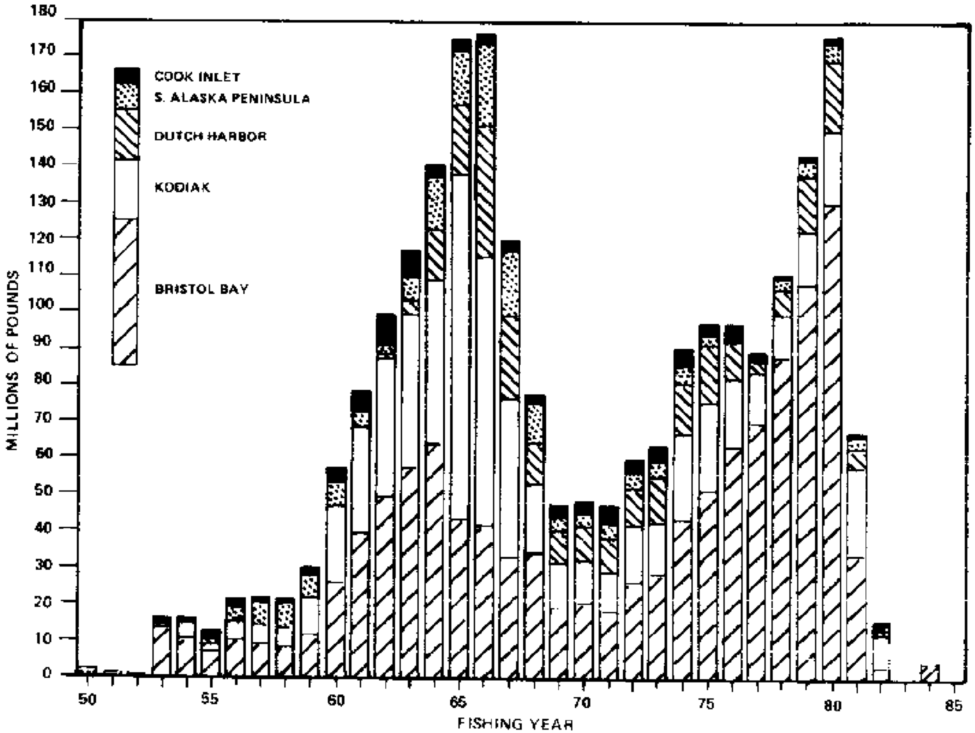


Figure 2.--Historical Alaskan red king crab catch 1950-1984 in the Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet management areas.

Bristol Bay king crab between 1953-1974, contributing over half of the U.S. catch each year until 1971 (Otto 1981). Bristol Bay's total catch was second only to Kodiak in the 1960's, but was dominant in the 1970's, peaking at nearly 130 million pounds in the 1980-81 season, a single season record for any area in Alaska (Fig. 1, Table 1).

Table 1.--Summary of total catch, number of seasons fished, average catch and peak year and amount of catch of red king crab from five management areas in western Alaska 1950-1984.

	Total Catch (Millions lb)	Number Seasons Fished	Avg. Catch (Millions lb)	Season & Amount of Peak Catch (Millions lb)	
Bristol Bay	1,164.7	31	37.6	1980	129.9
Kodiak	666.1	33	20.0	1965	94.4
Dutch Harbor	251.1	22	11.4	1966	35.9
Alaska Peninsula	175.1	33	5.3	1966	22.6
Cook Inlet	91.7	31	3.0	1962	8.6

The king crab harvest from Kodiak has been a little more than half that of Bristol Bay during the past 35 years and second overall (Table 1). Dutch Harbor, Alaska Peninsula and Cook Inlet ranked third, fourth and fifth in total production during this time period (Table 1). Peak single season catches occurred in all areas in the 1960's, except for Bristol Bay (Table 1). Comparing the total king crab catches for each respective area during the 1950's, 1960's, and 1970's decades, the 1960's also represented the highest production period for each management area except Bristol Bay (Fig. 2).

King crab fishing began in Dutch Harbor in 1961, later than the other five management areas. The earliest consistent king crab fishing began in the Alaska Peninsula management area with 6.9 million pounds being taken in the 1947-1949 period (ADF&G 1985). Of the five management areas, Cook Inlet has the least amount of king crab habitat and overall king crab production has been lowest in this area.

Methods and Materials

Standard NMFS trawl surveys began in in Bristol Bay in 1969, with ADF&G beginning its pot surveys in 1972. The NMFS crab surveys were conducted in May-June each year. Trawls were the sampling gear used with at least one tow taken in every 20 x 20 nautical square mile block of a fixed grid system. King crab carapace length, to the nearest mm, sex, and exoskeleton age were recorded for crabs caught in each trawl. Quantitative estimates of crab abundance were made using the area swept technique by combining estimates from each block towed. Of the 15 year NMFS survey time series since 1969, only the data from 1971 has been excluded due to poor performance of the sampling gear. The area surveyed is shown in Figure 1 and the data includes small (<1%) red king crab catches from the Pribilof Islands.

Annual crab surveys by ADF&G began first in Kodiak in 1972, followed by Alaska Peninsula and Cook Inlet in 1974 and Dutch Harbor in 1975. The extent of the areas historically surveyed is shown in Figure 1. Surveys occurred between June to early September. Commercial size pots measuring 7'x7'x30", weighing 650 pounds, with tunnel eye openings of about 8" x 36" were used. Each pot was covered with #72 tarred nylon thread with 3½" stretch mesh compared to the 10" stretch mesh normally used in the commercial fishery. The smaller mesh size enabled the retention of smaller crab. Pots were baited only with chopped frozen herring contained in two one-quart perforated bait jars. Two two-quart bait jars were used in Cook Inlet. Pots were lifted daily with averages generally ranging from 20 in Cook Inlet to 40 in Kodiak. Soak times averaged 17-23 hours except when weather or break periods prolonged fishing times. Catches of crabs were standardized to a 24 hour soak time based on the relationship determined from the 1964-1969 Kodiak commercial king crab logbook data (Rothschild et al. 1970). Only raw survey data is presented for Cook Inlet since it has not been standardized.

Pots were set within stations generally running in a west-east direction. Stations were arranged in a systematic checkerboard pattern. Bay stations usually consisted of three or four pots set 1/3 mile apart, averaging 1 pot/1.0 nm². Ocean stations were generally sampled with 10 or 13 pots spaced 1/2 mile apart, averaging 1 pot/3.0 nm². In Cook Inlet 4 or 5 pots were spaced 1/4 mile apart. They were fished in either 2 nm² or 5 nm² grid patterns in the Southern or Kamishak districts respectively, averaging 1 pot/1.0 nm².

The carapace lengths of king crab were measured with Vernier calipers to the nearest mm. Legal male crab were tagged to estimate rates of fishing mortality, migration and growth. Subsampling of a particular group (e.g. adult females, legal or sublegal males) often occurred when catches exceeded 100 crabs/pot lift. On both the NMFS and ADF&G surveys other data was also recorded including: exoskeleton age and estimated clutch size of king and Tanner crab; sex, carapace width and species determination for Tanner crabs (<u>Chionoecetes</u> spp.); species identification, enumeration and weights or lengths of certain fish (e.g. walleye pollock, yellowfin sole, Pacific cod and halibut) and data on miscellaneous invertebrates (e.g. octopus, sea stars, snails, urchins, sand dollars) were also taken.

By law fishermen are required to report the number of legal crab harvested, the area fished and the number of pot lifts made for each landing on an ADF&G fish ticket. Crab processors are also required to place the price per pound or total sale price on the fish ticket and in this fashion the ex-vessel price can be determined for each landing. The total harvest, number of pot lifts, catch per unit of effort (CPUE) and average ex-vessel price in a particular season are determined from these fish tickets.

The exploitation rate for any particular king crab season in Bristol Bay is simply the number of legals harvested divided by the preseason population estimate of legals. The exploitation rates for the four areas surveyed by ADF&G (Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet) are based on tag recoveries using the Petersen mark-recapture technique. In some areas for some years the percent tag recovery was adjusted higher or lower based on further analysis (i.e. was major catch coming from areas where tags were not released and adjustments for estimated unreported tags). Once the best estimate of exploitation rate was made then it was divided into the number of legals harvested to get a postseason back-calculated "preseason" estimate of the legal male population.

Although the data presented is the best agency data available, the reader is cautioned that there are unknowns and variables inherent in both trawl and pot surveys and commercial catch data that may affect the accuracy of the king crab population data presented including: assumptions about catchability of crabs; estimated fishing power of gear; sampling intensity needed relative to stock size and distribution; estimation of both fishing and natural mortality; and reliability of commercial catch and catch per unit of effort data. Other factors which may affect the accuracy of the survey projections include: errors in estimating the size of the crab habitat and extrapolation of area swept catches into very large areas; variations in gear, stations fished, survey timing and quality of bait used in pots; use of soak time standardizations that do not take into account changes in crab abundance or population levels of interactive species; a redefinition of Kodiak male size classes since 1980; and inability to recover all tags captured by the commercial fishery which may result in underestimation of the true exploitation rate.

The commercial catch of legals is believed to be fairly accurate, yet commercial effort, CPUE and ex-vessel price may not be entirely accurate as catches may be misreported. Fishermen sometimes under-report their effort (pot lifts) as declining CPUE is often used by managers to close seasons. The true ex-vessel price can be in error since at times the fish ticket price does not reflect the total compensation. Average price for the total season's catch is not weighted so the total ex-vessel price for a season may be high or low.

Results and Discussion

Between 1969-1984 57 annual crab surveys were conducted in the five management areas considered. Bristol Bay had the longest time series with 15 surveys, followed by Kodiak with 13, Alaska Peninsula and Cook Inlet both with 11 and Dutch Harbor having the least at 7 (Table 2). Over 1.5 million king crab were caught on these surveys of which 62% were from Kodiak alone. The total survey period catch from the other areas ranged from 114,000-185,000 (Table 2). Kodiak averaged the highest king crab catch per pot although effort in terms of pot lifts averaged three times greater than Dutch Harbor, Alaska Peninsula or Cook Inlet. Nearly 61,000 legal king crab have been tagged by ADF&G since 1972. Kodiak tag releases comprised 58% of the total releases and Cook Inlet was second with 21% (Table 2).

Table 2.--Summary of red king crab survey effort, catch and tags released for the five management adjacent areas in western Alaska, 1969-1984.

Management Area	Years of Surveys	No. Survey Years	Total Crab Number	Total Crab CPUE	Average Potlifts/ Survey	No. Tags Released Legal Males
Bristol Bay	1969-70 1972-84	15	147,300	*	*	**
Dutch Harbor	1975-77 1979-81, 1984	7	149,800	36	591	5,067
Alaska Peninsula	1974-84	11	184,900	31	546	7,700
Kodiak	1972-84	13	966,400	40	1,863	35,439
Cook Inlet	1974-84	11	114,300	32	409	12,439
		57	1,562,700			60,645

*The total number of tows was not obtainable from NMFS data at the time of this report so the average number of crabs caught per tow or tows per survey could not be calculated.

**No red king crab were tagged by NMFS during annual trawl surveys, but some tagging has been done on special charters for growth and migration purposes.

The population or relative abundance estimates of king crab by area by survey year are depicted in Figures 3-7. The length frequencies of the king crab caught are also shown in these figures and they are grouped into four categories: juvenile females, adult females, sublegal males and legal males. Catch per pot values presented are rounded to the nearest whole numbers and total crabs caught on each survey are rounded to the nearest 100. King crab preseason population size, commercial catch, effort, value and estimated exploitation rates are given for each area surveyed in Tables 3-7. The initial year this data is shown corresponds with the initial survey year in each area with the exception of Bristol Bay for reasons previously mentioned. The following discussion and conclusion sections will explain these figures and tables more completely.

The trackability of length frequency modes and cohorts for female and male king crabs has been excellent from annual survey data (Figs. 3-7). Annual growth of Kodiak females is a clear example of the trackability of a cohort for nine years, appearing first as juveniles in 1976 and 1977, then as adults from 1978-1984 (Fig. 6). Similar long term tracking of the same cohorts can be seen in each of the other four areas from 1975 onward (Figs. 3-7). Crabs are caught at a smaller size on the NMFS Bristol Bay trawl surveys (Fig. 3), than on the ADF&G pot surveys (Figs. 4-7). Bristol Bay crabs less than 70 mm carapace length do not track well from year to year and are caught only in a few stations which may be due to juvenile schooling behavior. The catchability of small crabs generally increases for their first three years of susceptibility to retention in pots on ADF&G surveys. This is believed due to increasing availability and catchability of crabs 70-115 mm in carapace length (Figs. 4-7). Tracking legal male cohorts is more complex because of increasing skipmolting and commercial harvesting.

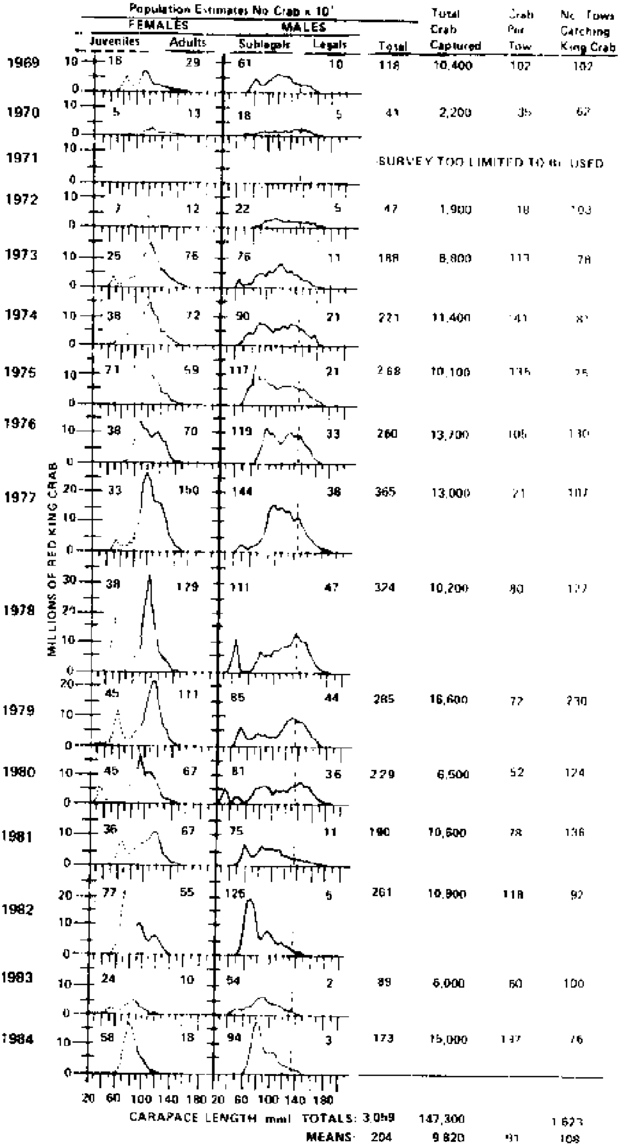
The abundance trends of king crab in each management area can be characterized similarly during the survey period covered even though the abundance of crab recruited to the sampling gear varied considerably between areas. A low abundance period existed between 1969-1972 as evidenced by the lower survey catches in Brisol Bay and Kodiak (Figs. 3 & 6) and by the lower harvests (Fig. 2) during this period. The suspected regionwide low mating populations available in 1970 and 1971 gave rise to two successive year classes in 1971 and 1972 that apparently had a higher than normal survival rate in all management areas. The 1971 year class was the stronger of the two. These strong year classes first became apparent on the 1975 and 1976 surveys. The high abundance of the 1971 and 1972 year classes combined with all other year classes in 1977 to produce the highest survey abundance on record for each management area (Figs. 3-7). Due to natural mortality, commercial harvesting and lower recruitment of small crab, the populations in each management area (except Bristol Bay) began to decline from 1978 on, reaching historic lows in 1983 and 1984. In Bristol Bay, recruitment of juvenile crab appears more regular than in the other four survey areas.

The outlook for Bristol Bay crab populations is good as the third highest juvenile abundance in survey history was encountered in 1984. In contrast, survey abundance of juveniles has remained very low in all other management areas for four consecutive years beginning in 1981. Due to the low abundance of juveniles in the Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet management areas (Figs 4-7), 1989 is the earliest that a substantive increase in legal males could occur.

In addition to the excellent trackability of cohorts over time in each survey area, there is generally good trend agreement between the survey catch per unit of effort (CPUE) of legals and harvest CPUE of legals (Figs. 4-7 & Tables 4-7). This demonstrates the reliability of the surveys as a management tool. Generally the commercial CPUE is higher than that found on surveys since commercial fishermen target on areas of legal abundance and commonly bait their gear more heavily than is done on ADF&G surveys.

Preseason population estimates compared with the number of legals harvested also displays a trend analagous to the commercial versus survey legal CPUE. Preseason abundance estimates and subsequent commercial harvests have synchronous ups and downs. The estimated preseason number of legal crabs was always greater than the number harvested (Tables 3-7, Figs. 8-10).

Bristol Bay had the highest average population estimate, number of legals harvested, number of pots lifted, CPUE, value and exploitation rate during the survey period considered, followed by Kodiak, Dutch

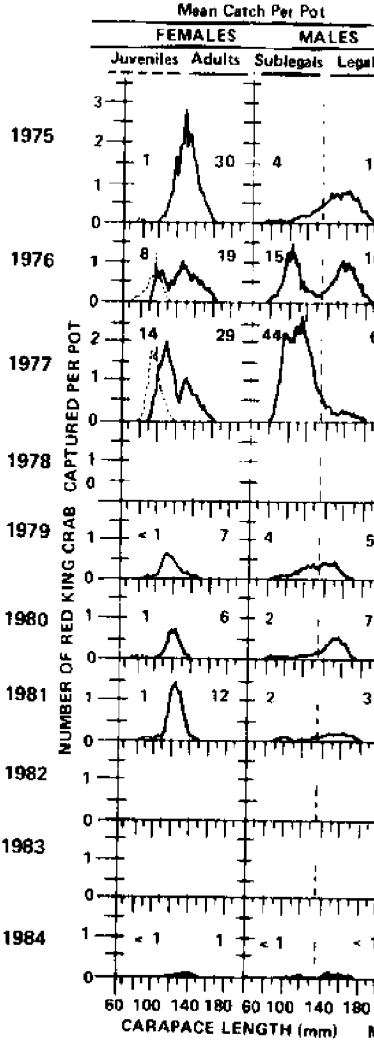


	Population Estimates No Crab x 10⁶					Total Crab Captured	Crab Per Tow	No. Tows Catching King Crab
	FEMALES		MALES					
	Juveniles	Adults	Sublegals	Legals	Total			
1969	18	29	61	10	118	10,400	102	102
1970	5	13	18	5	41	2,200	35	62
1971	SURVEY TOO LIMITED TO BE USED							
1972	7	12	22	5	47	1,900	18	103
1973	25	76	76	11	188	8,800	113	78
1974	38	72	90	21	221	11,400	141	82
1975	71	59	117	21	268	10,100	135	75
1976	38	70	119	33	260	13,700	105	130
1977	33	150	144	38	365	13,000	71	107
1978	38	179	111	47	374	10,200	80	127
1979	45	111	85	44	285	16,600	72	230
1980	45	67	81	36	229	6,500	52	124
1981	36	67	75	11	190	10,600	78	136
1982	77	55	126	5	261	10,900	118	92
1983	24	10	54	2	89	6,000	60	100
1984	58	18	94	3	173	15,000	137	76
				TOTALS:	3,059	147,300		1,623
				MEANS:	204	9,820	91	108

Figure 3.--Length frequencies and population estimates of female and male red king crab from the Bristol Bay management area, Alaska. Data from trawl surveys conducted by National Marine Fisheries Service 1969-1984.

Table 3.--Legal male red king crab preseason population estimates, numbers of legals harvested by effort level, their value and exploitation rate in the Bristol Bay management area, Alaska 1969-1984.

Fishing Year	Preseason Population Estimate No. Legal Crab x 10^3	No. Legals Harvested x 10^3	Pot Lifts x 10^3	CPUE	Ex-vessel $ Value x 10^6	Exploitation Rate
1969-70	9,916	1,749	98	18	0.2	.18
1970-71	5,249	1,682	97	17	2.0	.32
1971-72	-------	2,405	119	20	4.1	---
1972-73	5,360	3,994	205	20	12.0	.75
1973-74	10,869	5,000	201	25	23.7	.46
1974-75	20,819	7,654	212	36	15.9	.37
1975-76	21,188	8,745	205	43	19.5	.41
1976-77	32,732	10,603	321	33	37.1	.32
1977-78	37,574	11,733	451	26	77.7	.31
1978-79	46,567	14,746	406	36	107.8	.32
1979-80	43,913	16,808	315	53	108.9	.38
1980-81	36,655	20,845	567	37	117.0	.57
1981-82	11,250	5,308	542	10	50.4	.47
1982-83	4,678	541	142	4	9.2	.12
1983-84	1,530	---------------SEASON CLOSED---------------				
1984-85	3,108	794	113	7	11.4	.26
TOTALS:	291,408	112,607	3,994	-	596.9	-
MEANS:	19,427	8,043	266	30	39.8	.36

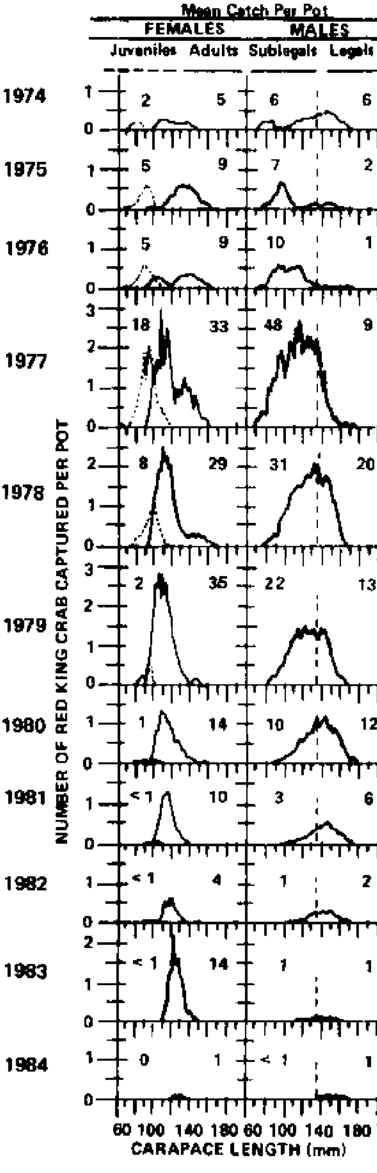


	Total Crab CPUE	Total Crab Number	Pot Lifts
1975	50	24,500	493
1976	58	33,300	573
1977	94	56,400	602
1978	NO SURVEY		
1979	16	10,200	640
1980	15	12,900	833
1981	17	12,100	702
1982	NO SURVEY		
1983	SURVEY TOO LIMITED TO BE USED		
1984	2	400	292
TOTALS:		149,800	4,135
MEANS:	36	21,400	591

Figure 4.--Length frequencies and catch per pot of female and male red king crab from the Dutch Harbor management area. Data collected on ADF&G pot surveys 1975-1984, data standardized.

Table 4.--Legal male red king crab preseason population estimates, number of legals harvested by effort level, their value and exploitation rates in the Dutch Harbor management area, Alaska 1975-1984.

Fishing Year	Preseason Population Estimate No. Legal Crab x 10^3	No. Legals Harvested x 10^3	Pot Lifts x 10^3	CPUE	Ex-vessel $ Value x 10^6	Exploitation Rate
1975-76	7,952	2,147	87	25	6.7	.27
1976-77	5,913	1,360	83	16	6.6	.23
1977-78	2,715	543	47	11	3.7	.20
1978-79	5,498	1,234	52	24	9.2	.22
1979-80	13,426	2,551	121	21	13.5	.19
1980-81	8,443	2,955	262	11	19.4	.35
1981-82	2,319	742	220	3	10.4	.32
1982-83	------	64	73	1	1.5	---
1983-84	------------------------NO SEASON----------------------					
1984-85	------------------------NO SEASON----------------------					
TOTALS:	46,266	11,596	945	-	71.0	-
MEANS:	6,609	1,450	118	12	8.9	.25

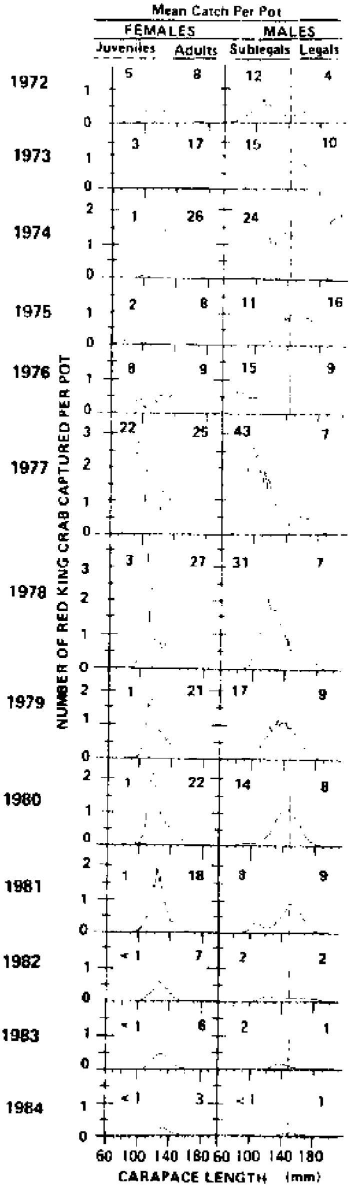


	Total Crab		Pot
	CPUE	Number	Lifts
1974	19	13,100	675
1975	14	8,600	610
1976	24	19,200	801
1977	109	38,600	354
1978	88	31,400	355
1979	72	23,700	330
1980	37	26,100	700
1981	20	15,100	750
1982	6	3,600	630
1983	15	4,700	307
1984	2	800	498
TOTALS:		184,900	6,010
MEANS:	31	16,809	546

Figure 5.--Length frequencies and catch per pot of female and male red king crab from the Alaska Peninsula management area. Data collected on ADF&G pot surveys 1974-1984, data standardized.

Table 5.--Legal male red king crab preseason population estimates, number of legals harvested by effort level, their value and exploitation rates in the Alaska Peninsula management area, Alaska 1974-1984.

Fishing Year	Preseason Population Estimate No. Legal Crab x 10^3	No. Legals Harvested x 10^3	Pot Lifts x 10^3	CPUE	Ex-vessel \$ Value x 10^6	Exploitation Rate
1974-75	1,498	644	45	14	2.0	.43
1975-76	816	367	35	11	1.1	.45
1976-77	275	126	18	7	0.6	.45
1977-78	680	120	11	11	0.7	.18
1978-79	1,363	520	31	17	3.9	.38
1979-80	2,045	739	42	18	4.1	.36
1980-81	2,272	821	54	15	4.9	.36
1981-82	1,360	516	52	10	4.4	.38
1982-83	475	271	31	9	5.4	.57
1983-84	132	--------------NO SEASON--------------				
1984-85	137	--------------NO SEASON--------------				
TOTALS:	11,053	4,124	319	-	27.1	-
MEANS:	1,005	458	35	13	3.0	.37

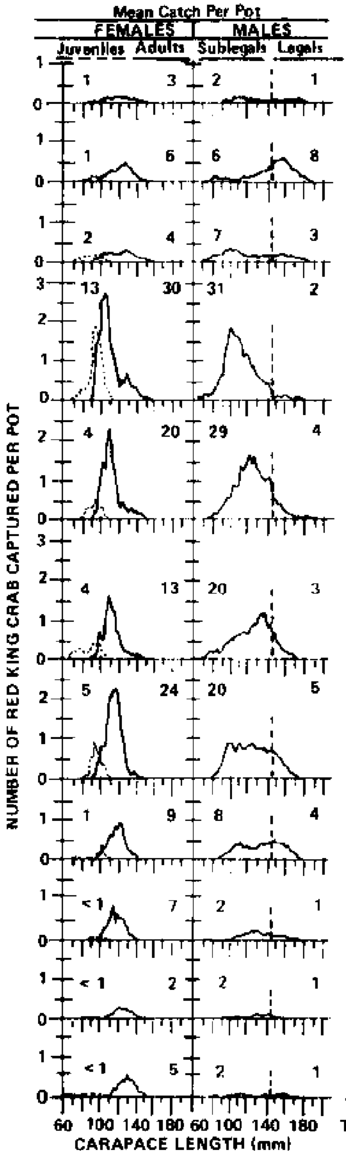


	Total Crab		Pot
	CPUE	Number	Lifts
1972	28	67,100	2,391
1973	45	89,300	1,990
1974	72	144,600	2,017
1975	37	69,500	1,895
1976	41	80,700	1,946
1977	98	160,500	1,646
1978	67	59,700	895
1979	48	81,500	1,709
1980	45	104,800	2,339
1981	36	64,300	1,793
1982	11	19,200	1,721
1983	9	16,600	1,891
1984	4	8,600	1,991
TOTALS		966,400	24,224
MEANS	40	73,300	1,863

Figure 6.--Length frequencies and catch per pot of female and male red king crab from the Kodiak management area. Data collected on ADF&G pot surveys 1972-1984, data standardized.

Table 6.--Legal male red king crab preseason population estimates, number of legals harvested by effort level, their value and exploitation rates in the Kodiak management area, Alaska 1972-1984.

Fishing Year	Preseason Population Estimate No. Legal Crab x 10^3	No. Legals Harvested x 10^3	Pot Lifts x 10^3	CPUE	Ex-vessel $ Value x 10^5	Exploitation Rate
1972-73	-----	2,030	71	29	8.5	---
1973-74	7,108	1,848	78	24	6.5	.26
1974-75	7,658	2,910	110	26	10.6	.38
1975-76	7,834	2,977	114	26	15.9	.38
1976-77	5,445	2,178	131	17	24.6	.40
1977-78	4,676	1,590	146	11	18.1	.34
1978-79	3,405	1,464	177	8	39.2	.43
1979-80	4,948	1,979	208	9	13.9	.40
1980-81	7,532	2,787	202	14	21.5	.37
1981-82	6,072	3,036	389	8	48.5	.50
1982-83	2,528	1,011	284	4	32.7	.40
1983-84	880	---------------NO SEASON---------------				
1984-85	1,061	---------------NO SEASON---------------				
TOTALS:	59,147	23,810	1,910	-	220.0	-
MEANS:	4,929	2,165	174	12	20.0	.38



	Total Crab		Pot
	CPUE	Number	Lifts
1974	7	1,600	240
1975	20	7,200	356
1976	14	5,600	386
1977	75	34,600	459
1978	57	26,100	461
1979	40	20,900	516
1980	55	29,500	538
1981	22	9,100	411
1982	13	3,700	292
1983	5	2,100	422
1984	9	3,900	422
TOTALS:		114,300	4,503
MEANS:	32	13,118	409

Figure 7.--Length frequencies and catch per pot of female and male red king crab from the Kodiak management area. Data collected on ADF&G pot surveys 1974-1984, raw data not standardized for soak time differences.

Table 7.--Legal male red king crab preseason population estimates, number of legals harvested by effort level, their value and exploitation rates in the Cook Inlet management area, Alaska 1974-1984. Information is from the Kamishak and Southern Districts only; the two major districts in the Cook Inlet area.

Fishing Year	Preseason Population Estimate No. Legal Crab x 10^3	No. Legals Harvested x 10^3	Pot Lifts x 10^3	CPUE	Ex-vessel $ Value x 10^6	Exploitation Rate
1974-75	-----	520	78	7	2.2	---
1975-76	2,753	340	--	---	2.0	.12
1976-77	1,159	436	33	13	3.3	.38
1977-78	714	163	37	4	1.4	.23
1978-79	473	153	46	3	1.2	.32
1979-80	535	196	34	6	1.1	.37
1980-81	937	292	35	8	1.8	.31
1981-82	658	213	35	6	2.6	.32
1982-83*	274	112	27	4	2.7	.41
1983-84*	92	27	10	3	2.5	.29
1984-85	--------------------SEASON CLOSED--------------------					
TOTALS:	7,595	2,452	335	-	20.8	-
MEANS:	844	245	37	6	2.1	.25

*Data is only for Kamishak District.

Harbor, Alaska Peninsula and Cook Inlet (Tables 3-7). Bristol Bay's average was at least double that of any other area in each category except in number of pot lifts and exploitation rate.

The year of the highest legal male population estimates for each area was: Bristol Bay 1978, Dutch Harbor 1979, Alaska Peninsula 1980 and 1975 for both Kodiak and Cook Inlet. The lowest estimated legal populations occurred in all areas from 1982-1984 (Tables 3-7 & Figs. 8-10). In each area the fishing season which produced the highest number of harvested legals coincided with the highest number of pot lifts. The highest harvest and effort for Bristol Bay, Dutch Harbor and Alaska Peninsula occurred in 1980 while Kodiak and Cook Inlet peaked in 1981 and 1974 respectively (Tables 3-7 & Figs. 8-10). As mentioned previously, the 1980 harvest in Bristol Bay set a historic single season record for any area in Alaska, with nearly 130 million pounds harvested. The peak harvests in all areas (except Cook Inlet) were due to the excellent recruitment of legal crabs, progeny of the 1970 and 1971 parent years. Just two to three years after these peak harvests, four of the five management areas were completely closed in 1983 to any commercial harvesting; with a small harvest coming from one district in Cook Inlet. Ironically, the peak harvest of the 1980-81 season was followed just three seasons later by the lowest total harvest in 30 years (Fig. 2).

For all areas combined the average ex-vessel price per pound paid for king crab was approximately 30 cents in 1972, rising to $3.00 in 1982 (ADF&G 1985). The highest total ex-vessel value for each area for a single season in millions of dollars was: $117.0 in Bristol Bay (1980), $19.4 in Dutch Harbor (1980), $5.4 in Alaska Peninsula (1982), $48.5 in Kodiak (1981) and $2.7 in Cook Inlet (1982) (Tables 3-7). The highest total ex-vessel price paid in Bristol Bay, Dutch Harbor and Kodiak coincided with peak harvest and effort levels occurring during their respective survey periods.

By 1982 the legal crab populations of each area were declining rapidly compared to the levels of 1980 and 1981. The historic high prices paid for king crab kept effort levels disproportionately high on the remaining harvestable stocks (Figs. 8-10). Average exploitation rates on legal males were: Bristol Bay 39%, Dutch Harbor 25%, Alaska Peninsula 37%, Kodiak 38% and Cook Inlet 25% (Tables 3-7). The ADF&G management goal throughout most of this period was to harvest no more than 40% of the legal males annually. Sixty-five percent of the annual exploitation rates for all management areas ranged between 20%-40% with a maximum range of 12%-75% amongst the time periods shown for all areas (Tables 3-7). In 1982 the 40% harvest goal was reduced in most areas to 25% or less as mandated by the king crab harvest strategy regulation (5 AAC 34.080) when legal populations are depressed and prerecruit abundances are declining. The highest or next to the highest exploitation rates for each area all occurred in the 1980's.

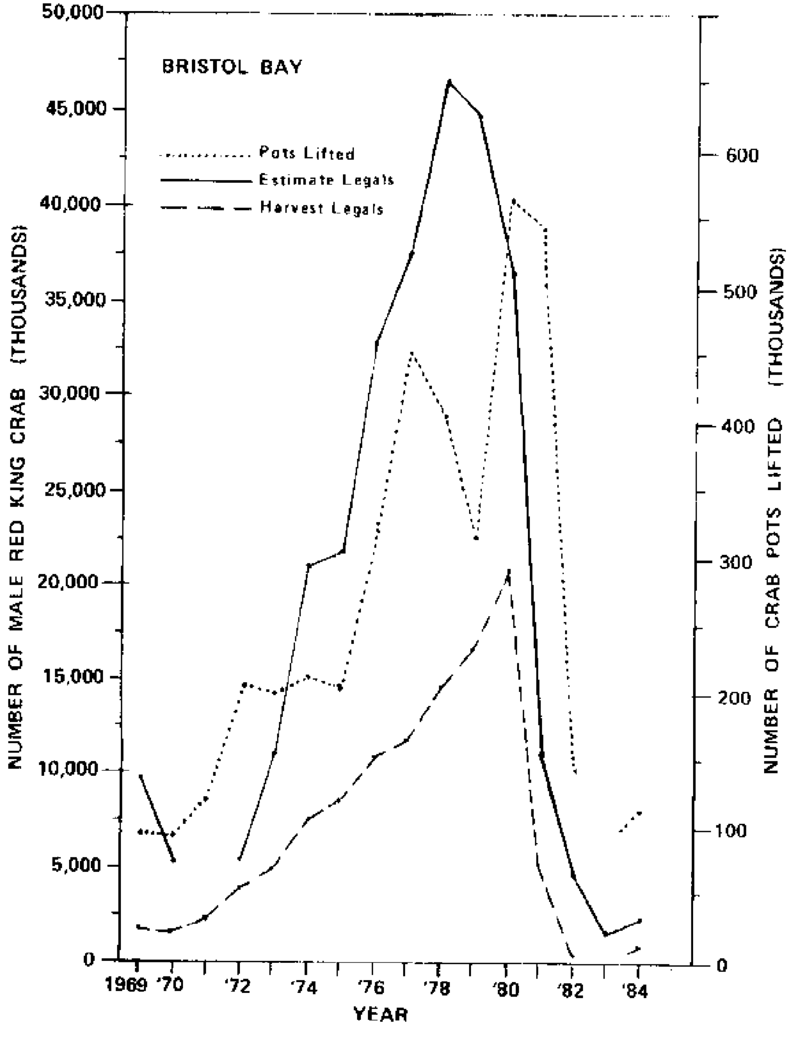


Figure 8.--Estimated preseason population and subsequent harvest of legal male red king crab versus the commercial effort for each fishing season in the Bristol Bay management area, 1969-1984. Supporting data for points plotted above are from Figure 3 and Table 3.

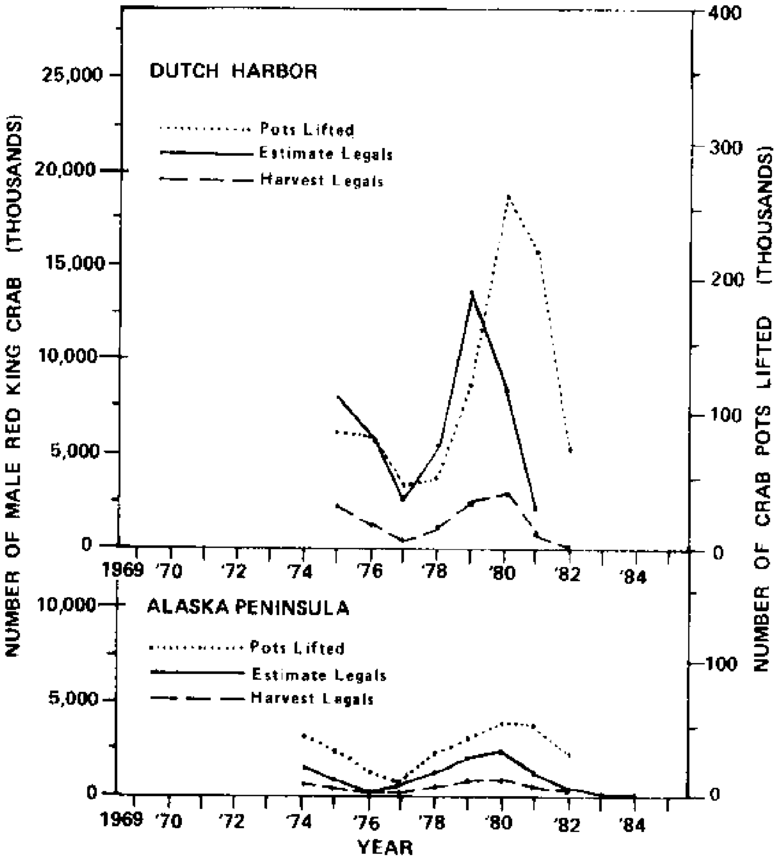


Figure 9.--Estimated preseason population and subsequent harvest of legal male red king crab versus the commercial effort for each fishing season in the Dutch Harbor and Alaska Peninsula management areas 1974-1984. Supporting data for points plotted above are from Figures 4 & 5 and Tables 4 & 5.

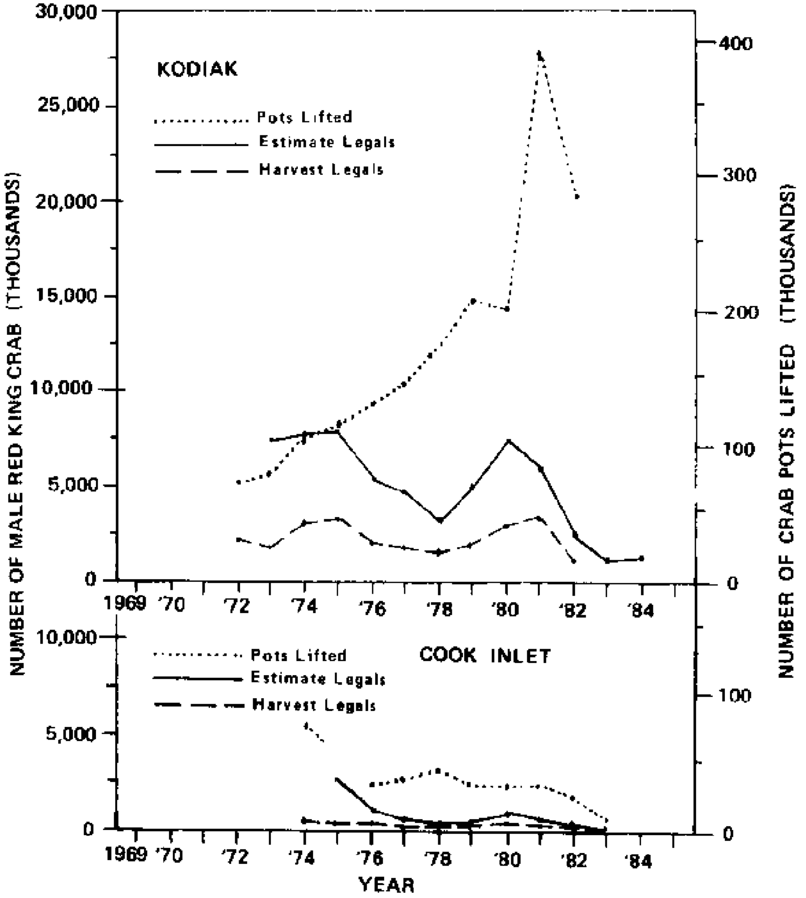


Figure 10.--Estimated preseason population and subsequent harvest of legal male red king crab versus the commercial effort for each fishing season in the Kodiak and Cook Inlet management areas 1972-1984. Supporting data for points plotted above are from Figures 6 & 7 and Tables 6 & 7.

Conclusions

The annual surveys conducted by either NMFS or ADF&G since 1969 in the Bristol Bay, Dutch Harbor, Alaska Peninsula, Kodiak and Cook Inlet management areas have proved reliable in tracking and estimating the population status of red king crab over time. Researchers have been successful in estimating the population of legal males from survey results while managers have generally been able to control harvests within the stated exploitation goals based on preseason population estimates. The king crab industry was able to plan and and make adjustments to their choice of fishing grounds or processing needs as a result of the annual surveys. These surveys have also greatly increased the knowledge of the king crabs' natural history including growth, migration, recruitment, female reproductive condition and natural mortality.

The abundance of king crab in the five areas surveyed is consistent with their harvest history over the last 35 years. Bristol Bay has been the highest producer followed by Kodiak, Dutch Harbor, Alaska Peninsula and Cook Inlet. Since red king crab live primarily on the continental shelf the historic abundance of king crab in each management area is closely related to the amount of shelf area and good habitat available within each area. For example, Bristol Bay and Kodiak have the largest continental shelves and produce the most king crab.

The abundance of juvenile red king crab year classes fluctuated greatly throughout the areas surveyed in western Alaska. The degree of fluctuation, in terms of the ratios between the lowest and highest survey abundance of juvenile crab in each survey area has been the least in Bristol Bay, where the average historic abundance of crabs has been the highest. Phenomenal recruitment of small crab occurred in all management areas as a result of very successful hatching and/or survival of the 1971 and 1972 year classes. These year classes were the progeny of the 1970 and 1971 parent year populations which were believed at low levels. Combined with adjacent year classes the 1971 and 1972 year classes were mainly responsible for the peak king crab abundances in each area in 1977. The strength of these same two year classes was also responsible for the record harvests from 1979-1981. In a period of four years, the harvest of king crab declined from a peak in 1980 of 176.4 million pounds, to just 100,000 pounds harvested in 1983 as four management areas were closed to fishing for the first time in history. This crash was the most severe in the 30-year history of commercial king crab fishing and was caused by consecutive poor recruitment of legals in each area. The environmental factors which combine to regulate survival and recruitment of small king crab is poorly understood.

Bristol Bay is the only area at present with a hope of an increasing commercial harvest over the next four years. Kodiak, Dutch Harbor, Alaska Peninsula and Cook Inlet areas have no hope of any substantive commercial harvests until at least 1989. The red king crab populations in each of these areas could remain severely depressed for quite a long time.

Acknowledgements

A great deal of credit is due all the NMFS and ADF&G researchers and managers who were involved in collecting the survey and fishing data presented herein. Special thanks to Dr. Robert Otto of NMFS who graciously provided the Bristol Bay survey data and his interpretation of it. I appreciate the guidance and editing by Richard D. Peterson and Jerry A. McCrary of ADF&G on this paper. Thanks also to ADF&G's Mary Ellen Harris who provided the length frequency plots and Sharon J. Theis who typed the manuscript. Finally, I thank Wade A. Watkins for his assistance in preparing the figures.

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King crabs in British Columbia

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Abstract

Two species of king crab, the red (*Paralithodes camtschatica*) and golden (*Lithodes aequispina*), have been commercially exploited in British Columbia in recent years. Landings have been restricted to inlets and fjords of the northern mainland coast, and have been divided between deep-water, golden king crab and shallower-water, red king crab. The commercial fishery for golden king crab was centered in Alice and Hastings Arms of the Portland Inlet system, and peaked a few years ago, whereas red king crab were predominantly exploited in 1983, with landings from as far south as Grenville Channel.

Concern as to the impact of tailings disposed in deep water from a molybdimun mine in Alice Arm on local king crab stocks resulted in a number of recent studies of king crabs in northern British Columbia. A broad survey of king crab populations in mainland inlets south of Alaska to Gardner Canal has shown that red king crab predominate in all inlets other than the Portland Inlet system, and that concentrations were few and scattered. Overall density appears low, although survey design did not permit reliable abundance estimation at any specific site. The largest observed population of golden king crab is heavily parasitized by the rhizocephalan barnacle *Briarosaccus callosus*, with 41% of the adult population infertile. The biology and population characteristics of this population are briefly discussed.

Overall fishery prospects for king crab in mainland inlets and fjords appear poor for more than a few vessels. The main value of this resource may be in biological research. The discrete nature of the populations in sheltered waters make them particularly amenable to research and experimental management.

Introduction

Three species of king crab occur in British Columbian waters: *Paralithodes camtschatica*, *Lithodes aequispina*, and *L. couesi*. British Columbia is the southern range of distribution (Fig. 1) of the first two species, commonally called red and golden king crab respectively. *L. couesi* is a relatively small, deep-water species which has been collected as far south as San Diego (Hart, 1982). The biology of red king crab and its importance as a fishery in Alaska is well documented (this Symposium) but in British Columbia, it is landed in quantities of only a few tonnes annually. Fishermen either exploit it as an occasional bycatch or in a small directed trap fishery involving a few

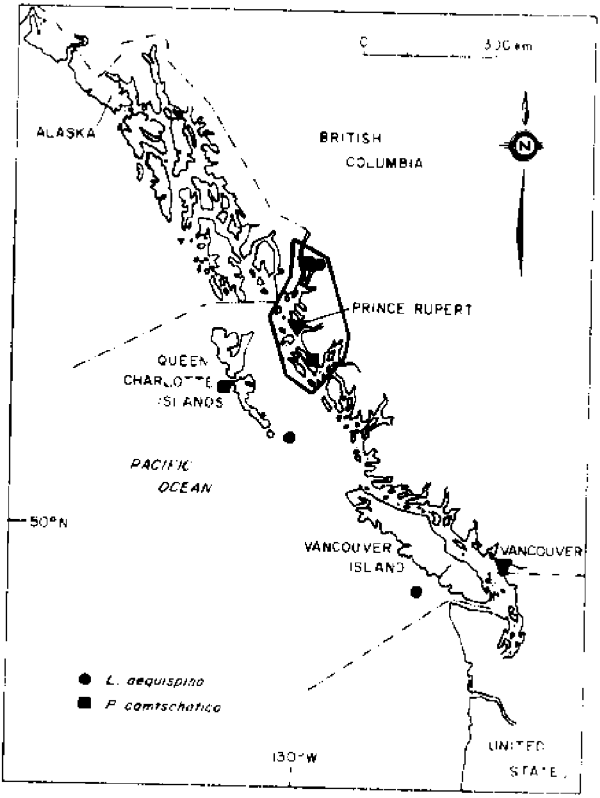

Figure 1. The geographical location of the study area and the capture locations of red and golden king crab in British Columbia.

vessels in the winter or spring when other more traditional fisheries are closed (Butler and Hart, 1962). Deeper-water, golden king crab have also been exploited to a minor extent in recent years in the Portland Inlet System of northern British Columbia. King crab landings in British Columbia have been included with Dungeness crab landings and no statistical breakdown by species is available (Jamieson, 1985).

However, this does not imply that king crab, and in particular golden king crab, are not of interest in British Columbia. They have recently

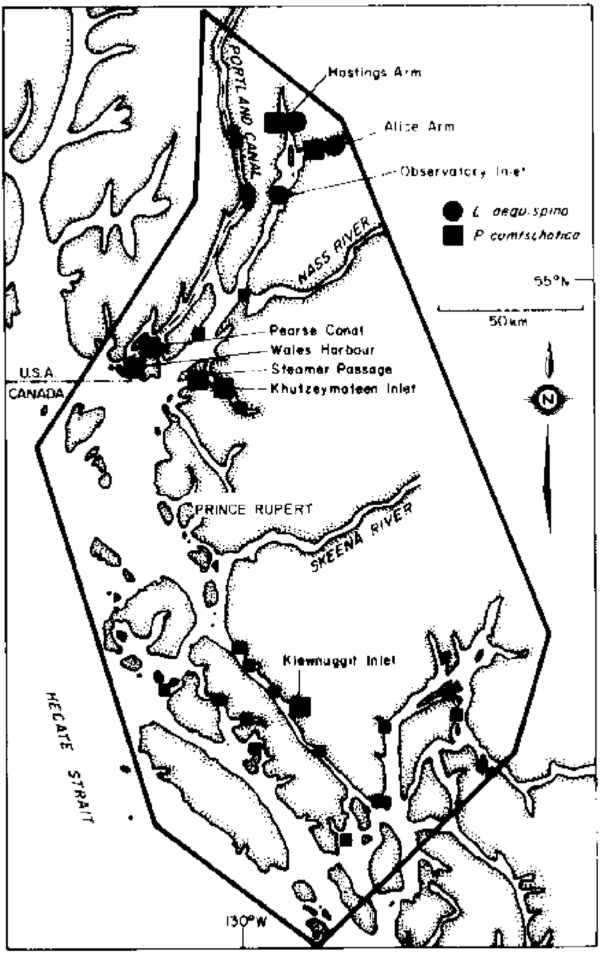

Figure 2. Capture locations of red and golden king crab in the study area in northern British Columbia. Large and small markings refer to locations of potential commercial interest and where species were caught, but not in abundance, respectively.

been the focus of an environmental pollution controversy and the occurance of golden king crab in relatively defined and accessible populations provides a unique opportunity for research on this species.

Golden king crab are primarily found in two areas, Alice and Hasting Arms, at the upper end of Observatory Inlet (Fig. 2). Shortly after this species began to be commercially exploited in 1980, a molybdenum mine began operation in Alice Arm. Approximately 12,000 t of tailings were dumped daily through an outfall into the deeper waters of the fjord between April, 1981 and October, 1982 (Farrell and Nassichuk, 1984). Over the next few years, crab catch per unit effort declined and controversy developed as to whether this was due to the presence of the tailings, some other factor, or population depletion through fishing because of a small initial population size. A number of studies (eg. Reid and Baumann, 1984) were subsequently funded by the federal Department of Fisheries and Oceans, and two relating specifically to king crab are reported here. An exploratory survey of other northern British Columbian inlets and fjords was conducted in 1982 to establish if other commercially-exploitable king crab populations existed, and a detailed study of crab biology was initiated after it was discovered by the mining company in late 1982 that the golden king crab in Alice Arm were heavily parasitized by the rhizocephalan Briarosaccus callosus.

Mainland Inlet and Fjord Survey

Materials and methods: Alaskan side-entry king crab pots measuring 1.8 x 1.8 x 0.9 m covered with 10 cm stretch mesh netting were used. Pots had two tunnels of 7.5 cm stretch mesh lining, each with 88.0 x 19.0 cm openings and each pot was baited using two, 2 L, perforated jars. This was the gear used by the commercial fisherman who had exploited golden king crab in British Columbia.

Details of methods are given by Jamieson et al (1985) but to summarize, a survey for king crab was undertaken from May 4 - June 18, 1982, in mainland inlets and fjords from Portland Canal south to the Estevan Group (Fig. 2.) Traps were set individually, with traps within 3.7 km (2 nautical miles) of each other and at similar depths grouped into sets. A total of 239 king crab pot sets were made. Sets were made at depths ranging from 9-521 m, with 44 sets at a depth > 137 m (75 fath). Exploratory shallow and deep water sets were made for red and golden king crab respectively, since depth preference between the species differs (Sloan, 1985a). Catches were described and documented, with carapace lengths (CL) of all crabs caught measured to the nearest millimeter. Bait was a combination of herring, spring salmon carcasses, and skate carcasses. Soak times ranged from 15.5 - 176.5 h, with a mean and standard deviation of 74 and 40.25 h respectively. In the absence of specific regulations, the fisherman had arbitrarily defined king crab with a carapace width (CW) >165 mm, and tanner crab (Chinoecetes bairdi) with an estimated weight >0.7 kg, as "keepers." Site potential was evaluated by the quantity of keepers fished, with keeper catches >7 kg trap^{-1} considered to indicate fishery potential. Trap yield represents the weight of keeper king crabs added to half the weight of keeper tanner crabs caught, since the price of tanner crabs was about half that of king crabs.

Commercial catch per unit effort (CPUE) information in Alice Arm was provided by P. Wallin (pers. comm.) for the years 1980 - 82. This data is compared with the results obtained in our 1983 - 84 research cruises for golden king crabs with a CL >136 mm (= >165 mm CW (Jewett et al, 1985)).

Results: Twenty-eight sets, located in 4 general areas (Alice Arm, Wales Island, Steamer Passage and Klewnuggit Inlet), had an average catch > 7 kg trap^{-1} (Fig. 2). Wales Island included sets from Wales Harbour, Wales Passage, Pearse Canal and Winter Inlet, while Steamer Passage included sets from Khutzeymateen Inlet and Steamer Passage. King crabs were fished in an additional 20 locations (Fig. 2) but at an average CPUE < 7 kg trap^{-1} (Jamieson et al, 1986).

Golden king crab were only fished in commercial abundance in Alice Arm, and in only 2 sets were tanner crabs alone abundant enough to indicate commercial interest (Alice Arm and Wales Passage). However, since king crab traps, not tanner crab traps, were being used, this later observation may indicate gear bias and so these results should be treated with caution.

Male red king crab had a mean CL of about 125 mm at both Wales Island and Klewnuggit Inlet, and of about 138 mm at Steamer Passage. Using the regression, CW = -2.5748 + 1.2312 CL, derived for Yakutat red king crab in 1970 by D. Buchanan (W. Colgate, pers. comm.), this represents modal CWs of 151 and 167 mm respectively. The legal size of red king crab in Alaska in Statistical Area A (Southeastern - Yakutat) is 178 mm CW (= 147 mm CL) and with this minimum size limit, 8, 27, and 1% of male red king crab caught at Wales Island, Steamer Passage and Klewnuggit Inlet respectively were exploitable. With a minimum exploitable carapace width of 165 mm (= 136 mm CL), an arbitrary level used earlier in the absence of regulation, 20, 53 and 7% respectively of male red king caught would be exploitable.

Number of golden king crab fished in Portland Inlet (202) were too few with this survey to give an accurate description of relative proportion by size class for this species.

Red king crab were fished at depths ranging from 9 - 157 m, with the largest catch rate per set being 98 kg trap^{-1}, averaged over 8 traps, in Wales Harbour. The greatest catch per pot was 205 kg, also at this location. The maximum catch of golden king crab was 17 kg trap^{-1} in Alice Arm, and for tanner crab, 19 kg trap^{-1} in Wales Passage.

About 20% of the red king crab caught were female and of these, 96% had recently moulted and had eggs. In contrast, 51% of male crabs had not moulted recently and had hard carapaces with epizoans. In Alice Arm, 41% of the 86 female golden king crab caught were ovigerous but while the presence of the rhizocephalan parasite *Briarosaccus callosus* was noted, the degree of population infestion was not recorded. This parasite causes gonadal atrophy (Bower and Sloan, 1985). Also, depth preference of ovigerous female *L. aequispina* gradually increases following egg extrusion (Sloan, 1985b). Matted setae females and parasitized females are predominantly at depths > 200 m, indicating that a 'percentage ovigerous' statistic is only meaningful if qualified by an appropriate depth range. The range of depth fished ($\bar{x}$ = 216 m, SD = 120 m) in the Arm was too great in relation to the number of sets fished (6) to satisfactorily allow evaluation of this population parameter.

Of the 1072 tanner crab fished, 99% were males, with an average CL of

102 mm. Using the regression CW = 3.35 + 1.2476 CL (G. Jamieson, unpub.), determined from 127 male tanner crab fished in 1984 from mainland inlets near Cape Caution, British Columbia, this corresponds to a mean CW of 131 mm. Eight of the eleven females caught, ranging in size from 69 - 81 mm CL, were ovigerous. However, the selectivity of the gear was low for tanner crab and so results should be treated accordingly.

King Crab Biology

Study site: The Observatory Inlet system is a group of deep, interconnected fjords in the larger Portland Inlet in northern British Columbia. Sills partially isolate two Arms, Hastings and Alice, at the head of the inlet, which in turn is partially separated by a sill from the main part of Portland Inlet (Fig. 3). Sill depths are 18 - 25, 55 and 40 - 46 m for Alice, Hastings and Observatory respectively. The relatively level trough bottoms of these fjords is characterized by soft sediment, similar to other deep north-eastern Pacific fjords (Cimberg, 1982; Levings et al, 1983).

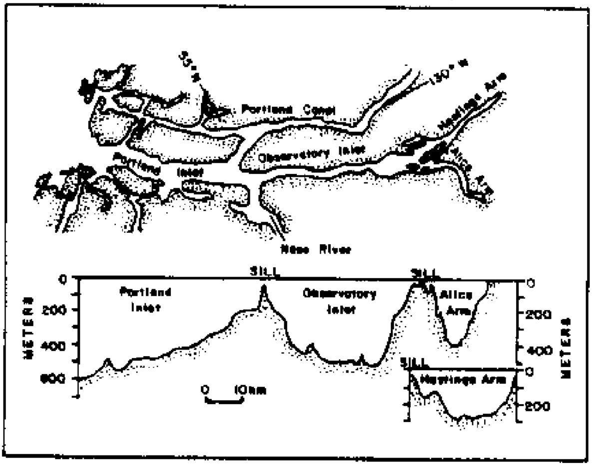

Figure 3. Longitudinal depth profile showing the position and depth of sills in the study site in northern British Columbia (modified from Sloan 1984a).

Materials and methods: The gear used was the same as in the exploratory survey, and details of fishing methods are described in a number of studies (Sloan 1984a, b, 1985a; Bower and Sloan, 1986). In summary, three cruises were undertaken to the Portland Inlet system with the R/V J. B. Reed on the following dates: October 27 - November 8, 1983; February 23 - March 5, 1984; and July 20 - 30, 1984. A total of 390 single king crab pot sets were made at depths between 51-569 m, with catches described and documented. Bait was frozen herring and soak times ranged from 6 - 97 h, with a mean of 34.8 h. The presence of B. callosus externae or the scars left after their removal were noted.

During the July cruise, an attempt was made to collect king crab larvae at five stations in Alice Arm (Fig. 4). Three sampling methods were utilized, a benthic sled and both oblique and horizontal bongo net tows. Salinity was felt to be too low (<5%) in surface waters (<1 m) to warrant extensive use of neuston nets; three tows along the length of Alice Arm yielded no crab larvae.

The epibenthic sled was constructed of steel reinforced plywood and consisted of three main parts: an outer 91.5 x 152.5 cm frame with skids, a 30.5 x 61 cm sampling box suspended inside to which was attached a standard, 500μ, 0.25 m^2 bongo net with a zippered codend, and an iron grating to protect the mouth of the net. A more detailed description of the sampler and its performance may be obtained from A. Phillips (Pacific Biological Station, Nanaimo, B.C. V9R 5K6).

The sled, equipped with a General Oceanics flowmeter, was towed at about 1 m sec^{-1} (2 kt) for 10 min for a linear distance of about 0.5 km. Previous studies (J. Mason, unpub. data) indicated essentially no water flow through the sampler on descent and only minimal flow through on recovery, amounting to less than 2% in a tow of this length in 200 m water depth. Crab larvae collected were in good condition, although juvenile Chionocetes bairdi had substantial leg loss. All specimens were preserved in 4% buffered formaldehyde solution for later identification.

All bongo tows were made with a 0.25 m^2 bongo equipped with 350μ Nitex nets of modified SCOR design and center-mounted General Oceanics flow meters. A 90 kg, cylindrical weight was suspended from the bongo yoke and all sampling gear was black to minimize larval avoidance and resulting catch bias. Tow procedure for oblique bongos was a vessel speed of 1 m sec^{-1}, gear descent at a cable payout rate of 60 m min^{-1} and gear ascent at a cable recovery rate of 20 m min^{-1}. Tows were made to within 5 m of the sea floor at all stations. Specimens were preserved as described above.

Single oblique bongo and benthic sled tows were made at each station (Fig. 4), and at station 3 in the center of Alice Arm, a horizontal bongo tow was made in each of the following depth ranges: 10 - 100, 100

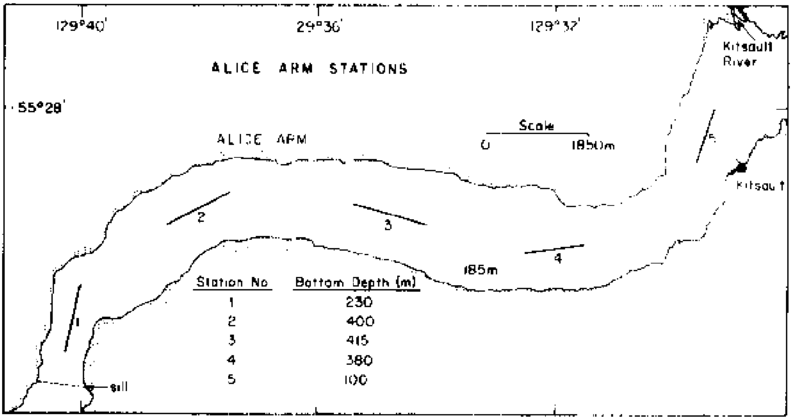

Figure 4. Larval sampling transect locations in Alice Arm, July, 1984.

- 200, 200 - 300 and 300 - 400 m. Larval catch rates were converted to catch per 300 m^3 to permit comparison of results.

Results: In all three research cruises to the Observatory Inlet system, which were timed at four month intervals throughout a year, golden king crab were the predominant king crab species fished. Some red king crab were found in the shallower areas of the system. Fishing and catch characteristics for the first two trips are presented in Table 1. The sex ratio of golden king crab in both Hastings and Alice Arms was about 1:1, with approximatley 41% (n = 3045), irrespective of sex, parasitized by B. callosus. In Observatory Inlet, the overall density of golden king crab and the proportion of the population parasitized (4%) was low. Only one of the 184 red king crab caught was parasitized.

Table 1. Fishing effort, depth and catch of Paralithodes camtschatica and Lithodes aequispina (with percent parasitized by Briarosaccus callosus) in fjords within the Portland Inlet system; October to November, 1983 and February to March, 1984 (modified from Sloan, 1984a).

	Fishing characteristics			Catch characteristics		
				Number of L. aequispina and (%) parasitized by B. callosus		
Months/year	Fishing effort		Mean			
Fjord	Pots fished	Mean soak (h)	depth (m)	Male	Female	Total
Oct.-Nov. 1983						
Alice Arm	44	32.6	216	444 (43.3)	588 (37.1)	1032 (39.7)
Hastings Arm	44	33.3	255	139 (41.7)	119 (34.5)	258 (38.4)
Observatory Inlet	31	34.7	409	62 (1.6)	42 (4.8)	104 (2.9)
Portland Inlet	31	23.6	335	2 (0.0)	0 (0.0)	2 (0.0)
Total	150	31.4	305	647 (38.9)	749 (34.8)	1396 (36.7)
Feb.-Mar. 1984						
Alice Arm	98	47.7	109	767 (42.4)	717 (45.6)	1484 (43.9)
Hastings Arm	34	29.4	291	83 (44.6)	82 (40.7)	165 (42.4)
Work Channel	19	24.2	233	0 (0.0)	0 (0.0)	0 (0.0)
Total	151	40.6	166	850 (42.5)	799 (45.[illegible])	1649 (43.7)
Grand total	301	36.0	235	1497 (40.9)	1548 (40.1)	3045 (40.5)

The tendency for parasitized crabs to continuously inhabit deeper waters is discussed by Sloan (1985 a, b), and this phenomenon may largely account for the increased average CPUE of golden king crab at depths >250 m (Table 2). The overall abundance of crab in the trough bottom is likely greater than that <250 m, since the trough comprises the largest horizontal area of the fjord. Shallow water is largely confined to the ends of the Arms and represents a small proportion of the overall area. This probably explains why shallower-water, red king crab are in relatively low abundance in the system. The average depth at which *L. aequispina* was fished was 272 m whereas that for *P. camtschatica* was 114 m (Sloan 1985a).

Table 2. Average number ($\bar{N}$) and whole weight ($\bar{W}$; kg) of *L. aequispina* caught per trap in Alice and Hastings Arms; n = number of traps. Average soak time = 34.8 h.

A. All crab sizes

	Nov., 1983			Feb., 1984			July, 1984		
Depth(m)	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$
0-250	23	16.2	23.4	44	9.6	13.0	41	3.4	5.0
250-500	49	18.7	25.3	57	14.7	18.3	33	9.3	12.4

B. Crab >165 mm CW

	Nov			Feb			July		
	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$
0-250	20	7.1	14.4	42	3.9	8.0	30	1.4	4.3
250-500	49	6.7	13.1	46	5.3	10.2	26	4.3	8.0

C. All research fishing dates combined

	All sizes			>165 mm CW			>181 mm CW		
	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$	n	$\bar{N}$	$\bar{W}$
0-250	106	8.8	12.4	90	4.1	8.3	10	1.3	4.1
250-500	139	14.9	19.4	128	5.4	10.7	36	1.4	4.2

Regardless of depth, CPUE decreased over the study period (Table 2), even though most of the crabs fished were released after their morphometric characteristics were measured. This decrease was most evident in water <250 m depth, but since CPUE also decreased in deeper water, no obvious explanation is available.

Jewett et al (1985) recommended a minimum size limit for golden king crab in Alice and Hastings Arms of 163 mm CL (= 181 mm CW), based on three moult increments (totalling 48.6 mm CL) beyond the average size of male sexual maturity (114 mm CL). A size limit of 136 mm (= 165 mm CW) was self-imposed in earlier commercial fishing (P. Wallin, pers comm.). Average CPUE at depths >250 m with these minimum size limit restrictions were 4.2 and 10.7 kg trap^{-1} respectively (Table 2).

Tanner crabs occurred in >80% of the traps set, and halibut (*Hippoglossus stenolepis*) bycatch was inversely proportional to golden king crab abundance in a trap. Halibut bycatch incidence in Portland Inlet, Observatory Inlet and the two Arms combined was 62, 35 and <5% of the traps set respectively.

During the period 1980 - 82, commercial catch per trap of golden king crab (CW >165 mm) in Alice Arm was reported (P. Wallin, pers. comm) to have declined from 29.9 to 6.4 kg trap^{-1} (Table 3). The population has not been commercially exploited since 1982, and using the same gear and 20 - 60 h soaks in 1984, the decrease in average CPUE appears to have stopped. The mine has not dumped tailings since 1982 and so the cause of the decline in CPUE may never be established.

Parasitism by B. callosus affects somatic growth in addition to gonadal development. However, only the size and weight of male, not female, crabs are reduced in comparison to non-parasitized individuals (Sloan, 1984a). Parasitized crabs >163 mm CL were rare, indicating that with this minimum size limit (= 181 mm CW), a commercial fishery utilizing only this regulation would be based largely on unparasitized, male crabs.

Table 3. Commercial and research cruise CPUE for L. aequispina (CL>136; CW>165 mm) in Alice Arm from 1980 to 1983-84. *P. Wallin, pers. comm.

A. Commercial operation*, Alice Arm

Year	No. traps	No. crab per trap	Wt. crab per trap (kg)
1980	192	11.0	29.9
1981	287	7.5	20.3
1982	135	2.4	6.4

B. Research cruises, Alice Arm (20-60 hr soak)

1983-84	157	5.6	10.7

B. callosus and L. aequispina are both aseasonal spawners in the Observatory Inlet system, with about the same proportion of the population in each reproductive state throughout the year (Sloan 1985a, b). This is in contrast to the few red king crab collected, where virtually all the females caught had eyed eggs in February and newly extruded eggs in July.

Golden king crab ranging in size from 59 - 194 mm CL were caught, whereas the size range of red king crab was 74 - 170 mm CL. Only a few king crab smaller than 80 mm CL were fished, but their relative absence, as with tanner crab, is felt to reflect the fishing charactersitics of the gear and perhaps the presence of larger individuals within the traps, rather than a general low abundance in the inlets.

The relationship between crab size, sex and reproductive state in relation to depth preference is discussed in detail by Sloan (1985a, b).

Larval sampling of crab in Alice Arm was inconclusive as while it was known that golden king crabs eggs were hatching througnout the year, no king crab larvae were collected. However, crab larvae and/or juveniles of *Chinoecetes bairdi* and *Cancer magister* were collected, which indicated that each gear type was fishing properly (Table 4). In the horizontal bongo tows, megalopae of both later species were predominantly caught at depths <100 m. Neverthless, oblique bongos and the epibenthic sled also caught zoea and megalopae of both species, with the abundance of settled megalopae for both species about the same at depths >250 m.

Table 4. Catch rates of crab larvae by species for the different gear types and strategies utilized.

A. Bottom sled, Oblique bongo

No. Stations	Mean depth (m) (±SD)	Species	Catch (N/300 m^3) ±SD Bongo	Sled
4 bongo/ 3 sled	273 ± 37	*C. bairdi* megalops	8.3 ± 5.6	5.3 ± 4.9
		C. magister zoea V	2.3 ± 2.2	0
		" " megalops	29.8 ± 45.0	5.7 ± 9.8
		Pagurid zoea	.3 ± .6	0
		" glaucothae	1 ± 0	7.7 ± 8.6
1 bongo/ 1 sled	92	*C. bairdi* megalops	100	3
		" " juvenile	0	33
		C. magister zoea V	8	0
		" " megalops	2	0
		Pagurid glaucothae	0	22
		M. quadraspina	2	0

B. Horizontal bongo (mid-Alice Arm)

Species	Catch (N/300 m^3) at depth (m) 400-300	300-200	200-100	100-10
C. bairdi zoea	0	0	0	1
" " megalops	1	3	3	19
C. magister megalops	0	1	1	2

Discussion

The king crab resource in the mainland inlets of British Columbia is relatively small and patchy in distribution. Localized concentrations of crabs exists which may support periodic fishing by a few vessels. However, although relatively minor from an exploitation perspective, the existence of these relatively isolated, discrete king crab populations provides some unique opportunites to study king crab population dynamics, and in particular, the relationship between Briarosaccus callosus and Lithodes aequispina.

Jewett et al (1985) proposed a minimum legal size limit of 181 mm CW, but this should only apply to unparasitized crabs. Since parasitized crabs cannot reproduce, are a source of infective parasite nauplii and utilize resources which might otherwise be available for unparasitized crabs, all sizes of both sexes of parasitized crabs should be harvested and the externae of the parasite immediately destroyed in a way to prevent possible continued release of nauplii (Sloan 1984a). With an exploitation strategy of harvesting all parasitized crabs, and unparasitized crabs with a CW $\geq$ 181 mm, average CPUE was 9.6 kg trap^{-1} in 1983-84. Live parasitized crabs should not be relocated, as rhizocephalan parasites have been shown to readily establish themselves in new areas if suitable host species are present (Boschma, 1972).

The presence of similar, high levels of infection in both Alice and Hastings Arms presents an opportunity for experimental management, with one inlet having both legal size (CW $\geq$ 181 mm), unparasitized crabs and all parasitized crabs fished, and the other having only legal size, unparasitized crabs exploited. Parasitism levels in both Arms could be monitored on an annual or biannual basis, and while the possiblitity exists that exchange of B. callosus nauplii between the two Arms may be of such magnitude that any fishery-induced perturbation of only part of the system would be relatively inconsequential, the possibility of biologically separate systems also remains. Sloan (1984a) discussed the importance of deep, silled fjords as a physical factor in the retention of larvae of deep water species and the effect this may have in the isolation of such populations. However, there is no specific data to suggest what the actual larval exchange rate may be between the two Arms of this system. Both host and parasite populations have probably been isloated in the Arms for centuries, based on the recent geological history of the region and the present apparent pattern of population distribution. It is not clear whether the present incidence of parasitism represents an equilibrium between the two species in the system or whether the relative abundance of parasitized crabs cycles in some manner. Closely monitored experimental mangement might resolve this uncertainty.

The early life history of L. aequispina remains largely unknown in Canadian waters as neither larvae nor newly-settled juveniles were collected. L. aequispina larvae have rarely been collected and never in sufficient number to indicate their pattern of distribution in either the vertical or horizontal planes.

The absence of golden king crab larvae may indicate that 1) while larvae are being hatched continuously, it is at a relatively low rate, and more extensive sampling is required to establish their presence; or 2) sampling methodology, either by gear type, depth, time of day or location, was not optimal. Female king crab with eggs in the process of hatching were caught during the survey, so the presence of zoae somewhere in Alice Arm was established.

The collection of Cancer magister megalopae in numbers comparable to that of Chinoecetes bairdi in deep water in Alice Arm was unexpected. Adult C. magister were caught shallow water at the head of the Arm but no adults were fished in deep water. Whether this was the result of gear selectivity, the presence of other crab species in the traps or the absence of large Dungeness crab in deep water in unclear. It is possible that this represents larval wastage, i.e. larvae which have settled in areas where they will not survive. If so, it suggests that C. magister megalopae are relatively unselective as to where they settle, since Alice Arm is quite small geographically with shallow water always nearby.

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Distribution by depth of *Lithodes aequispina* and *Paralithodes camtschatica* confined in northern British Columbia fjords

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Abstract

In deep, narrow fjords of northern British Columbia, life history characteristics of two king crab species, sampled over 10 consecutive months, are discussed in relation to depth. The normally contenental shelf-and slope-dwelling *Lithodes aequispina* occurred deeper than the intertidal to shelf-dwelling *Paralithodes camtschatica*. Reproductive state of unparasitized *L. aequispina* and parasitism of the remainder (N=1558; 41.0% of sample), by the rhizocephalan *Briarosaccus callosus*, evoked differences in depth-related distribution. *L. aequispina* demonstrated continuous, aseasonal reproduction. Juvenile *L. aequispina* were most common at <100 m depth, females usually mate and extrude eggs at <150 m, then incubate eggs at 150 to 250 m and post-spawned females dominate the unparasitized crab population from 251 to 400 m. Adult males are less migratory and tend to remain at 50 to 150 m. Parasitized male and female *L. aequispina* are similar to post-spawned females and were the largest component of the total crab population from 200 to 400 m. *P. camtschatica* was less parasitized by *B. callosus* (N=1; 0.6% of sample). Female *P. camtschatica* demonstrated marked seasonal reproductive synchronization but there were insufficient data to describe migration.

Introduction

The little known, deep-water golden king crab, *Lithodes aequispina*, occurs throughout the north Pacific from British Columbia through the Bering Sea to Japan (Hiramoto and Sato 1970; Otto et al. 1983; Sloan 1985a). Recently a population of *L. aequispina* was discovered along with red king crab, *Paralithodes camtschatica*, in northern British Columbia fjords by fishermen (P. Wallin pers. comm.).

I report here on the depth-related distribution and reproduction of *L. aequispina* in an interconnecting group of silled, narrow and steep-sided fjords within the Portland Inlet system, British Columbia. Comparative data on a small sample of coexisting *P. camtschatica* are also discussed.

Materials and Methods

On three occasions between October, 1983 and July, 1984; 435 pot sets were made between 51 to 569 m ($\bar{x}$=230 m) in five fjords at the extreme north end of the British Columbia coast (55°N:130°W) (see Sloan 1985a for detailed description). Captured king crabs were sexed, measured for carapace length and right cheliped height (males only) to the nearest mm and examined for the presence of the rhizocephalan parasite *Briarosaccus callosus*, or their remaining scars, on the body surface. Reproductive state of unparasitized female king crabs was classified as juvenile (no eggs nor their remnants on pleopod setae), new-egged (uniformly coloured eggs attached to pleopods), eyed-egged (attached eggs with dark, embryonic eye spots) and matted setae (post-spawned condition in which pleopods have long, entangled setae sometimes bearing egg remnants). Unparasitized male *L. aequispina* with a carapace length <114 mm were classified as juveniles (Jewett et al. 1985). Shell class among *L. aequispina* was noted as either: 1 for crabs that had moulted recently, i.e., clean, light-coloured exoskeleton showing little abrasion; or 2 for other crabs having discoloured, abraded exoskeletons with epizooites.

Results

In the two fjords (Alice Arm and Hastings Arm) in which both king crab species were captured, *L. aequispina* were taken between 51 and 402 m ($\bar{x}$ 272 m; N=3694) and *P. camtschatica* between 59 to 384 m ($\bar{x}$=114 m; N=184), with only six crabs taken at >150 m. Figure 1 illustrates the depth-related distribution of juvenile, adult and parasitized *L. aequispina* from 50 to 400 m.

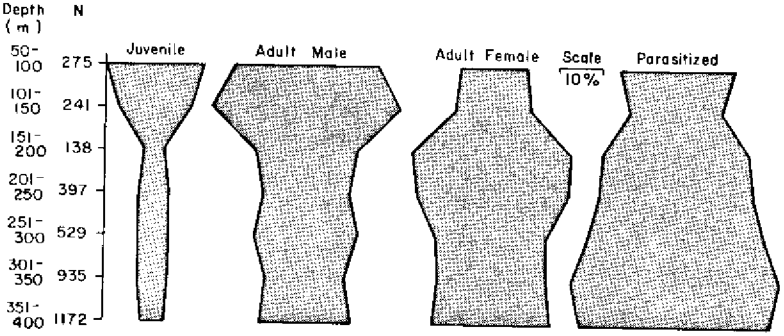

Fig. 1. Distribution of proportions of juvenile, adult male, adult female and parasitized *Lithodes aequispina* (N=3687) according to depth (50 to 400 m) in the Portland Inlet system (from Sloan 1985a). Scale bar is 10% of the population.

Data from deeper pots (401 to 569 m) were excluded as only one pot in Alice and Hastings Arms was >400 m and, of the 106 *L. aequispina* taken outside the two Arms, only three were infected with *B. callosus* (Sloan 1985b). Proportions of juvenile *L. aequispina* were maximum at 50 to 100 m, adult males at 101 to 150 m, adult females at 151 to 250 m and parasitized crabs at 251 to 400 m.

Table 1 demonstrates that similar proportions of different reproductive states of unparasitized female *L. aequispina* were found throughout the sampling period, with the majority being in the matted setae condition. The proportion of matted setae females increased steadily from 50.0 to 66.3% between late October/early November, 1983 to July, 1984. *P. camtschatica* coexisting with the *L. aequispina* demonstrated marked synchrony between females, all of whom were egg-bearing.

Table 1. Reproductive state of unparasitized female *Lithodes aequispina* and female *Paralithodes camtschatica* from Alice Arm and Hastings Arm, Portland Inlet system.

	Lithodes aequispina					*Paralithodes camtschatica*				
		% of unparasitized females					% of unparasitized females			
Sample date	n	Juv.	New eggs	Eyed eggs	Matted setae	n	Juv.	New eggs	Eyed eggs	Matted setae
Oct./Nov., 1983	448	9.5	20.9	19.6	50.0	32	0.0	100	0.0	0.0
Feb./March, 1984	439	13.2	15.9	14.6	56.3	10	0.0	0.0	100	0.0
July, 1984	226	10.6	12.5	10.6	66.3	75	0.0	100	0.0	0.0

Between 50 to 100 m, 58.2% of unparasitized female and 38.2% of unparasitized male *L. aequispina* were recently-moulted, shell class 1 individuals. At 101 to 150 m these proportions increased to 72.1% and 62.3% of unparasitized females and males respectively, and then decreased so that by 351 to 400 m they were 15.0% and 29.4% respectively.

Figure 2 illustrates the depth-related distribution (to 400 m) of unparasitized female *L. aequispina*. Highest proportion of juveniles occurred between 50 to 150 m, new egged females from 101 to 150 m, eyed-egged individuals between 151 to 200 m and matted setae females dominated at depths >200 m. Among unparasitized males, juveniles were most common at 50 to 100 m and a minor component of males from 101 to 400 m. Approximately 68.4% of all unparasitized *L. aequispina* between 50 to 150 m were males whereas females comprised 57.4% of all unparasitized crabs between 301 to 400 m.

Discussion

Confinement in narrow, steep-walled British Columbia fjords may enhance contrasts in depth-related distributions between *L. aequispina*, a continental slope-and shelf-dwelling species (Otto et al. 1983), and *P. camtschatica*, a shelf-dwelling to intertidal species (Hayes 1983). Vertical distribution of fjordic *L. aequispina* relates to sexual maturity of unparasitized crabs and parasitism by *B. callosus* in the

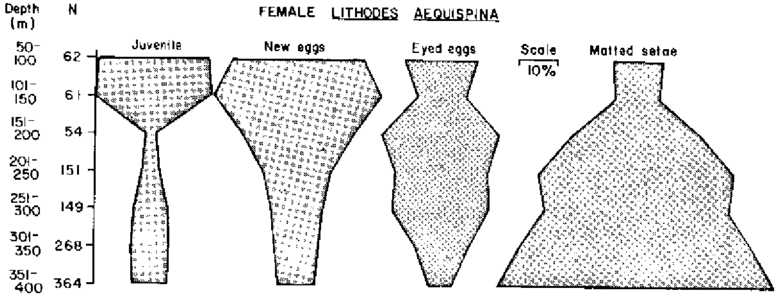

Fig. 2. Distribution of proportions of juvenile, egg-bearing and matted setae female (unparasitized) (N=1109) *Lithodes aequispina* according to depth (50 to 400 m) in the Portland Inlet system (from Sloan 1985a). Scale bar is 10% of the unparasitized female population.

remainder. Among the unparasitized *L. aequispina* most moult at <150 m where the females probably moult before mating but it is not known whether the males moult before or after mating (Sloan 1985a). The following aseasonal life history pattern is proposed for fjordic *L. aequispina*: (1) concentration of juveniles in the shallows (<100 m); (2) moulting, mating and egg extrusion slightly deeper, although still relatively shallow; (3) downward migration among incubating females while adult males tend to remain in shallower water; (4) hatching and larval release at depth; (5) post-spawning recovery in deep water; (6) eventual upward migration by females to moulting and mating grounds in shallower fjordic depths to begin a new cycle. Parasitized male and female *L. aequispina* are probably castrated and generally behave similar to post-spawned females by congregating in deep water (Sloan 1985b). This could be for long periods as the parasites may remain with their hosts, permanently sterilizing them (Bower and Sloan 1985).

Among the five *Lithodes* spp. for which there are data (see Sloan 1985a), northeast Pacific *L. couesi* from seamounts (Somerton 1981) and fjordic *L. aequispina* (Sloan 1985a) are reported to have continuous, aseasonal reproduction. Otto et al. (1985) proposed that *L. aequispina* from continental slope and canyon habitats in the Bering Sea and Aleutian Islands have a protracted spawning period from at least February to April and a variable length (to 2 years) reproductive cycle with a differing seasonality according to area. Northwest Pacific populations of *L. aequispina* apparently demonstrate seasonal spawning in warm months (Hiramoto and Sato 1970; Rodin 1970). Hiramoto (1985) has reviewed his data and suggested "asynchronous spawning" with an "indistinct" seasonal cycle; citing "prominent periods" of mating, incubation and hatching. Preliminary observations indicated spawning aggregations according to season and depth, followed by segregation of incubating females from males. My data do show a progressive increase in the proportion of spawned-out females from cold to warm months, but whether this is an appreciable level of synchrony requires further study. It is now evident that the reproductive biology of *L. aeuqispina* varies according to locality and thus the question of seasonal versus aseasonal reproductive characteristics must be assessed on a site-specific basis.

Female *P. camtschatica* in the fjords demonstrated a seasonally-synchronized reproduction well known for the species elsewhere (Hayes 1983). There is, however, insufficient data to describe any seasonal migration in fjordic *P. camtschatica*. The presence of eyed-egg females in early March suggests a similar April-May spawning as described for Alaskan *P. camtschatica* (Hayes 1983).

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King crabs of the world or the world of king crabs: an overview of identity and distribution—with illustrated diagnostic keys to the genera of the Lithodidae and to the species of *Lithodes*

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Introduction

The "King Crab" of the North Pacific, Paralithodes camtschatica (Tilesius), is, undoubtedly, the best known of the stone crabs collectively forming the family Lithodidae. Indeed, this species and the problems of its fishery provides the central theme of this International King Crab Symposium.

There are, however, many other species of stone crabs (or, as we should prefer to call them, king crabs) which are virtually unknown, even to decapod specialists, but knowledge of which is becoming increasingly necessary as the traditional fisheries continue to decline.

Over the past few years there has been a renewal of interest in king crabs on the world scene, not only because of market pressures, but as a result of the many new records from deeper sea operations in regions as far apart as South-west Africa and Hawaii. Information which would be helpful for the identification of species is not only widely scattered throughout the literature but is generally well out of date. No recent treatment of the Lithodidae exists, making it difficult for the non-specialist to find out what is known about these animals, let alone try to identify a specimen.

The last systematic review of the family was that of Bouvier in 1896, so modern keys to the 16 genera and to the 79 species which constitute it are now a necessity. We have made a preliminary attempt here to provide this information, as well as listing all those species of the family so far described, in the hope that this will provide a useful tool for fisheries biologists and others who may have felt so frustrated in the past that they have helped to perpetuate the lack of knowledge of the distribution and ecology of this significant group of Crustacea.

Following the discovery of king crabs in southern New Zealand waters in 1960, identified by Yaldwyn and Dawson (1970) as *Lithodes murrayi* Henderson, 1888, now known to be a southern circumpolar species, two other genera, *Neolithodes* and *Paralomis*, have been found with new species recognised as *N. brodiei* Dawson and Yaldwyn, 1970 and *P. zealandica* Dawson and Yaldwyn, 1971. In addition to extending the known range of these three species within the New Zealand region, other records of king crabs have been made, notably a form indistinguishable, at the present state of our knowledge, from the endemic Japanese *Acantholithus hystrix* (de Haan, 1849), and, only a few days before the International Symposium, the recognition of the Japanese *Lithodes longispina* Sakai, 1971. The task of proper identification of the New Zealand species has led us to re-examine all the known species of *Lithodes*, *Neolithodes*, and *Paralomis* and, rather reluctantly, what was intended to be simply a report on the New Zealand scene expanded itself to a world revision with new keys and redescriptions for these three genera.

Our work was not before time because since it began many new and exciting discoveries of new species of king crabs or interesting extensions of known ranges have been made, some of which are indicative of commercial fishery potential in parts of the world where these crabs were never suspected to exist. It is remarkable that whereas in the years 1758 to 1956, 56 species of Lithodidae had been described, since 1970 (when we began our study), 22 new species have been added to the family. A new basis for theories of zoogeographic and evolutionary speculation on the Lithodidae (perhaps based, as is now fashionable, on plate tectonics) is now available, and it will be interesting to see how the classic map given by Makarov (1938) will be changed and whether the alleged significance of *Lithodes* as a bipolar element will be modified.

The problems besetting the king crab industry of the Northern Hemisphere, the crash of the Alaskan fishery, the tightening of the traditional markets of Japan and the Soviet Union, and the interest in developing new deeper water fisheries for such species as the Golden king crab, *Lithodes aequispina*, all indicate the need for the presentation of an overview of the king crabs of the world, focusing attention, particularly, on the potential offered by the Southern Hemisphere, its species and stocks and possible entry into the world market.

Hence, we see a need to appreciate the extent of the king crab fauna of the world, to be aware of what is not known of identity, distribution and biology, to state again the questions that research should attempt to answer for industry (as so succinctly put by Stevens in 1955 well before the Alaskan scene blossomed), and, as a first move, to be able to identify the species of likely interest and record their distribution and evaluate its significance. This is our primary concern in our contribution to the International Symposium.

King crabs have been recognised and utilised commercially in Chile and Argentina and, more recently, in Peru, for some years. South Africa has made an initial attempt to exploit *Lithodes murrayi* (see Melville-Smith 1982) and *Neolithodes* has also been noted in what could be commercial quantities; our New Zealand species, *Neolithodes brodiei*, occurs in appreciable numbers off south-eastern Australia and we have, in New Zealand waters, at least three species of king crabs close inshore and in the deep south likely to be of commercial significance.

The French in the southern Indian Ocean, led by Dr Patrick Arnaud, have already made notable assessments of the stocks of Lithodes murrayi (see Arnaud and Do-Chi 1977; Arnaud et al. 1976, and 'in press'). Clearly, the Southern Hemisphere could hold the key to the continuance of supply of king crabs to the markets of the world hitherto dependent on the now dwindling supply from the North Pacific.

Our taxonomic and distributional offering is only a preliminary attempt. We have been handicapped, for example, by our lack of first-hand knowledge of the subfamily Hapalogastrinae, found only in the North Pacific, about which we have written but never seen. We make an appeal, at this stage, for the loan or gift of species for our National Collection. It is appropriate to note here, also, that of the 79 species of Lithodidae now known, most have not been illustrated sufficiently well for easy taxonomic recognition, some never illustrated at all, and for some such as the best-known, the Kamchatka, Alaskan, or Red king crab, Paralithodes camtschatica, apparently so well recognised commercially that no adequate description of its morphological variation has been given, it is still possible for aberrant specimens to be described as new species (see, for example, Navozov-Lavrov 1929: Paralithodes longirostris) and Mackay 1932: Paralithodes rostrofalcatus).

The Lithodidae have been traditionally regarded as a Northern Hemisphere family, evolving through the Hapalogastrinae, the small subtidal crabs well-known in Alaskan and Californian waters. Makarov (1938) postulated a theory of evolution and biogeography that has now become well outmoded by more recent discoveries, and lithodids are now known from nearly all regions of the world. Our annotated checklist of species will serve as a summary of geographic and bathymetric distribution. It seems clear that as new parts of world seas are critically explored and king crabs are recognised for what they are, further new species and extensions of ranges of already known forms are to be expected.

A Few Words of Caution

In using the key to the species of Lithodes some caution must be observed if only a single specimen of an unknown lithodid is available. Although some species apparently show little variation in morphology especially as adults, others may show a sufficiently great variation in, for example, rostral characters, degree of fusion of abdominal plates and spinulation of the carapace, to lead a user of our keys along a false path. The philosophy that a total "feel" for a species, so well postulated by Pantin (1954), also referred to by ornithologists as "jizz", is a valid tool for the recognition of king crab species is exceedingly difficult to work into the conventional taxonomic key, but is, nevertheless, a realistic aid for those of us who have handled a great variety of king crabs on a world-wide basis.

Our key to the species of the type genus, Lithodes, is based on the observation that all known Lithodes have rostra appearing either bifid or trifid in dorsal view, i.e. with a double spine as the most anterior projection or a single spine set between two other spines may be subequal or greater in length. However, variations on these patterns are known. The bifid rostrum of Lithodes aequispina may, occasionally, be found as a single spine although the accessory spines are present in the usual characteristic form. The relative lengths of the rostral spines of Lithodes longispina and L. turritus may vary and the proportional thicknesses of the shafts of each may also give an unusual impression.

Our colleague, Dr Patrick Arnaud of Marseilles, who has handled several thousand Lithodes murrayi in his studies in the southern Indian Ocean, has found that an appreciable number of individuals may have any of the following variations (using the nomenclature of our Figure B, see also Figure G) - R as a single spine with pre-A but lacking A or b; single R with b but lacking A or pre-A; single R with A, pre-A with b; with R spines of very unequal lengths; and "subtruncate and serrated in the frontal area" with or without pre-A but with A and b (pers. comm. 30 Oct. 1982).

Macpherson (1984) has recently described an alleged new species, Lithodes unicornis, from the Valdivia Bank, SE Atlantic, characterised by a single anterior projection to its rostrum. Dr Arnaud, whom we thank for drawing our attention to this publication, convinced us, during a visit on 2 February, that L. unicornis is a variant of L. murrayi, and we follow him in this for the purpose of our key. Similarly, there is an apparent confusion about the alleged trifid rostrum of Lithodes panamensis, and further caution is needed with any lithodids appearing trifid. We await the results of current correspondence with Dr E. del Solar in elucidation of the apparently conflicting figures of this species which he has shown (del Solar 1974, 1981; cf. Faxon 1895).

A final word of caution is necessary in trying to distinguish, at the level of detail given in our key, between Lithodes longispina and L. turritus, regarding the relative development of anterior and posterior cardiac spines, the number of prominent dorsal branchial spines, and the relative lengths of posterior marginal spines. The exciting identification of large numbers of L. longispina in south-east Australian waters, made by one of us during a visit to Sydney following the International Symposium, indicates the need for a definition of clear distinguishing features of king crabs likely to be of commercial interest. We, therefore, urge users of our keys to go to the original descriptions of any species about which they feel some uncertainty. Our hope is that users of these illustrated keys will offer us their constructive criticism so that a definitive edition, more comprehensively illustrated and annotated, can be issued for wider circulation. Accordingly, this preliminary version is offered as a working document capable of considerable refinement and modification.

A resumé of the systematic position of the Lithodidae is as follows:

Class CRUSTACEA
Subclass Malacostraca
Superorder Eucarida
Order Decapoda
Suborder Reptantia
Section Anomura
Superfamily Paguridea
Family Lithodidae

King crabs (or stone crabs) forming the family Lithodidae are grouped with the hermit crabs (Paguridae) in the superfamily Paguridea included with the squat-lobsters (Galatheidea), mole crabs (Hippidea), and the burrowing mud shrimps (Thalassinidea) in the Anomura, a major division of the decapod Crustacea contrasting with the true crabs (Brachyura) and the true shrimps (Macrura). The "stone crab" of North American literature is *Menippe mercenaria*, a true crab (Brachyura : Xanthidae).

Considering the various features which serve to distinguish each of these groups, lithodid crabs can be readily recognised by the following combination of characters:

(a) unlike most decapods, there appears to be only four pairs of legs (one pair of chelipeds and three pairs of walking legs); however, a 5th pair of reduced, weakly chelate legs (4th walking legs) is tucked into the gill chambers;

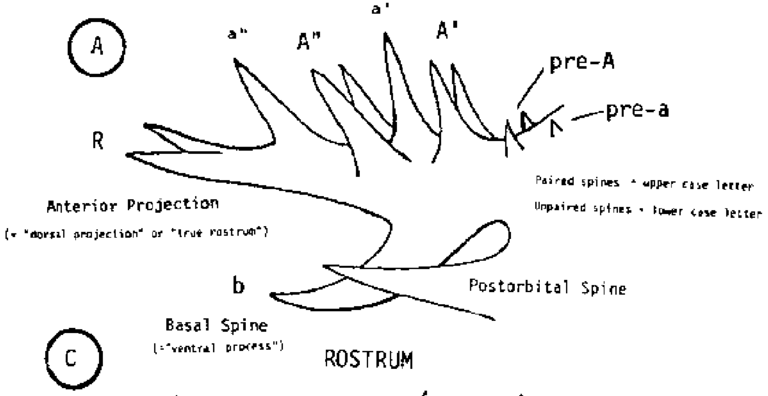
(b) the carapace is flattened, crab-like and more or less triangular;

(c) the abdomen is bent forward beneath the carapace, not strongly calcified, symmetrical in males, asymmetrical in females, curving to the right;

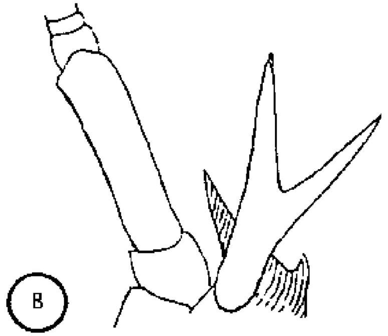
(d) additionally, the third pair of legs is never chelate and the antennal flagella are well developed.

The illustrations on which our keys are based have been taken from a variety of published sources which will be detailed in our later definitive versions. In particular, we acknowledge the fine work of N. Kondakov, the artist of Makarov's 1938 monograph. Figures have also been adapted from such publications as Henderson's "Challenger" report (1888), Bouvier's analytical summary (1894), Faxon's "Albatross" report (1895), Sakai's works on Japanese crabs (1971, 1976, 1980), and Haig's (1974) work on Peruvian lithodids. Figure 45 in the generic key is of *Paralomis truncatispinosa* specially drawn from the original photograph of Takeda & Miyake (1980) by Mr W.R. Webber, National Museum of New Zealand, who also drew the figures of *Lithodes nintokuae* (figs 4, 6, 8, of species key) for a forthcoming contribution in *Pacific Science*.

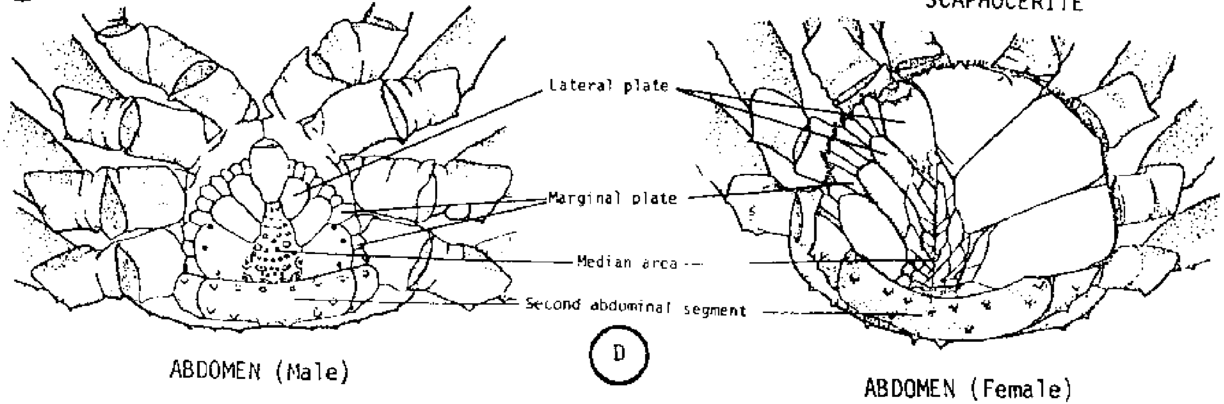
FEATURES USED FOR THE IDENTIFICATION OF LITHODIDAE: 1



ROSTRUM



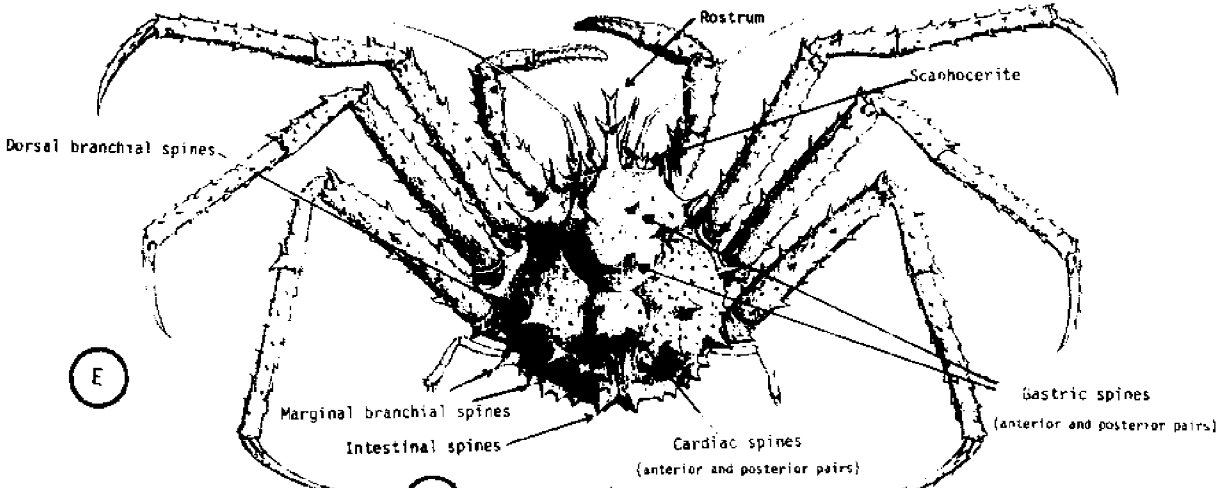
SCAPHOCERITE



ABDOMEN (Male)

ABDOMEN (Female)

FEATURES USED FOR THE IDENTIFICATION OF LITHODIDAE: 2



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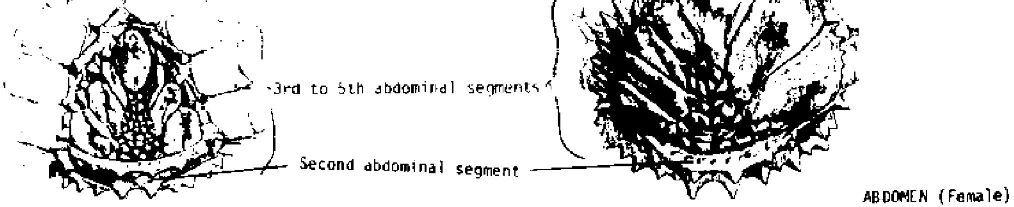
ROSTRUM



F

ABDOMEN (Male)

ABDOMEN (Female)

I: PROVISIONAL KEY TO THE GENERA OF LITHODIDAE

1(20) Rostrum usually well developed (e.g. figs 10,20,24), consisting of basal spine B (fig. A) with anterior projection A, or a basal spine only (as in fig. 10), with or without secondary dorsal or dorsolateral, paired A, or unpaired A, spines; abdomen firm and flat, integument of 3rd to 5th segments consisting of well calcified plates (e.g. figs 9,26,33,42,43), sometimes with membranous areas (fig. 59), species usually large in size. ....Subfamily LITHODINAE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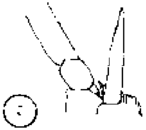
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2(19) Third to 5th abdominal segments with lateral plates entire (e.g. figs 21,33,42); scaphocerite either rudimentary (fig. 1), simple or blade-like (fig. 2), sometimes with spines (figs 3-6) but never with foliaceous lobes.


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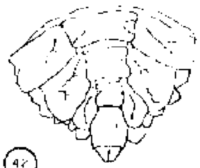
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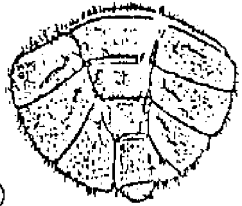
3(8) **Second abdominal segment divided by sutures into 5 plates (i.e. a pair of marginals, a pair of laterals and a median as in fig. 7).**

7

4(5) Carapace broadly triangular in shape and granulate but not spined; cardiac area elevated and spherical, separated from remainder of dorsal surface of carapace by a distinct curved depression; rostrum short and unarmed dorsally; 3rd to 5th abdominal segments with median plates separated from one another by a transverse row of nodules more or less fused together, and with marginal plates fused to corresponding laterals (fig. 9); scaphocerite well developed and spined..<u>Rhinolithodes</u> Brandt, 1848 (fig. 8)

8



9

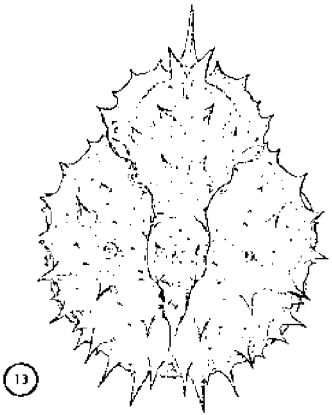
5(4) Carapace broadly pentagonal in shape and spined; cardiac area not unusually elevated, not separated from remainder of dorsal surface of carapace by distinct curved depressions; rostrum armed dorsally (fig. 10); 3rd to 5th abdominal segments with marginal plates either distinct (fig. 12) or fused to corresponding laterals; scaphocerite well developed or rudimentary.


10

6(7) Third to 5th abdominal segments with calcified nodules fused to some degree into lateral plates in adults (male with several small plates as in fig. 12, female with three plates on left side); rostrum lacking anterior projection (R in fig.A)but with basal spine (b in fig.A) simple, elongate, acute with a pair of elongate, acute spines projecting dorsally from near its base (fig. 13), scaphocerite usually rudimentary. ....*Neolithodes* A. Milne Edwards & Bouvier, 1894 (fig. 11)


12


13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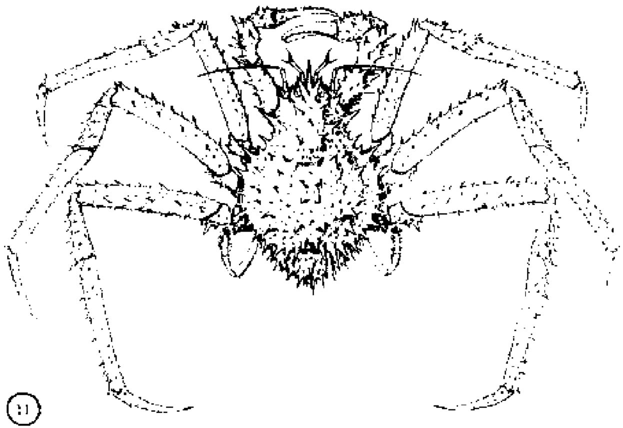
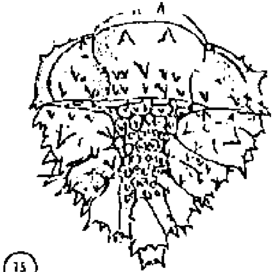

11

7(6) Third to 5th abdominal segments with calcified nodules in median area only and with distinct lateral and marginal plates on each side (fig. 15); rostrum lacking anterior projection but with basal spine short, broad and usually acute with one or more pairs of short dorsal spines (figs 10,16) and sometimes with unpaired median anterodorsal spines (fig. 17); scaphocerite well developed..................*Paralithodes* Brandt, 1848 (fig. 14)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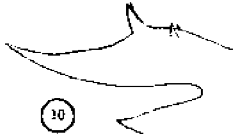
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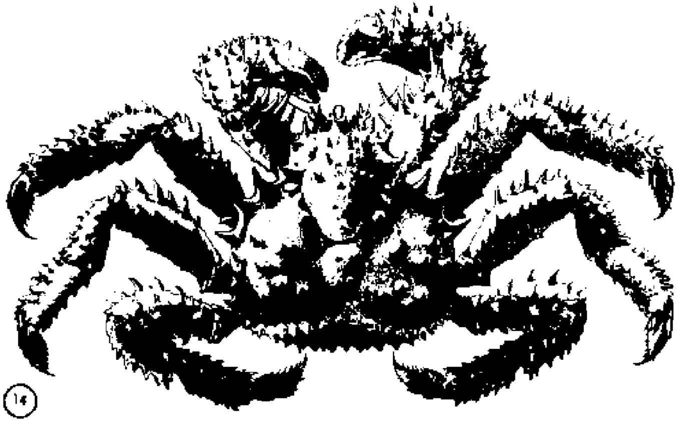
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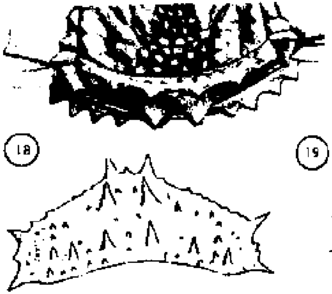
16

8(3) Rostrum inclined upwards, usually with distal part bent downwards, at least to some extent, towards the horizontal (fig. 9); one to 5 distinct, and usually enlarged, spines on each dorsal branchial area.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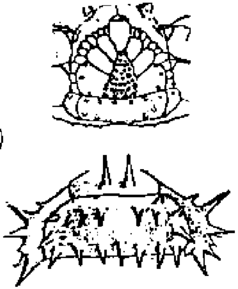
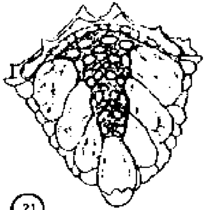

19

9(10) Third to 5th abdominal segments with calcified nodules (but not median plates) in median area, marginal plates free (i.e. not fused with corresponding laterals as in figs 21 male and 23) at least on right side (fig. 22 female); 2nd abdominal segment either entire or divided into 3 plates; rostrum usually elongate (fig. 20), armed dorsally (figs 24 and 25), always with basal spine (8 in fig.) and anterior projection (9 in fig.); scaphocerite usually rudimentary.........*Lithodes* Latreille, 1806 (fig. 20)


25


24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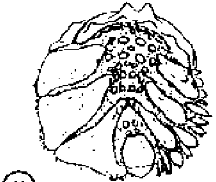
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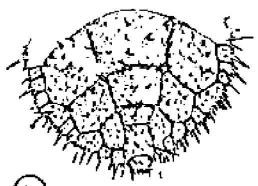
20

10(9) Third to 5th abdominal segments with median plates (often separated from one another by nodules as in fig. 26); 2nd abdominal segment entire; rostrum often consisting of basal spine only (i.e. without obvious anterior projection), usually armed dorsally and sometimes ventrally (figs 27-32); scaphocerite usually well developed.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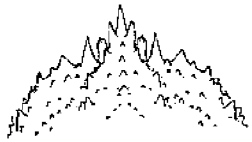
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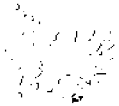
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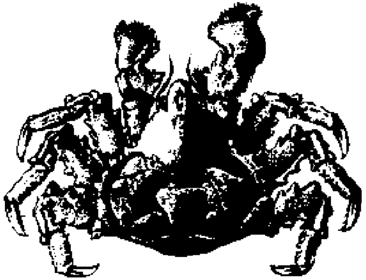
29

11(16) Carapace not calappid-like, i.e. usually not wider than long and not extending as roof over base of legs; median plates of 3rd to 5th abdominal segments usually separated from one another by a transverse row of nodules more or less fused together (fig. 33).


33

12(11) Rostrum club-shaped and bluntly rounded anteriorly (fig. 34); scaphocerite reduced, with a single terminal spine; 3rd to 5th abdominal segments with marginal plates free (i.e. not fused with corresponding laterals; at least on right side, 4th and 5th abdominal segments with median plates transversly divided into two and with small plates and nodules between the median plates (fig. 35)..*Sculptolithodes* Makarov, 1934 (fig. 34)


34

13(12) Rostrum acute with ventral swelling (fig. 36) or spines (fig. 37); scaphocerite truncate or elongate triangular with one or more lateral or terminal spines (figs 38-41); 3rd to 5th abdominal segments either with marginal plates free at least on right side (fig. 33), or with marginal plates of at least 3rd abdominal segment fused, or partly fused, with corresponding lateral plates (figs 42,43).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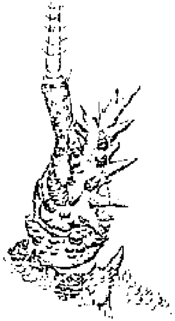
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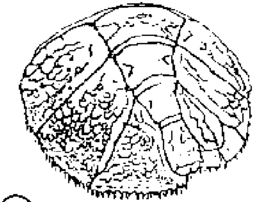
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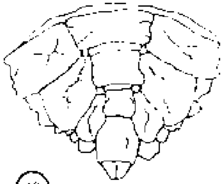
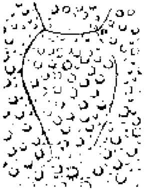

42

14(15) Cardiac area not separated from remainder of dorsal surface of carapace by distinct curved depression; carapace with granules (fig. 44), tubercles (fig. 45), short spines (fig. 46) or other ornamentation; rostrum short and generally armed with a pair of dorsal spines (fig. 47) as well as ventral tubercles (figs 36 and 37)......*Paralomis* White, 1858

(incl. *Acantholithus* Stimpson, 1858)

(fig. 46)


36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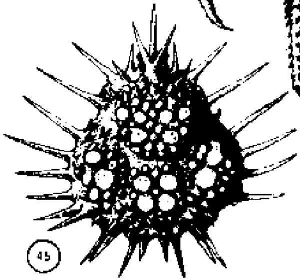
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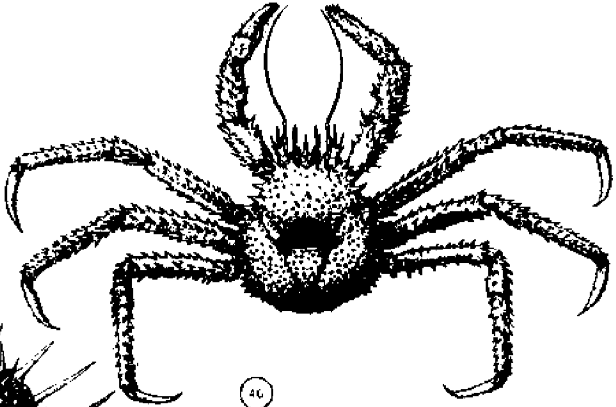
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47


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48

15(14) Cardiac area separated from remainder of dorsal surface of carapace by a distinct curved depression and enclosed within crescent-shaped, rounded branchial ridges, carapace with granules or tubercles, but not spines; rostrum short and unarmed dorsally . . . . . . *Glyptolithodes* Faxon, 1895

(fig. 48)

16(11) Carapace calappid-like, i.e. wider than long and more or less extending as roof over base of legs (figs 51,55,56).

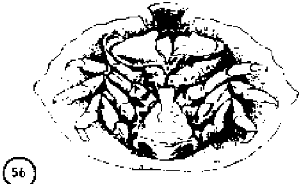
17(18) Rostrum short and conical, with one or more pairs of dorsolateral spines (fig. 50); lateral expansions of carapace do not fully cover legs in dorsal view (fig. 51), in some species legs can fold under carapace; scaphocerite triangular, with spines on edges and on some species on dorsal surface (fig. 52), marginal plates of 3rd abdominal segment fused or not fused to corresponding lateral plates, marginal plates on 4th and 5th not fused (figs 53,54)..................<u>Lopholithodes</u> Brandt, <u>July</u> 1848

(syn. <u>Echinocerus</u> White, <u>Nov</u>. 1848)

(fig. 49)


(51)


(55)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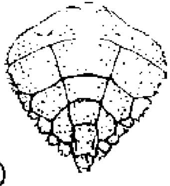
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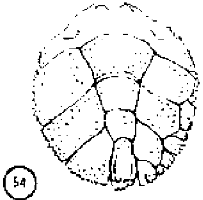
(54)


(52)


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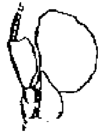
18(17) Rostrum broad, depressed and truncate, unarmed and down-curved (figs 55,56); lateral expansions of carapace cover legs completely, or almost completely, in dorsal view; scaphocerite broad and lamellate (fig. 57); marginal plates of 3rd to 5th abdominal segments fused to corresponding lateral plates (fig. 56)........................<u>Cryptolithodes</u> Brandt, 1848


(57)

19(2) Third to 5th abdominal segments (and also 2nd) with lateral plates having membranous areas occupied by calcified tubercles (fig. 59); scaphocerite produced into prominent foliaceous lobes (fig. 60); dorsal surface of carapace with two pits within triangular area surrounded by rounded, papillated tubercles............................<u>Phyllolithodes</u> Brandt, 1848 (fig. 58)


(59)


(60)


(55)


(56)


(58)

20(1) **Rostrum short and simple (fig. 62); abdomen usually in the form of a soft membranous sac (fig. 62), integument of 3rd to 5th segments poorly calcified but usually with thin plates (fig. 61); species usually small in size**...Subfamily HAPALOGASTRINAE

61

21(24) Lateral margins of branchial area armed with spines (fig. 62); abdomen swollen, 2nd abdominal segment usually with unpaired median plate and with paired lateral and marginal plates.

22(23) Carapace poorly calcified, with a network of non-calcified lines on the branchial area, without spines but hairy or pubescent, rostrum simple and unspined; one species with calcified nodules in place of median plate on 2nd abdominal segment, chelae move in horizontal plane; walking legs flattened with a series of teeth on anterior margins hidden in thick hair ....*Hapalogaster* Brandt, 1850

(Fig. 62)

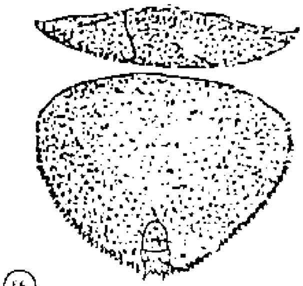
62

62

23(22) Carapace firmly calcified without any network of lines but with numerous subequal spines; rostrum spined dorsally and laterally (figs 64 and 65); all species with unpaired median plate on 2nd abdominal segment (fig. 66); chelae move in vertical plane; walking legs with long hairs from tips of spines.......................................*Acantholithodes* Holmes, 1895 (fig. 63)


64


65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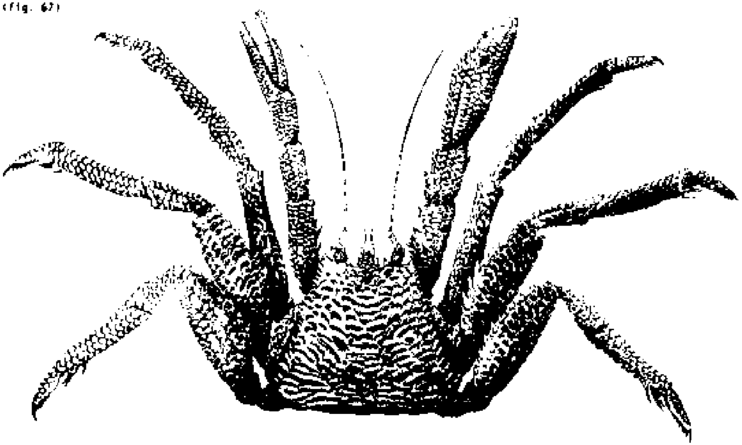
63

24(21) Lateral margin of branchial area of carapace unarmed; 2nd abdominal segment without median plate but with paired lateral plates (which may meet in midline suture) and marginal plates.

25(26) Carapace weakly calcified and flattened; carapace and appendages covered with transvere scale-like prominences; abdomen flattened, 2nd abdominal segment with fused marginal and lateral plates meeting in midline suture; chelipeds subequal with walking legs, elongate and not unduly swollen; walking legs long (more than twice carapace length)........................ ....*Placetron* Schalfeev, 1892

(fig. 67)



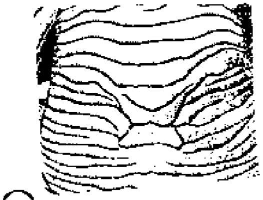
67

26(25) Carapace hard and swollen, with either large transverse "wrinkles" (fig. 68) or rounded squamous crests (fig. 69); abdomen swollen, 2nd abdominal segment with wide membranous median area between lateral plates (fig. 68); chelipeds short and swollen (figs 68,69); walking legs short (less than twice carapace length).

27(28) Surface of carapace and chelipeds with transverse "wrinkles"; scaphocerite depressed, straight and elongate; third maxilliped with two distal segments not dilated.............................<u>Dermaturus</u> Brandt, 1850 (fig. 68)

70

28(27) Surface of carapace with numerous small semi-circular squamae; chelipeds with prominent rounded tubercles; scaphocerite flat, crescent-shaped and granulated (fig. 70); third maxilliped with two distal segments dilated.. ....<u>Oedignathus</u> Benedict, 1894 (fig. 69)



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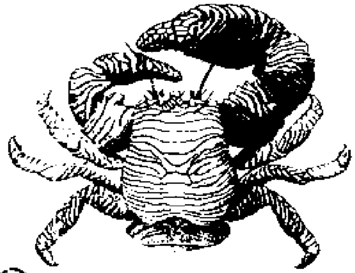

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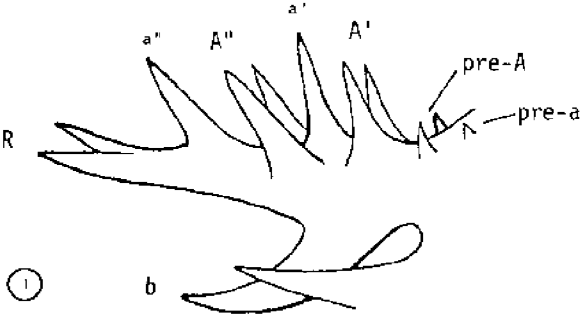
II: PROVISIONAL KEY TO SPECIES OF THE GENUS LITHODES

1(18) Rostrum terminally bifid in dorsal view, as in fig. 5 (the most forwardly-projecting part is the anterior projection of the rostrum - R, rather than the basal spine of the rostrum - B, see fig. 1).



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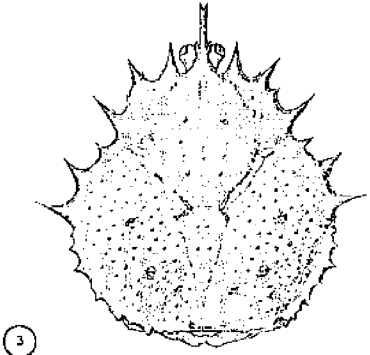
2(13) Rostrum armed dorsolaterally with a single pair of strong spines (A) in addition to the terminal bifurcation (fig. 7), a small pair of supernumerary spines (pre - A), may sometimes be present dorsolaterally at base of rostrum (see fig. 1); carapace usually with 2 pairs of gastric, and one or 2 pairs of cardiac spines (fig. 3)..the "L. tropicalis" group

Note: This key applies to adult specimens only. Specimens of Lithodes with carapace lengths (orbit to midpoint of posterior carapace margin) of less than about 50 mm (depending on the species) have the spines on the carapace, rostrum, and legs elongated and are referred to as "juveniles". The degree of elongation of spines on juveniles decreases with increasing size. In some cases, larger juveniles will key out if allowance is made for their "spiny" nature but careful comparison with published illustrations is essential for the satisfactory identification of juvenile specimens of Lithodes.

3(B) Rostrum inclined upwards, usually with distal part (i.e. that part anterior to dorsolateral spines) a straight continuation of proximal part (a slight recurving upwards of distal part may occur in some rostra), fig. 4; one, 4 or more distinct, and usually enlarged spines on each dorsal branchial area (i.e. excluding marginal branchial spines, fig. 3).



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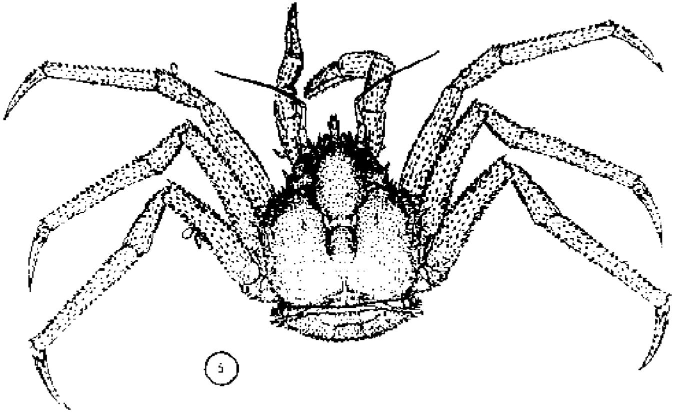
4(5) One pair of cardiac spines, one distinct spine on each dorsal branchial area; carapace with numerous closely-spaced spinules over surface including base of rostrum. ... .*Lithodes wiracocha* Haig, 1974 (off Peru; deepwater) (fig. 5)



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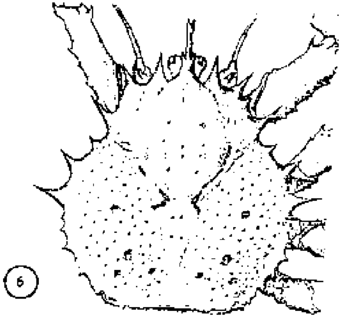
5(4) Two pairs of cardiac spines, though anterior pair may be greatly reduced in size (fig. 6); 4 or more distinct spines on each dorsal branchial area; carapace with scattered spinules and tubercles (not extending on to rostrum).



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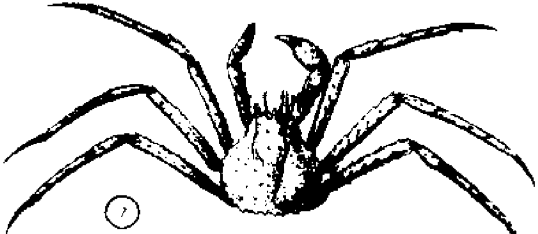
6(7) Anterior pair of cardiac spines subequal to posterior pair; 5 or more distinct spines on each dorsal branchial area; about 8-9 more or less subequal marginal branchial spines on each side (excluding intestinal pair, fig. 3)..................*Lithodes tropicalis* A. Milne Edwards, 1883
(off West Africa; deepwater)
(fig. 7)



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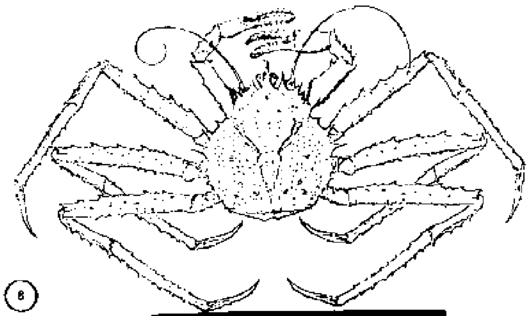
Footnote: *L. ferox* A. Milne Edwards, 1883 (fig. 20), known from West African deepwater specimens up to 55 mm in carapace length, is obviously a juvenile form recognizable at once by its slim, the elongated rostral spines and the numerous strong spines on carapace and legs. *L. ferox*, which might possibly be the juvenile of *L. tropicalis* known from the same area, can be distinguished from *L. maja*, and from juvenile *L. maja*, by the presence of 2 pairs of strong spines and some unpaired median tubercles on gastric area and by 2 pairs of strong spines and in addition anterior pair of smaller spines on cardiac area. In contrast *L. maja* has at least 2 pairs of weak spines and several unpaired tubercles on gastric area and has several pairs of weak spines on cardiac area. Sutures are present on 2nd abdominal segment between marginals and fused laterals and median plates in both *L. ferox* and juvenile *L. maja* but are absent in adult *L. maja*. Specimens of *L. maja* with carapace lengths 8, 12 and 15 mm have distinct sutures while specimens 23 mm and more have undivided 2nd abdominal segments.

7(6) Anterior pair of cardiac spines distinctly smaller than posterior pair, sometimes almost suppressed but always spinulate; usually only 4 distinct spines on each dorsal branchial area; about 10-13 marginal branchial spines on each side (excluding intestinal pair), anterior 3 usually distinctly larger than posterolateral series........................ ....<u>Lithodes</u> <u>nintokuae</u> Sakai, 1978

(Hawaiian Ridge and Emperor Seamounts, northern Central Pacific; deepwater)

(fig. 8)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8(3) Rostrum inclined upwards, usually with distal part bent downwards, at least to some extent, towards the horizontal (fig. 9); one to 5 distinct, and usually enlarged, spines on each dorsal branchial area.


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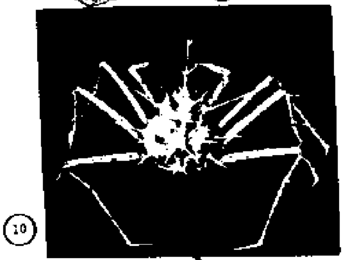
9(10) One pair of cardiac spines, with an anterior pair of cardiac tubercles sometimes present; 2 or 3 strong spines on each dorsal branchial area with some smaller spines; posterior half of carapace with 4 or more marginal branchial spines of differing sizes on each side of intestinal pair of spines, rostrum elongate but slender and with widely divergent, long terminal bifurcations.... ....<u>Lithodes</u> <u>longispina</u> Sakai, 1971

(North-west and Central Pacific, Japan to Midway Islands; deepwater)

(fig. 10)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10(9) Two pairs of cardiac spines, anterior pair may be greatly reduced but are always present as spines (Fig. 11); 2 to 5 distinct spines on each dorsal branchial area; rostrum elongate and with relatively short terminal bifurcations (Fig. 12).

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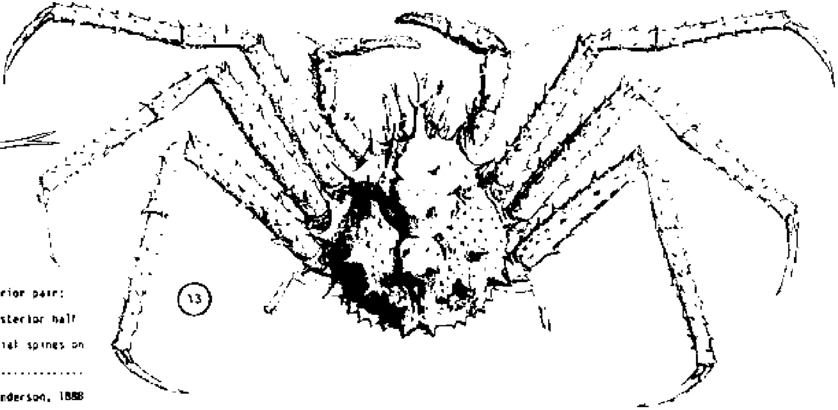

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11(12) Anterior pair of cardiac spines distinctly weaker than posterior pair: 2, 4 or 5 distinct spines on each dorsal branchial area; posterior half of carapace with 4 or more, relatively short marginal branchial spines on each side of intestinal pair of spines..*Lithodes murrayi* Henderson, 1888

(Southern Ocean, circumpolar; shallow and deepwater)

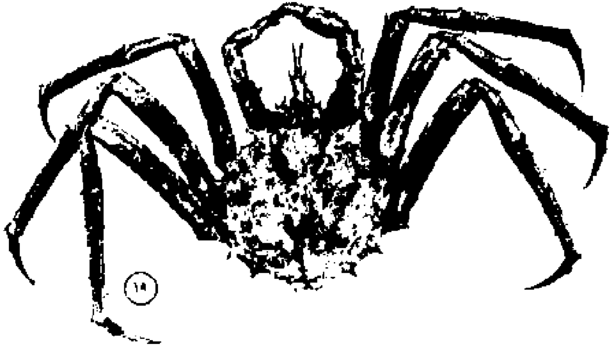
(Fig. 13)

12(11) Anterior pair of cardiac spines subequal with or stronger than posterior pair: 2 or 3 distinct spines on each dorsal branchial area; posterior half of carapace with 3 strong marginal branchial spines on each side of intestinal pair...............................*Lithodes turritus* Ortmann, 1892

(off Japan; shelf edge to deepwater)

(Fig. 14)

⑭



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13(2) Rostrum armed dorsolaterally with 2 or more pairs of spines in addition to terminal bifurcation (fig. 15); never with only 2 pairs of gastric and 2 pairs of cardiac spines, additional spines (either paired or unpaired) or tubercles present on both areas.

14(13) Rostrum armed dorsolaterally with 2 pairs of spines (pair near middle - A, longer than pair near base - pre-A), fig. 15; scaphocerite rudimentary (fig. 16) - the "L. *maja*" group.

15(16) Rostrum not armed dorsally with median unpaired spines; 2nd abdominal segment with sutures present between marginals and fused laterals and median plates (fig. 17)............................*L. couesi* Benedict, 1894

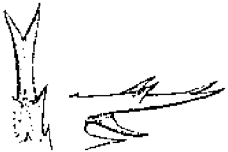
(North Pacific from Japan to Southern California; deepwater)

(Fig. 18)

16(15) Rostrum (fig. 15) armed dorsally with median unpaired basal spine (pre-A, fig 15); 2nd abdominal segment in adult specimens without sutures (i.e. marginals, laterals and median plates fused into single structure)............................... *Maja* Linnaeus, 1758

(North Atlantic, shallow and deepwater)

(Fig. 19)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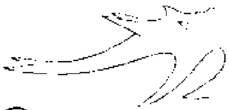
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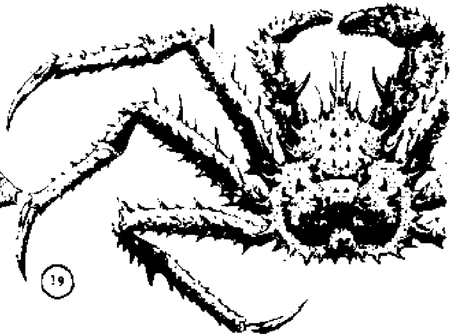
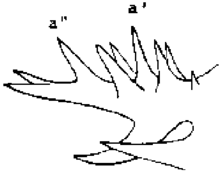

19

17(14) Rostrum armed dorsolaterally with three pairs of spines (two pairs near middle, A' and A" in fig. 1, subequal and larger than pair at base, pre-A) and two large unpaired dorsal spines (a' and a") as in fig. 21; scaphocerite well-developed (fig. 22) - the "L. *aequispina*" group........
....L. *aequispina* Benedict, 1894

(North Pacific from Japan to Bering Sea; deepwater)

(fig. 23)



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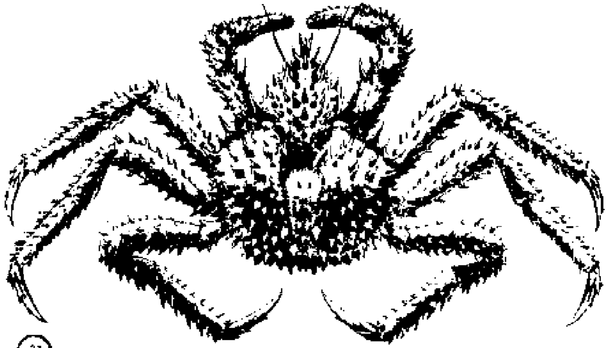
18(17) Rostrum not terminally bifid in dorsal view, rostrum appearing either simple (fig. 24) or trifid (fig. 25) - the "L. *antarcticus*" group.



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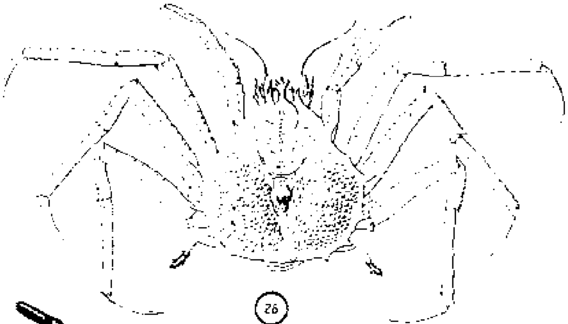
19(20) The most forwardly-projecting part of the rostrum (which appears trifid * terminally) is the anterior projection (A) consisting of a terminal and a pair of lateral spines; scaphocerite well-developed or rudimentary; cardiac area with one pair of spines; dorsal branchial area with 2 spines and numerous tubercles; 3 to 4 principal and a few lesser marginal branchial spines........................*L. panamensis* Faxon, 1893

(off Pacific coast of central and northern South America; deepwater)

(fig. 26)



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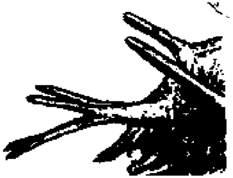

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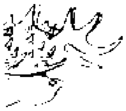
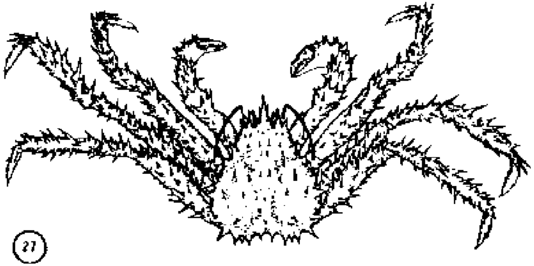
20(19) The most forwardly-projecting part of the rostrum is the basal spine (B) - aberrant specimens may appear trifid (two A spines with B); scaphocerite rudimentary; cardiac area with 2 subequal pairs of large spines and a smaller pair and/or, one or more single spine(s) posteriorly; dorsal branchial area with 10 or more subequal spines; 8 (or more) principal and more lesser marginal branchial spines..*L. antarcticus* Jacquinot, 1853

(southernmost South America; shallow water)

(fig. 27)





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* See "Postscript"

Acknowledgments

We are greatly indebted to those colleagues who received this contribution so well at its original presentation at the International King Crab Symposium, and to those, notably Dr M. Takeda (National Science Museum, Tokyo), Dr R. Ingle (British Museum (Natural History), London), Dr P.M. Arnaud (Station Marine d'Endoume, Marseilles), and Dr J.K. Lowry (The Australian Museum, Sydney) who assisted materially during a subsequent world tour in search of lithodids.

Additionally, one of us (EWD) wants to thank those new friends made at the International Symposium who offered assistance in so many ways towards a common goal - that of increased knowledge of that academically-fascinating and commercially-important group of marine animals, the king crabs of the world.

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"Postscript"

A letter from Dr Enrique del Solar of Lima, Peru, dated 15 May 1985, received after this manuscript was submitted, informs us that the coloured illustration of the side view of the rostrum of a juvenile *Lithodes panamensis* Faxon given by him in 1974 is an incorrect representation by the artist in that the most forwardly-projecting part of the rostrum is shown as a single spine. He assures us that at every stage of its growth (as illustrated in the figures on pages 7 and 9 of his 1981 paper), *L. panamensis* shows a bifid rostrum. We thank Dr del Solar for his valued comments on this problem. It seems, then, that Faxon's (1895 : Plate X, Figs 1, 1a, 1b) apparently trifid rostrum (see also Fig. 25 of our species key) may be of a damaged or otherwise aberrant specimen. However, Haig's (1974: 153) specimen from Peru is described as having a rostrum with a median and two lateral spines as in the holotype of *L. panamensis*. We repeat, therefore, the caution necessary in examining any specimens of a *Lithodes* which appears to have a trifid rostrum or in which the most forwardly-projecting part of the rostrum seems to be a single spine. Consideration must therefore be given to the sum of all the other features used in the identification of the Lithodidae (carapace spinulation, abdominal plates, scaphocerite, etc.) in trying to determine the identity of any specimen seemingly aberrant in rostral features.

Appendix I : Genera and Species of Lithodidae

(Type species indicated *)
Genera arranged in alphabetical order; species listed chronologically.

[+] Family LITHODIDAE
Subfamily Lithodinae

1. ACANTHOLITHUS Stimpson, 1858

**A. hystrix* (de Haan, 1849): Japan; shallow water and (?) New Zealand; deep water [also regarded as in *Paralomis*]

2. CRYPTOLITHODES Brandt, 1848

**C. typicus* Brandt, 1848: Aleutian Is to northern California; shallow water

C. sitchensis Brandt, 1853: southern Alaska to southern California; shallow water (low intertidal to at least 15 m)

C. expansus Miers, 1879: northern Japan, Korea; shallow water

3. GLYPTHOLITHODES Faxon, 1895

**G. cristatipes* (Faxon, 1893): Peru, Chile; deep water

4. LITHODES Latreille, 1806
[incl. *Pseudolithodes* of Birshtein & Vinogradov, 1972)

**L. maia* Linnaeus, 1758: Newfoundland to Spitzbergen(?), incl. U.K.; shallow to deep water

L. antarcticus Jacquinot, 1853: southernmost S. America; shallow water [incl. *P. zenkevitschi* Birshtein & Vinogradov, 1972]

L. ferox A. Milne Edwards, 1883: West Africa; deep water

L. tropicalis A. Milne Edwards, 1883: West Africa; deep water

L. murrayi Henderson, 1888: Southern Ocean, circumpolar (incl. New Zealand and Chile); shallow and deep water [incl. *P. pyriformis* Birshtein & Vinogradov, 1972 and *L. unicornis* Macpherson, 1984]

L. turritus Ortmann, 1892: Japan; deep water

L. panamensis Faxon, 1893: Baja California, Panama to Peru; deep water

L. aequispina Benedict, 1895: Japan to British Columbia deep water

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[+] Total: 16 genera, 78 species (largest is *Paralomis* with 30 species and *Lithodes* with 12; also to be included - *Neolithodes* n.sp. Dawson and Yaldwyn manuscript).

L. couesi Benedict, 1895: Japan to southern California; deep water

L. longispina Sakai, 1971: Japan, Central and South Pacific (Guam, New Caledonia, south-eastern Australia, New Zealand); deep water

L. wiracocha Haig, 1974: Peru; deep water

L. nintokuae Sakai, 1978: northern Central Pacific; deep water

5. LOPHOLITHODES Brandt, 1848
[incl. *Echinocerus* White, 1848 and *Ctenorhinus* Gibbons, 1855]

L. mandtii Brandt, 1848: southern Alaska to California; shallow water

L. foraminatus (Stimpson, 1859): British Columbia to southern California; shallow and deep water

L. diomedeae (Faxon, 1893): Panama to Peru; deep water

L. odawarai Sakai, 1980: Japan; deep water

6. NEOLITHODES A. Milne Edwards & Bouvier, 1894

N. agassizii (Smith, 1882): western N. Atlantic and Gulf of Mexico, and off Suriname and French Guiana; deep water

**N. grimaldii* (A. Milne Edwards & Bouvier, 1894): northern North Atlantic; deep water [incl. *Lithodes goodei* Benedict, 1895]

N. diomedeae Benedict, 1895: southern California, Mexico to Scotia Sea; deep water

N. capensis Stebbing, 1905: southern South Africa; deep water

N. asperrimus Barnard, 1946: southern South Africa; deep water

N. brodiei Dawson & Yaldwyn, 1970: New Zealand and south-eastern Australia; deep water

N. nipponensis Sakai, 1971: Japan; deep water

N. martii Birshtein & Vinogradov, 1972: south-western Atlantic; deep water

N. "alcocki" n.sp. Dawson & Yaldwyn MS: Indian Ocean (Bay of Bengal); deep water [= "*L. agassizii*" of "Investigator" authors]

7. PARALITHODES Brandt, 1848

P. camtschatica (Tilesius, 1815): Japan Sea to northern British Columbia; shallow and deeper water (to 250 m)

**P. brevipes* (A. Milne Edwards & Lucas, 1841): northern Sea of Japan to Bering Strait; shallow water

P. platypus (Brandt, 1850): Japan Sea to Alaska; shallow water

P. californiensis (Benedict, 1895): southern California; deep water

P. multispina (Benedict, 1895): British Columbia; deep water

P. rathbuni (Benedict, 1895): southern California; deep water

8. PARALOMIS White, 1849
[incl. *Leptolithodes* Benedict, 1895 and *Pristopus* Benedict, 1895]

P. granulosa (Jacquinot, 1852): southern S. America incl. Falkland Is [Malvinas]; shallow water [incl. *P. verrucosa* (Dana, 1852)]

**P. aculeata* Henderson, 1888: Crozet and Prince Edward Islands; deep water

P. formosa Henderson, 1888: southwest Atlantic; deep water

P. aspera Faxon, 1893: Panama to Peru; deep water

P. longipes Faxon, 1893: Columbia to Peru, and off San Diego; deep water

P. multispina (Benedict, 1895): Japan to Gulf of California; deep water

P. papillata (Benedict, 1895): Baja California to Peru; deep water

P. verrilli (Benedict, 1895): Japan to Baja California; deep water

P. indica Alcock & Anderson, 1899: south-eastern Arabian Sea; deep water

P. investigatoris Alcock & Anderson, 1899: south-eastern Arabian Sea; deep water

P. bouvieri Hansen, 1908: north-east Atlantic; deep water

P. spectabilis Hansen, 1908: North Atlantic and circum-Antarctic; deep water

P. dofleini Balss, 1911: Japan; shallow and deep water

P. japonica Balss, 1911: Japan [Sagami Bay only]; shallow water

P. cubensis Chace, 1939: West Indies; deep water

P. zealandica Dawson & Yaldwyn, 1971: south and central eastern New Zealand; deep water

P. longidactyla Birshtein & Vinogradov, 1972: South Atlantic, off Uruguay; depth unrecorded

P. spinosissima Birshtein & Vinogradov, 1972: South Georgia deep water

P. inca Haig, 1974: Peru;
deep water

P. medipacifica Takeda, 1974: western Central Pacific;
deep water

P. haigae Eldredge, 1976: Guam;
deep water

P. seagranti Eldredge, 1976: Guam;
deep water

P. pacifica Sakai, 1978: north-western Central Pacific;
deep water

P. cristata Takeda & Ohta, 1979: Japan;
deep water (to *Lopholithodes* *fide* Dawson & Yaldwyn)

P. chilensis Andrade, 1980: central Chile to Peru;
deep water (incl. *P. aspera* of del Solar, 1972, 1981; and Haig 1974)

P. hystrixoides Sakai, 1980: Japan;
deep water

P. truncatispinosa Takeda & Miyake, 1980: East China Sea;
deep water

P. roeleveldae Kensley, 1981: east coast South Africa;
deep water

P. africana Macpherson, 1982: south-east Atlantic off Namibia;
deep water

P. shinkaimaruae Takeda & Hatanaka, 1984: south-west Atlantic;
deep water

9. PHYLLOLITHODES Brandt, 1848
[incl. *Petaloceras* White, 1856]

**P. papillosus* Brandt, 1848: Aleutian Is to California;
intertidal and shallow water

10. RHINOLITHODES Brandt, 1848

R. biscayensis Milne Edwards & Bouvier, 1900: eastern Atlantic;
deep water

**R. wosnessenskii* Brandt, 1848: Alaska to California;
shallow water

11. SCULPTOLITHODES Makarov, 1934

**S. derjugini* Makarov, 1934: northern Sea of Japan;
shallow water

Subfamily Hapalogastrinae

1. ACANTHOLITHODES Holmes, 1895

**A. hispidus* (Stimpson, 1860): Alaska to southern California;
shallow water

2. DERMATURUS Brandt, 1850

**D. mandtii* Brandt, 1850: northern Sea of Japan to southern Alaska; shallow water

3. HAPALOGASTER Brandt, 1850

H. dentata (de Haan, 1850): Sea of Japan; shallow water

*_H. mertensii_ Brandt, 1850: Aleutian Is to Washington; shallow water

H. grebnitzkii Schalfeev, 1852: northern Sea of Japan to northern California; shallow water

H. cavicauda Stimpson, 1878: Washington and northern California and Mexico (one record); shallow water (intertidal to at least 15 m)

4. OEDIGNATHUS Benedict, 1895

*_O.inermis_ (Stimpson, 1860): Korea and Japan to California; shallow water (intertidal) [incl. _O. gilli_ Benedict, 1895: Alaska]

5. PLACETRON Schalfeev, 1892
[incl. _Lepeopus_ Benedict, 1895]

*_P. wosnessenskii_ Schalfeev, 1892: Aleutian Is to Washington; intertidal and shallow water

P. forcipatus (Benedict, 1895): British Columbia; shallow water [sometimes regarded as synonymous with the previous species]

Appendix II : Synonyms and Names in the Lithodidae

A. Genera

Acantholithodes Holmes, 1895 = *Dermaturus* Brandt, 1850
Ctenorhinus Gibbons, 1855 = *Lopholithodes* Brandt, 1848
Echinocerus White, [Nov. 14] 1848 = *Lopholithodes* Brandt, [June 29] 1848
Lepeopus Benedict, 1895 = *Placetron* Schalfeev, 1892
Leptolithodes Benedict, 1895 = *Paralomis* White, 1849
Petaloceras White, 1856 = *Phyllolithodes* Brandt, 1848
Pristopus Benedict, 1895 = *Paralomis* White, 1849
Pseudolithodes Birshtein & Vinogradov, 1972 = *Lithodes* Latreille, 1806

B. Species

Cancer spinosus Ascanius, 1776 = *Lithodes maia* Linnaeus, 1758
Cryptolithodes alta-fissura Bate, 1864 = *C. sitchensis* Brandt, 1853
Cryptolithodes brevifrons Miers, 1879 = *C. typicus* Brandt, 1848
Ctenorhinus setimanus Gibbons, 1855 = *Lopholithodes mandtii* Brandt, 1848
Echinocerus cibarius White, [Nov. 14] 1848 = *Lopholithodes mandtii* Brandt, [June 29] 1848
Hapalogaster brandtii Schalfeev, 1892 = *Oedignathus inermis* (Stimpson, 1860)
Lepeopus forcipatus Benedict, 1895 probably = *Placetron wosnessenskii* Schalfeev, 1892
Lithodes arctica Lamarck, 1818 = *L. maia* Linnaeus, 1758
Lithodes goodei Benedict, 1895 = *Neolithodes grimaldii* (Milne Edwards & Bouvier, 1894)
Lithodes spinosissimus Brandt, 1848 = *Paralithodes camtschatica* (Tilesius, 1815)
Lithodes unicornis Macpherson, 1984 probably = *L. murrayi* Henderson, 1888
Maia vulgaris Bosc, 1802 = *Lithodes maia* Linnaeus, 1758
Oedignathus gilli Benedict, 1895 = *O. inermis* (Stimpson, 1860)
Paralithodes longirostris Navozov-Lavrov, 1929 = *Lithodes aequispina* Benedict, 1895
Paralithodes rostrofalcatus Mackay, 1932 = *P. camtschatica* (Tilesius, 1815)
Paralomis verrucosa (Dana, 1852) = *P. granulosa* (Jacquinot, 1852)
Petaloceras bellianus White, 1856 = *Phyllolithodes papillosus* Brandt, 1848
Phyllolithodes bicornis Bate, 1866 = *P. papillosus* Brandt, 1848
Pseudolithodes zenkevitschi Birshtein & Vinogradov, 1972 = *Lithodes antarcticus* Jacquinot, 1853
Pseudolithodes pyriformis Birshtein & Vinogradov, 1972 = *Lithodes murrayi* Henderson, 1888

C. Vernacular Names

Aburagani = *Paralithodes platypus*
Abura-tarabagani = *Paralithodes platypus*
Alaska(n) crab)
Alaska(n) king crab) = *Paralithodes camtschatica*
Ao-tarabagani = *Paralithodes platypus*
Blue king crab = *Paralithodes platypus*

Box crab = *Lopholithodes foraminatus* and *L. mandtii*
Butterfly crab = *Cryptolithodes typicus*
Centolla = *Lithodes antarcticus* and *L. murrayi*
Centolla del Sur = *Lithodes antarcticus*
Centollon = *Paralomis granulosa*
Crabbe épineux (of Ascanius, 1775) = *Cancer spinosus* (*fide* Desmarest, 1825) = *Lithodes maia*
Deep-sea king crab = *Lithodes couesi*
Deep-sea red crab = *Lithodes couesi*
Eri-tarabagani = *Sculptolithodes derjugini*
Ezo-ibaragani = *Paralomis multispina*
Gokaku-ezoibaragani = *Paralomis verrilli*
Golden king crab = *Lithodes aequispina*
Gray-bearded crab = *Rhinolithodes wosnessenskii*
Furry crab = *Hapalogaster cavicauda*
Hairy crab = *Dermaturus hispidus*
Hanasakigani = *Paralithodes brevipes*
Hari-ibaragani = *Lithodes longispina*
Hiraashi-ezoibaragani = *Paralomis cristata*
Hokuyou-ibaragani = *Lithodes aequispina*
Ibaragani = *Lithodes turritus*
Ibaragani-modoki = *Lithodes aequispina*
Ibo-ezoibaragani = *Paralomis truncatispinosa*
Ibo-gani = *Oedignathus inermis*
Igagurigani = *Paralomis* [*Acantholithus*] *hystrix*
Kamchatka crab = *Paralithodes camtschatica*
Kamchatskiy krab = *P. camtschatica*
Kita-ibaragani = *Lithodes couesi*
King crab = (generally) *Paralithodes camtschatica*
Kofuki-ezoibaragani = *Paralomis japonica*
Koluchiy krab = *Paralithodes brevipes*
Kraboid Deryugina = *Sculptolithodes derjugini*
Maia araignée (of Latreille, 1802) = *Lithodes maia*
Minamibara = *Lithodes murrayi*
Minamibaragani = *Lithodes murrayi*
Morshchinistiy krab = *Dermaturus mandtii*
Naigae-eorige = *Cryptolithodes expansus*
Nihon-ibaragani = *Neolithodes nipponensis*
Noduled crab = *Lopholithodes mandtii*
Pararomisu beriri = *Paralomis dofleini*
Podkamenschik Grebnitskogo = *Hapalogaster grebnitzkii*
Red king crab = *Paralithodes camtschatica*
Siniy krab = *Paralithodes platypus*
Sitka crab = *Cryptolithodes sitchensis*
Siwa-gani = *Dermaturus mandtii*
Stone crab = King crab (but in USA = *Menippe mercenaria* Say, Brachyura: Xanthidae)
Syojo-gani = *Hapalogaster grebnitzkii*
Tarabagani = *Paralithodes camtschatica*
Taragani = king crab (generally)
Trold Krabber)
Troll krab) = *Lithodes maia*
Tsubu-ezoibaragani = *Paralomis dofleini*
Turtle crab = *Cryptolithodes sitchensis* and *C. typicus*
Umbrella crab = *Cryptolithodes sitchensis*
Urokogani = *Placetron wosnessenskii*

SESSION II

LIFE HISTORY

Proc. Int. King Crab Symp.
Jan. 1985, Anchorage, Ak.

Reproductive biology of blue king crab, *Paralithodes platypus*, in the Pribilof Islands

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As part of an OCSEAP funded investigation of blue king crab (*Paralithodes platypus*) biology in the Pribilof Islands, a study was conducted on the reproductive cycle of this little known species. Previous studies are in general agreement that the reproductive cycle differs from that of its better known relative, *P. camtschatica* (Sasakawa 1973, 1975a; McIntosh, Otto and Fukuyama 1979; Somerton and McIntosh, 1982). *P. camtschatica* females produce eggs annually; females molt and mate and extrude a new clutch of eggs in spring soon after eggs of the previous year hatch. (Wallace et al 1949). However, large biennial decreases in the number of ovigerous female *P. platypus* have been reported (Otto et al. 1979; McIntosh et al. 1979) and, consequently, a two year reproductive cycle has been postulated for this species. Sasakawa (1973, 1975a) concluded from tagging experiments in the western Bering Sea that the reproductive cycle consists of a 19 month ovigerous period (time of embryonic development) followed by a five month period between hatch of old eggs and extrusion of new ones. Somerton and McIntosh (1982) in studies of blue king crab in Olga Bay, Kodiak Island, found evidence that females were ovigerous for about 12 months; in addition, some females appeared to be reproductively active for two years in a row. Otto et al. (1979) reported that most crab in the 101-110 mm size interval (first time spawners or primiparous females) reproduce annually, but that a radical biennial decrease in the number of ovigerous females starts at 111-115 mm.

Materials and Methods

Female blue king crabs were sampled aboard the NOAA ship MILLER FREEMAN in May and August of 1983 and April of 1984, using a three meter beam trawl. Carapace length, weight, and shell condition were recorded for all adult females; codes for shell condition were according to the

National Marine Fisheries "Manual of Crab Sampling" (1979) where code #1 equals "soft shell," #2 is a new shell, #3 is an old shell, and #4 is a skip molt (very old shell). Egg condition and clutch size were noted for ovigerous specimens. Specimens sacrificed for analysis were dissected onboard as time allowed or frozen for later processing. Small egg and ovary samples were fixed in Bouin's solution and later transferred to 70% ethanol. The remaining eggs, ovary, and body were dried to constant weight in drying ovens at 50°C.

Egg samples were examined under a dissecting scope and their development compared to the stages illustrated for Paralithodes camtschatica in Marukawa (1933). Ovary samples were embedded in Paraplast and sectioned on a microtome using standard histological techniques (Preece 1965). Sections were cut at 6 μm, and stained with Weigerts hematoxylin and eosin Y.

Ova diameters were measured using an ocular micrometer on a compound microscope at 100x magnification; only the largest and roundest ova were measured and the average diameter calculated. The gonosomatic (GS) index, expressing ovary weight as a percentage of the total body weight, was calculated by dividing the dried ovary weight by the total dried body weight and multiplying by 100.

Results

May 1983

A total of 64 female blue king crab were collected on the May cruise; of these, 35 specimens (including 14 of 15 ovigerous females) were dissected for study. Of the 15 ovigerous specimens, 12 had newly extruded eggs and clean, new shells (shell 2); the three remaining animals carried either eyed or hatching eggs and had fairly old shells (shell 3). All non-ovigerous adult females were shell 3 or 4 and had empty egg cases.

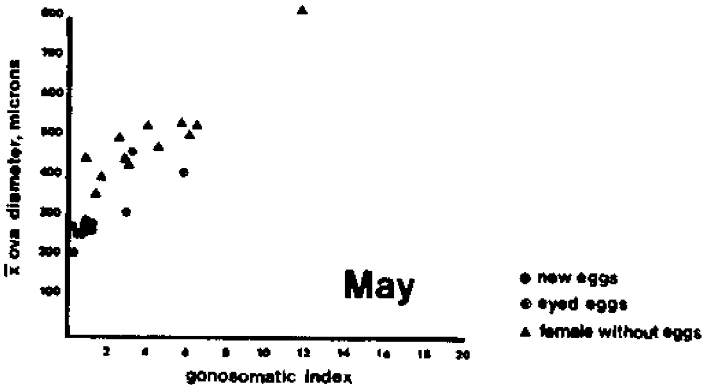

Fig. 1. Summary of reproductive information for female Paralithodes platypus; May, 1983

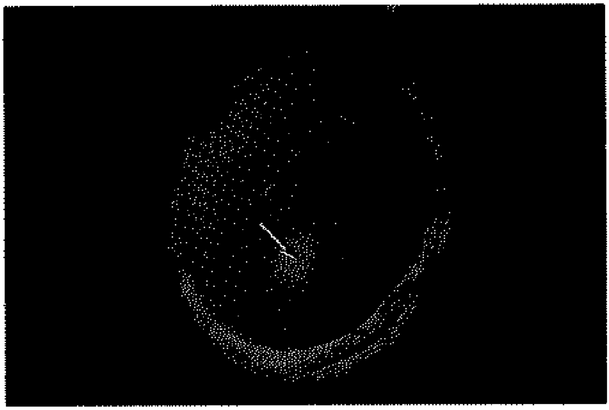

Fig. 2. Egg from a new shell female blue king crab taken in May, 1983, showing initial invagination. INV-invagination

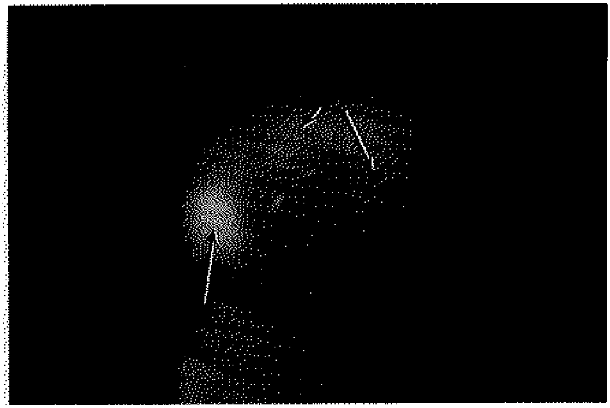

Fig. 3. Egg from a new shell female blue king crab taken in May, 1983; cephalic lobes beginning to appear. CL-cephalic lobes; INV-invagination

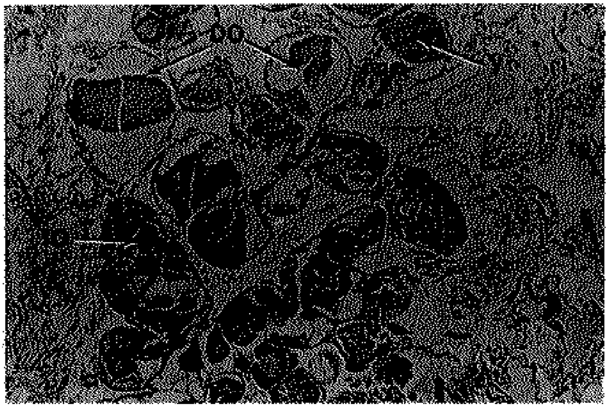

Fig. 4. Section of ovary from a female blue king crab taken in May of 1983 and carrying a newly extruded egg mass. Only immature and degenerating ova and connective tissue remain. DO-degenerating ova; IO-immature ova; Y-yolk

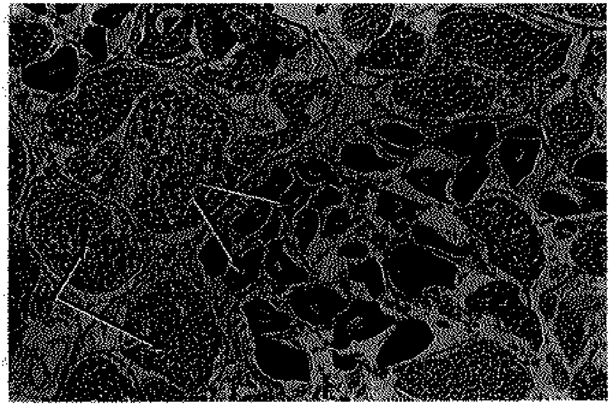

Fig. 5. Section of developing ovary from female blue king crab caught in May of 1983 and carrying eyed eggs. IO-immature ova; Y-yolk

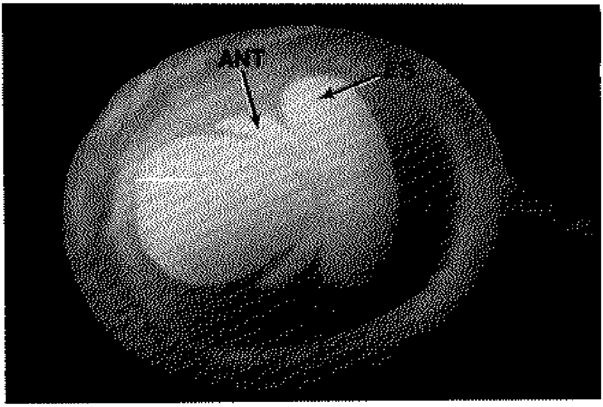

Fig. 6. Egg from a female blue king crab caught in August of 1983, showing embryo with prominent eyestalks and antennae. ES-eyestalk; ANT-antenna

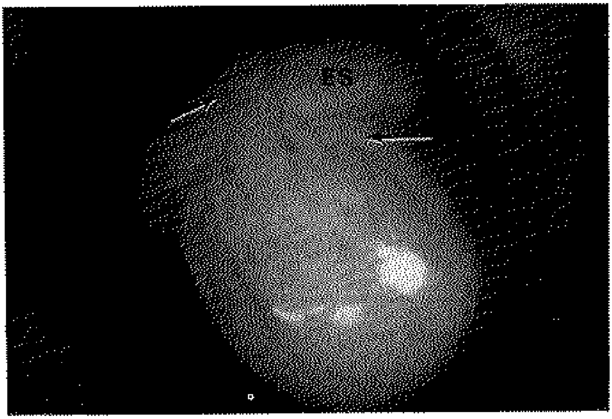

Fig. 7. Egg from a female blue king crab taken in August, 1983. Large embryo with well-developed telson. ES-eyestalk; T-telson; MXP-maxilliped

The data from the May crabs is summarized in Figure 1. Ovigerous females with newly extruded eggs had very thin, white ovaries; the GS index for these animals averaged 0.9% (s.d.= 0.4%), while those with eyed eggs had small pink ovaries with GS index values of 4.1% (s.d.= 1.6%). The remaining category with old shells and empty egg cases averaged 3.7% (s.d.= 1.9%), while a single specimen in pre-molt condition had a value of 12.1%.

Examination of eggs from new shell females revealed several stages of early development, from invagination (Figure 2) to the appearance of two cephalic lobes (Figure 3). Eyed eggs were fully developed and some were in the process of hatching.

Histological examination of the ovaries revealed that crabs with new eggs had only immature and fragmented, degenerating ova remaining (Figure 4), with a mean diameter of 246 um (s.d.= 32 um). Those with eyed eggs had developing ova with some yolk (Figure 5), and were 300-450 um (X =388 s.d.= 72) in diameter. Ova of old shell crabs with empty egg cases were generally between 300 and 500 um (X =444 s.d.= 76), also with yolk. The single pre-molt specimen had large, yolk-filled ova averaging over 800 um in diameter.

August 1983

Only 30 adult female blue king were captured on the August cruise. Of these, all five ovigerous specimens and 17 others were dissected for study. Those with eggs had clean, fairly new shells and were catagorized as shell 2; the remaining specimens all had old shells (shell 3) and carried empty egg cases (Table 1).

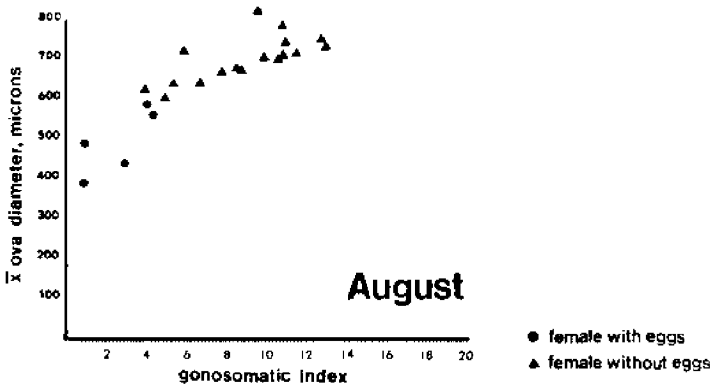

Fig. 8. Summary of reproductive information for August, 1983.

The GS index for the 5 ovigerous specimens averaged 2.7% (s.d.= 1.67%) compared to 9.0% (s.d.= 2.77%) for the non-ovigerous females. Egg development varied from embryos with well developed cephalic lobes and antennae (Figure 5) to large embryos with a fully developed telson (Figure 6). Ova diameters in the nonovigerous August specimens varied from 600-800 um (X =682 s.d.= 55.6), while those of the ovigerous females were 400-600 um (X =487 s.d.= 79) (Figure 8). Ovaries of

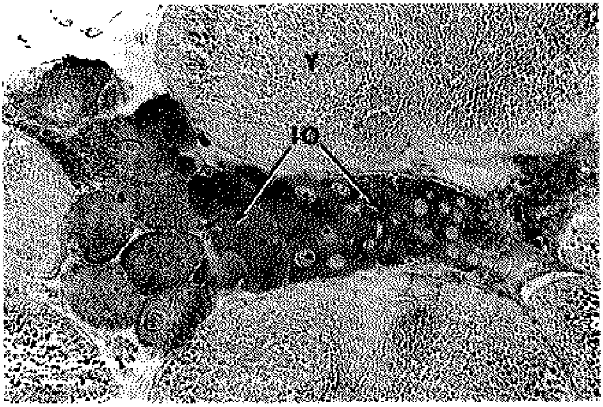

Fig. 9. Section from a developing female blue king crab ovary showing large, well-developed ova with yolk and small, non-vittelogenic ova. IO-immature ova; Y-yolk

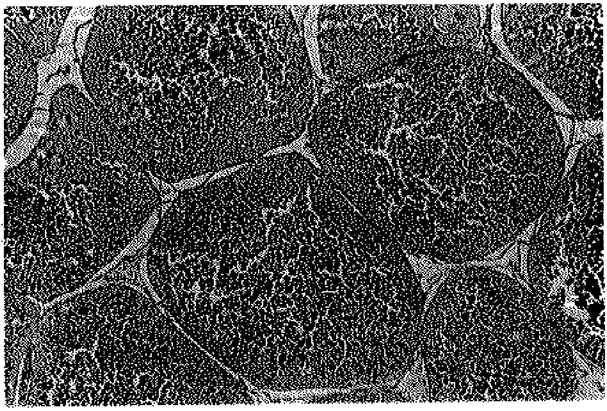

Fig. 10. Example of a large, fully developed ovary from a blue king crab. August, 1983.

	Egg condition	x carapace length	GS index ± S.D.	No.	Total no.
May	Eyed eggs or empty cases	118.2 ± 9.7	3.7 ± 1.8	[illegible]	67
	New eggs	122.9 ± 9.0	0.9 ± 0.4	10	12
August	No eggs	120.5 ± 10.0	9.9 ± 2.8	17	26
	With eggs	126.0 ± 16.3	2.7 ± 1.7	5	5
April	New eggs	117.9 ± 10.0	1.0 ± 0.3	8	54
	Eyed eggs	124.9 ± 9.2	3.5 ± 0.9	[illegible]	45
	Eyed eggs	111.9 ± 10.7	10.8 ± 2.2	6	9

Table 1. Egg condition and gonosomatic indices for Pribilof Island blue king crab

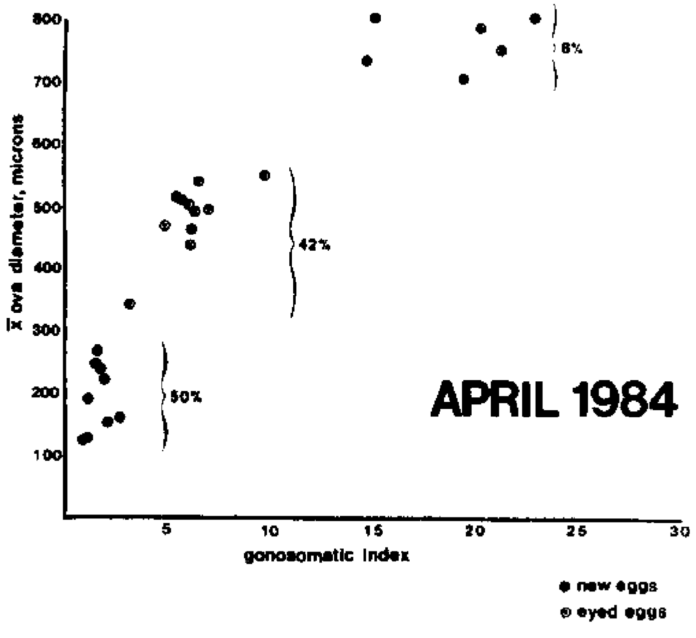

Fig. 11. Summary of reproductive information for female blue king crab; April, 1984

both types were composed of large, developing ova with yolk and immature, non-developing ova (Figures 9, 10).

April 1984

April sampling netted a total of 123 female crabs ranging from 78-145 mm.; 28 specimens were dissected. Of 110 ovigerous specimens, 57 had new shells and newly extruded egg masses and 53 were old shell and carried eyed eggs. Only one specimen had empty egg cases. Examination of the ovaries of specimens carrying eyed eggs revealed two separate groups, composed of specimens with small ovaries and others with large, well developed ovaries. Specimens with poorly developed ovaries tended to be larger (X= 124.9 s.d.= 9.7 mm) with a mean gonosomatic index of 3.5 (s.d.= 0.9); ova diameters averaged 486 um (s.d.=59). The other category, comprising only 8% of ovigerous females caught, had large ovaries (GS index 10.8 s.d.= 2.2; X ova diameter 766 um s.d.=40.9) and were in a premolt condition; these were generally smaller specimens (x = 111.9 s.d.= 10.7 mm) (Figure 11).

Discussion

Histological examination of ovaries taken from female blue king crab in May and August of 1983 and in April, 1984 revealed two distinct stages of reproductive growth for each sampling period. The presence of two radically different stages would be expected in a species with biennial reproduction because all individuals will not reproduce in the same year; consequently, at any time one would find two different reproductive stages separated by one year. The differences observed in the histological examinations were correlated with shell condition, egg condition, and the gonosomatic index to give the following scenario for oogenesis.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SHELL CONDITION				3				3					4		MOLT		2			2				
GS INDEX				3-6%				6-12%									0.1-1%			3-6%				
OVA DIAMETER				4-500µ				7-800µ									1-300µ			4-500µ				
EGG CONDITION				eyed/hatch				empty egg cases									new			antenna eyestalks				

Table 2. Timing of reproductive events over a two year period for large female blue king crab in the Pribilof Islands

Oogenesis

Females taken in May with new shells and newly extruded egg masses had thin, white ovaries which comprised only 1% of their total body weight.

These ovaries consisted primarily of connective tissue, accessory cells, immature ova and degenerating ova. Immature ova appeared to remain intact, possibly for subsequent years, while those that had undergone vitellogenesis but did not reach full size degenerated and were reabsorbed.

By August, the ovaries of ovigerous females had reached 3% of the total weight and were brown or pink in color; the ova were nearly 500 um in diameter and contained yolk. By April of the following year, the eggs were eyed and hatching but the ovary had increased very little in size over the winter, composing only 3.5-4% of the body weight. These animals were at the same stage in the reproductive cycle as those with eyed eggs or empty egg cases caught the previous May. As fall and winter are reported to be periods of reduced feeding activity in *Paralithodes camtschatica* (Feder and Jewett, 1980); it is likely that this is also a period of reduced feeding activity (and gonadal growth) for *P. platypus*.

The old shell females with empty egg cases taken in August represented the next stage of this cycle. The ova were large (700 um) and yolk-filled, and the ovary purple in color and 10% or more of the total dry weight. Again, gonadal growth remained relatively dormant through the winter until the animal molted and extruded eggs the following spring, as the mean ova diameter of specimens about to extrude eggs was 766 um.

Embryonic development

New, purple egg masses examined in May 1983 were in various stages of early development, from invagination to the appearance of two cephalic lobes. By August well developed embryos with eyestalks and antennae were visible; the larger ones had a well developed telson. The rate of development throughout the summer is approximately the same as that described by Marukawa (1933) for *P. camtschatsca*, thus, the 19 month ovigerous period proposed by Sasakawa (1975a) is not applicable to Pribilof Island blue king crab. Rather, it appears that egg development of blue king crab follows the same schedule as that for red: extrusion in the spring about late April to mid May; hatch the following spring in April. The timing of these events and the relationship to ovarian development and shell condition over a two year period are summarized in Table 2.

Based on histological evidence and shell condition, only one of the specimens collected in 1983 showed any sign of possibly reproducing two years in a row. However, relatively few small, reproductively active females were caught in 1983. In April of 1984 nearly all small females bearing eyed eggs had large ovaries and were clearly ready to molt and reproduce again. The mean carapace length of these specimens was 111.9 mm compared to 124.9 mm for those with eyed eggs and undeveloped ovaries. This is consistent with the findings of Otto et al. (1979) who reported that 101-110 mm crab reproduced annually and biennial reproduction started with 111-115 mm females.

It is apparent that biennial reproduction in large female blue king crab is due to an inability to produce a fully developed ovary in one year. Why they are unable to do this is not clear. Large ovigerous female red king crab (X=149 mm c.l.) from the same area in April, 1984, had large ovaries and were in a pre-molt condition; thus, reduced feeding activity due to cold water temperatures seems an unlikely explanation.

It has been noted that many biennially reproducing species have additional energy expenditures, such as breeding migrations or egg brooding, which may make irregular or biennial reproduction advantageous (Bull and Shine 1979). Although we found no evidence of extensive migrations in female blue king crabs, this theory cannot be fully discounted.

Ovarian growth of egg bearing females throughout the summer was somewhat less than in those without eggs, increasing an average of 2.4% of the total body weight compared to an increase of 6% for non-ovigerous specimens. It is possible that the presence of an egg clutch may physically or behaviorally inhibit feeding activity, resulting in reduced growth.

Acknowledgements

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Observations on the reproductive biology of golden king crab *(Lithodes aequispina)* in the Bering Sea and Aleutian Islands

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Abstract

Detailed research on golden king crab biology began in 1981 in response to the growing contribution of this species to western Alaskan king crab landings. Much of the data described were collected through cooperation with the fishing industry. Available information on the size at maturity and the timing of spawning are presented. Results show that: 1) spawning occurs over a protracted period extending at least from February to August, 2) there is an appreciable lag time between hatching and extrusion of a subsequent clutch of eggs, 3) there are differences in reproductive biology of crab from closely adjacent areas, and 4) the biotic potential of golden king crab is considerably less than that of Paralithodes spp. Results are discussed in the light of their management consequences.

Introduction

The golden king crab (Lithodes aequispina) is a large lithodid crab generally found at depths from 200 to 800 m in the North Pacific from British Columbia to Japan (Butler and Hart 1962, Suzuki and Sawanda 1978). Prior to 1981, there were small localized fisheries for this species in southeastern Alaska and in Japan. Golden king crab were also taken incidentally in fisheries for red king crab (Paralithodes camtschatica) and blue king crab (P. platypus) that provided the majority of Alaskan king crab landings. With the drastic declines in abundance of the latter two species, golden king crab fisheries in western Alaska developed rapidly (Table 1). Over the past three fishing seasons, golden king crab have provided 37.8 percent of landings, as opposed to 3.6 percent for the years 1975 to 1984. Prior to the advent of directed fisheries, there was little biological research on golden king crab and none in the Bering Sea-Aleutian Islands areas.

Table 1. Reported catches of various king crabs from the Eastern Bering Sea and Aleutian Islands, 1975-1984 (metric tons)[1]

Fishing	P. Camtschatica		P. platypus		L. aequispina		Total
Season[2]	Weight	%	Weight	%	Weight	%	Weight
1975-76	30,684	96.5	1,104	3.5	11	0.0	31,799
1976-77	33,620	91.8	2,999	8.2	1	0.0	36,620
1977-78	34,066	90.7	3,474	9.2	21	0.0	37,561
1978-79	44,160	92.1	3,801	7.9	0	0.0	47,961
1979-80	57,302	95.2	2,815	4.7	10	0.0	60,127
1980-81	69,187	93.1	5,076	6.8	27	0.0	74,290
1981-82	19,573	74.0	6,269	23.7	598	2.3	26,440
1982-83	2,647	20.6	6,010	46.7	4,201	32.7	12,858
1983-84[3]	1,062	9.4	5,307	46.9	4,945	43.7	11,314
1984-85[4]	2,653	36.9	1,846	25.6	2,699	37.5	7,198
TOTAL	294,954	85.2	38,701	11.2	12,513	3.6	346,168

[1] Adapted from Alaska Department of Fish and Game (1984); accuracy to the nearest ton and 0.1 percent; percentages may not total to 100 due to rounding.

[2] Seasons generally start in the fall and frequently continue into early spring.

[3] Fisheries for P. camtschatica were closed in Bristol Bay and Dutch Harbor during the 1983-84 season due to extremely low stock abundance.

[4] Preliminary data.

In 1981, the National Marine Fisheries Service (NMFS) began research on the biology of golden king crab in western Alaska. Most data were collected during trawl surveys and by placing biologists aboard commercial fishing vessels in widely separated localities (Fig. 1). Data consisted of standard morphometric measurements, observations of embryo development, geographic distribution and relative abundance. Ovaries and clutches of developing embryos (external eggs) were also collected. Somerton and Otto (in press) presented the findings of research conducted from 1981 to 1983. In the present report we provide a preliminary analysis of data collected during 1984 from the Aleutian Islands.

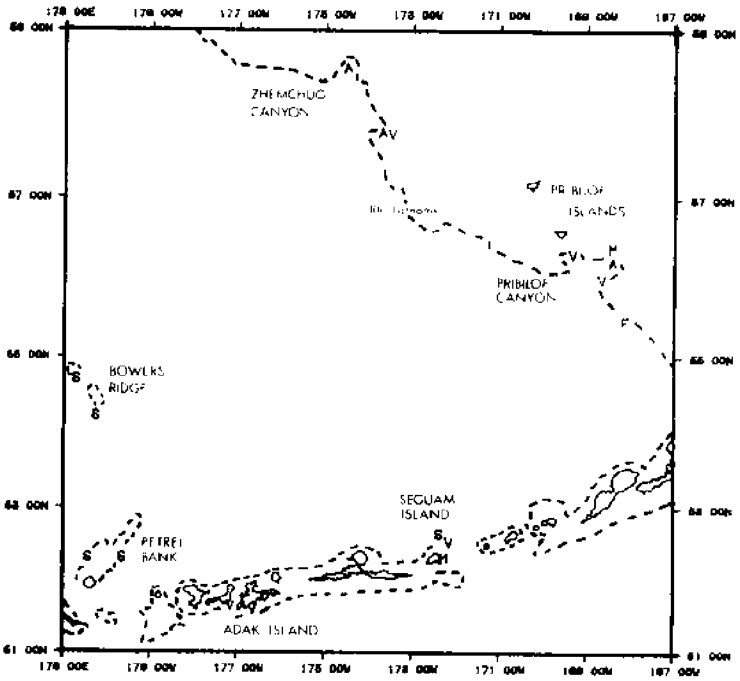

Fig. 1 Localities where golden king crab have been collected during NMFS research. Vessels were: F/V Valiant (V), R/V Miller Freeman (F), F/V American Eagle (A), F/V Morning Star (M) and F/V Starlite (S). Results from the F/V Starlite (June 10 to July 10, 1984) are reported here and other collections by Somerton and Otto (in press).

Materials and Methods

A commercial crab-fishing vessel (36 m) was chartered during June and July (June 10 to July 10) for the purpose of tagging golden king crab. During the course of the tagging operations we were able to make observations on the reproductive biology of golden king crab from Bowers Ridge, Petrel Bank and near Seguam Island (Seguam Pass). Crabs were captured in steel-framed king crab pots (2.1 x 2.1 x 0.9 m) with 5.0 cm (bar measure) tarred nylon mesh. Pots were fished at depths ranging from 150 to 700 m. Pots were set in "strings" of ten each with spacing of about 0.3 km between pots. Depths were recorded at the center of each string.

Catches were sorted by species and sex before individual crab were measured (Fig. 2). The presence of snailfish (cyclopteridae) eggs in branchial chambers and rhizocephalans (Briarosaccus callossus) attached to the ventral surface of the abdomen was also noted. Males were tagged with vinyl tubing threaded between the carapace and first abdominal somite (Gray 1965). Females were categorized according to the appearance of their pleopods or attached embryos: stage 1 (immature, clean setae), stage 2 (new eggs, yellow-orange with no discernible eye pigmentation), stage 3 (new-eyed eggs, embryos with crescent-shaped eye pigmentation but no other discernible development), stage 4 (more advanced embryos) and stage 5 (egg remnants and funiculi attached to pleopods). Masses of eggs were considered complete ("full clutch") if all pleopods were covered and there was no evidence of hatching. Full clutches were collected from selected stage 1 and stage 4 females. Whole ovaries were collected from females in each stage. A special collection of ovaries was made from females when hatching larvae were observed. Selection of samples was designed to spread collections of ovaries and clutches over the range of carapace lengths encountered for females in each stage. Full clutches and ovaries were preserved in 10 percent formalin-sea water for later examination.

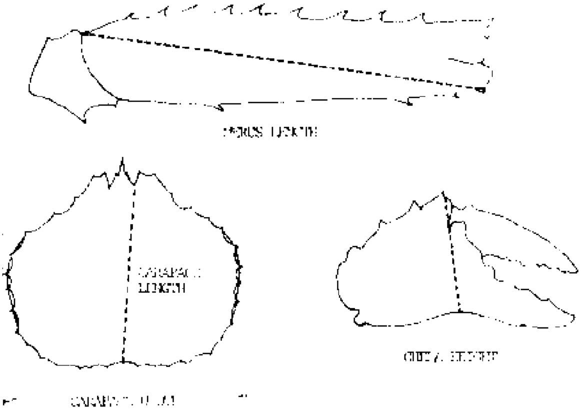

Fig. 2 Morphometric measurements (mm) taken during the summer of 1984 from golden king crab from Bowers Ridge, Petrel Bank and Seguam Pass.

Laboratory examination of preserved samples consisted of measuring egg diameters (0.01 mm, average length and width), weighing ovaries (0.1 mg) and estimating the number of eggs in each clutch. All measurements were made with an ocular micrometer and binocular dissecting microscope at 10 magnifications. Clutches were rinsed in xylene and air-dried to separate individual eggs. Dried clutches were then hand picked to remove portions of pleopods and setae. Individual dry embryo weights were estimated as the average derived from two counted and weighed samples of eggs from each clutch. We determined the number of eggs by dividing the total clutch weight by the average egg weight for each clutch.

Results and Discussion

Length-frequency data (Fig. 3) showed that the size of females was similar between collections from Bowers Ridge and Seguam Pass, but that males reached larger sizes at Seguam Pass. Females from Petrel Bank were of similar sizes to those of Bowers Ridge but too few males (15) were collected from Petrel Bank to judge relative size. We did not analyze size frequency data statistically because limited grounds were covered in each area and depths that were fished differed considerably

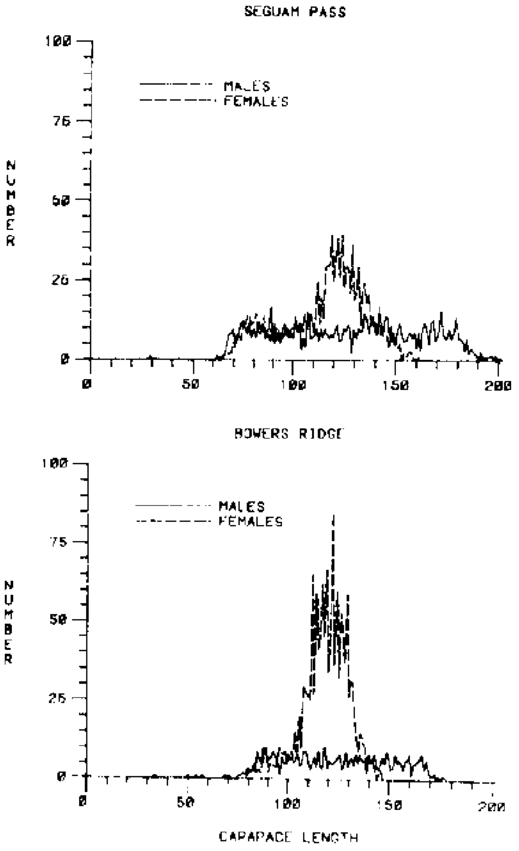

Fig. 3 Comparative length-frequencies for male and female golden king crab from Seguam Pass (N = 1,040 ♂♂, 415 ♀♀) and Bowers Ridge (N = 527 ♂♂, 1,411 ♀♀).

(see below). Sloan (1985) has shown that male and female king crab are stratified by depth according to their life stage and, hence, size. The larger size of males in the Seguam Pass area is, however, consistent with reports from numerous fishermen. The large modal groups of females observed in all areas is probably related to diminished growth associated with the onset of sexual maturity and subsequent accumulation of several year-classes of females in a narrow size range. A similar pattern of growth occurs in red king crab (Weber 1967).

Size at maturity was determined from the relationship between size and the proportion of mature females (ovigerous or stage 5) and from allometry in the relationship of chela height to carapace length in males. We considered the female size at maturity to be the length at which 50 percent were mature, while that of males was determined from the intersection point of lines characterizing the two phases of growth in the right cheliped. Analytical methods were those of Somerton (1980) and Somerton and MacIntosh (1983). Results are compared with those of Somerton and Otto (in press) in Table 2. Sizes at maturity for females were lowest on Petrel Bank (102.2 mm) and highest at Seguam Pass (110.7 mm), while those from Bowers Ridge were intermediate (106.4 mm). Males matured at a significantly ($P = 0.05$) larger size (113.2 mm) in Seguam Pass than on Bowers Ridge (106.4 mm). In comparison to previous collections, the Seguam Pass sample did not differ significantly with respect to males but was significantly different with respect to females, although the difference was small (2.5 mm).

Table 2. Carapace lengths (mm) at maturity for golden king crab collected from the Eastern Bering Sea (EBS) and Aleutian Islands (numbers in parens are standard deviations).

Area[1]	Males		Females	
	Length (sd)	N	Length (sd)	N
Northern EBS	92.0 (2.4)	205	97.7 (0.5)	324
Central EBS	107.0 (4.6)	1866	9.99 (0.2)	4783
Southern EBS	130.0 (4.0)	299	110.7 (0.8)	527
Bowers Ridge	108.6 (2.6)	515	106.4 (0.5)	1411
Petrel Bank	- -	15	102.2 (0.3)	787
Seguam Pass	120.8 (2.9)	775	113.2 (0.3)	415

[1] Values for northern, central and southern EBS are from Somerton and Otto (in press), northern refers to collections north of 58°31'N and southern to those south of 54°15'N. Most of the southern EBS sample was from the vicinity of Seguam Pass.

In the absence of genetic studies or sufficient tag returns from which to determine migratory patterns, we cannot ascribe differences in size or size at maturity to the existence of discrete populations. Somerton and Otto (in press), however, found that mean size and size at maturity tended to decrease with increasing latitude, and that the disparity between male and female size at maturity decreased with increasing latitude. In this respect, the 1984 data are similar to previous collections with respect to males but not for females, because Petrel Bank and Seguam Pass are at almost the same latitude (Fig. 1). The range of latitudes in 1984 collections, however, is only 2°27' (52°12' to 54°39') degrees.

If the maximum size is a reflection of growth rate, then environmental differences could account for the patterns observed if maturity in females tends to be size dependent while maturity in males tends toward age dependence. Somerton and Otto suggested that this was so because female fecundity and hence reproductive value is conditioned on size, while the reproductive value of males is probably related to the portion of the life span during which they are capable of mating. This implies that growth rates are higher in southern areas and that females mature later in northern areas. Differences in size and size at maturity between Bowers Ridge and Seguam Pass occur over a narrow range of latitude, suggesting that oceanographic processes, rather than latitudinal changes in temperature, result in differential growth. The Seguam Pass area is characterized by strong currents and turbulent mixing of North Pacific and Bering Sea waters, while currents in the Bowers Ridge and Petrel Bank areas are gentle. If high productivity is associated with turbulent conditions, then this could account for differences in growth rates between areas and consequently for observed differences in size at maturity among males.

Ovarian egg diameters ranged from 0.38 to 2.32 mm (Table 3). If ovarian egg diameters are plotted against female carapace length, without regard to the stage of embryo development, the range of diameters observed clearly increases as the size of maturity is approached and remains constant thereafter (Fig. 4). At smaller female lengths, two distinct sizes of eggs were observed, and at larger female lengths all sizes of eggs were observed. The maximum diameter of an ovarian egg is nearly the same as that of an external egg and there is a clear increase in ovarian egg sizes as external embryonic development progresses (Fig. 5, Table 3). The mean size of an ovarian egg from a female with hatching larvae is 1.70 mm (sd = 0.14) as compared to 2.18 mm (sd = 0.90) for an external egg. Converting average diameters to approximate (spherical) volumes shows that an ovarian egg increased from 2.57 cubic mm at the end of embryo development to 5.42 cubic mm at extrusion. At the end of embryo development an ovarian egg is 47 percent the volume of an external egg and therefore it appears that the time span between successive ovipositions is about twice that of embryo development. If embryo development takes about one year, as it does in red or blue king crabs (Somerton and MacIntosh 1983) and in the southern king crab (L. _antarcticus_, Vinuesa 1984), then spawning in golden king crab must occur every two years.

From the progression and range of egg sizes (Figs. 4, 5) for females in various reproductive states, we induce that females may be in virtually any point of the reproductive cycle during mid-summer. We have seen grasping (mating) pairs in February and May in the Pribilof Canyon and in July in the Zhemchug Canyon; fishermen in the Aleutians report them in December. The spawning period is hence protracted, as concluded by Otto and Somerton (in press). The numbers of females in various reproductive stages (Table 3), however, showed no homogeneity (chi-squared = 532.2, df = 6, $P < 0.005$), suggesting that while spawning is

Table 3. Numbers of female golden king crab examined from three areas of the Aleutian Islands during June and July of 1984, showing the number and percentage of females with embryos in various stages of development and characteristic ovarian egg diameters.[1]

Area	Immature Females	Mature Females	Embryo Development[2]			
			New	Crescent	Old	Empty
Bowers Ridge	280	1120	274 (24.2)	48 (4.2)	427 (37.8)	381 (33.7)
Petrel Bank	60	727	290 (39.9)	139 (19.1)	75 (10.3)	223 (30.7)
Seguam Pass	375	40	33 (82.5)	1 (2.5)	1 (2.)	5 (12.5)
Ovarian eggs:						
Mean diameter	1.48	-	1.07	1.47	1.68	1.95
Std. error	0.08	-	0.02	0.02	0.03	0.02
Range	0.38-2.30	-	0.56-1.60	1.24-1.85	1.19-2.17	1.42-2.32
N	55	-	97	32	47	66

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[1] Egg diameters are plotted in Fig. 5; ovaries were collected from various areas.

[2] New refers to embryos without visible eye pigmentation, crescent refers to embryos with new, crescent-shaped eye spots, old embryos are more advanced and empty means empty egg cases attached to pleopods with occasional dead (residual) embryos enmeshed in the mass of funiculii.

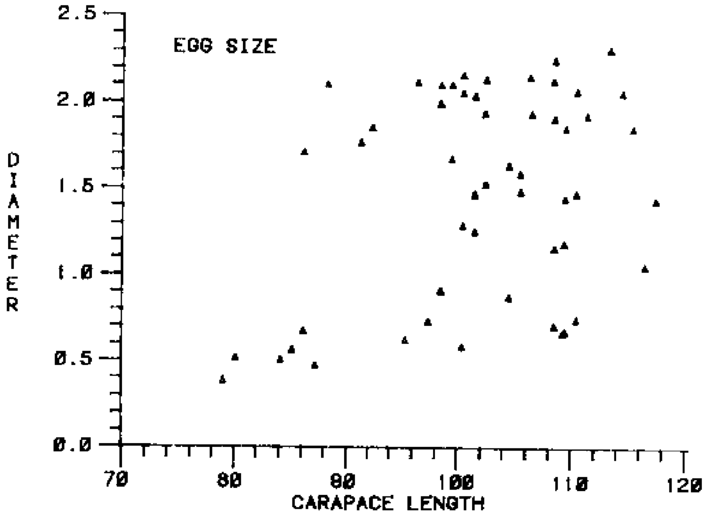

Fig. 4 Scatter plot relating ovarian egg diameters (mm) to female carapace length (mm) without regard to the presence or developmental stage of external embryos. Data represent combined collections for Bowers Ridge, Petrel Bank and Seguam Pass.

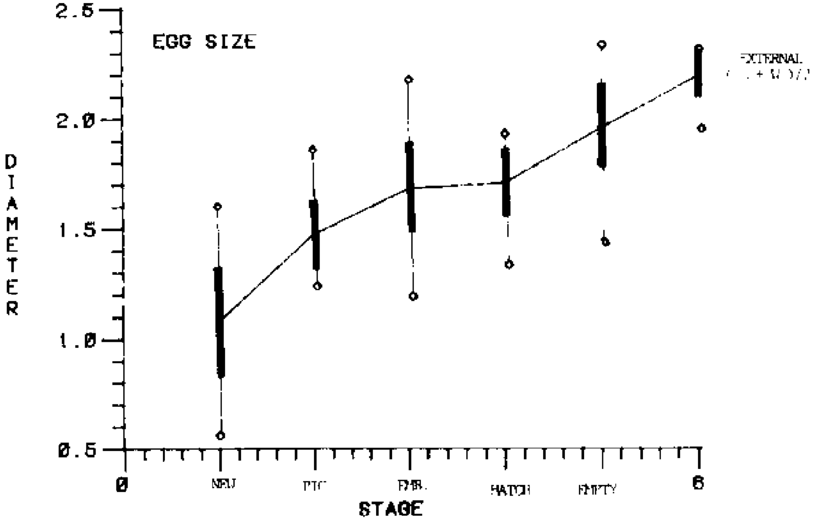

Fig. 5 Mean, confidence interval (95 percent, bar) and range of ovarian egg diameters for golden king crab carrying progressively more advanced embryos. Data are for combined collections from Bowers Ridge, Petrel Bank and Seguam Pass.

asynchronous or protracted, there may actually be seasonal peaks for various areas, or that females in a given reproductive state congregate. Data on depth distribution of females of various reproductive states from British Columbian fjords (Sloan 1985) showed that immature females and those carrying uneyed embryos tend to be in shallower water than those with more advanced embryos or empty egg cases. Unfortunately, depths recorded in 1984 were for the centers of strings of 10 pots that were often set over a distance of about two nautical miles and bracketed a considerable range of depths, hence obscuring depth distribution. Nevertheless, average recorded depth for the Seguam Pass collections was 244.8 m (sd = 34.2) as compared to 278.0 m (7.6) for Petrel Bank and 317.5 m (82.5) for Bowers Ridge. Since the Seguam Pass collection was from the shallowest water and also contained the highest percentage of immature females, relative depth distribution probably accounts for some of the observed heterogeneity in collections of females.

Fecundity was measured as the number of eggs attached to the pleopods of females with full clutches. The relationship between the number of eggs carried and carapace length was linear on logarithmic axes. Retransformed data (Fig. 6) show that the average number of uneyed embryos carried by female golden king crab is considerably lower than it is in red or blue king crab. A golden king crab of 120 mm length carries an average of 11,330 uneyed embryos. According to Haynes' (1968) data, a red king crab of 120 mm would carry an average of 151,260 embryos, while Somerton and MacIntosh's (1983) data show an average of 150,440 embryos for a 120 mm blue king crab. Comparison of the average number of uneyed and old-eyed embryos (9,549) for a 120 mm golden crab indicates a difference of 1,781, or 15.7 percent. If this is interpreted as average egg loss, the percentage is well within the range reported by Matsuura and Takeshita (13 to 24 percent, this volume) for red king crab.

External egg diameters averaged 2.2 mm for golden king crab, as compared to 1.0 mm for red king crab (Haynes 1968) and 1.1 mm for blue king crab (average of length and width, Somerton and MacIntosh 1983). Approximate (spherical) volumes for golden king crab (5.42 cubic mm) are hence 10.0 times the volume of those for red king crab (0.54 cubic mm). Since red king crab carry about 13 times as many eggs as golden king crab, most of the difference in fecundity is due to egg size rather than to the volume of eggs produced. The volume of golden king crab eggs are, however, only about six times the volume of blue king crab eggs, while blue king crabs produce 13 times as many eggs. Blue king crab are more fecund both because of the number and volume of eggs produced. Blue king crab spawn biennially, while red king crab spawn annually (Somerton and MacIntosh 1983).

Our egg diameter data are similar to those reported for other species of Lithodes, but differ slightly from those reported by Hiramoto and Sato (1970). The latter authors report an average egg length of 2.4 mm and widths ranging from 1.9 to 2.3 mm (no mean given). If we accept 2.1 mm as the width, Hiramoto and Sato's diameter (L+W/2.0) would be 2.25 mm, or only slightly larger than our values. Other reported diameters are 2.2 mm for L. antarcticus (Guzman and Campodonico 1972), 2.3 mm for L. couesi (Somerton 1981) and 2.3 mm for L. murrayi (Arnaud and Do-Chi 1977). Lithodes antarcticus is an annual spawner (Vinuesa 1984) while periodicity of spawning in the other species are unknown. The prevalence of females carrying empty egg cases in L. couesi,

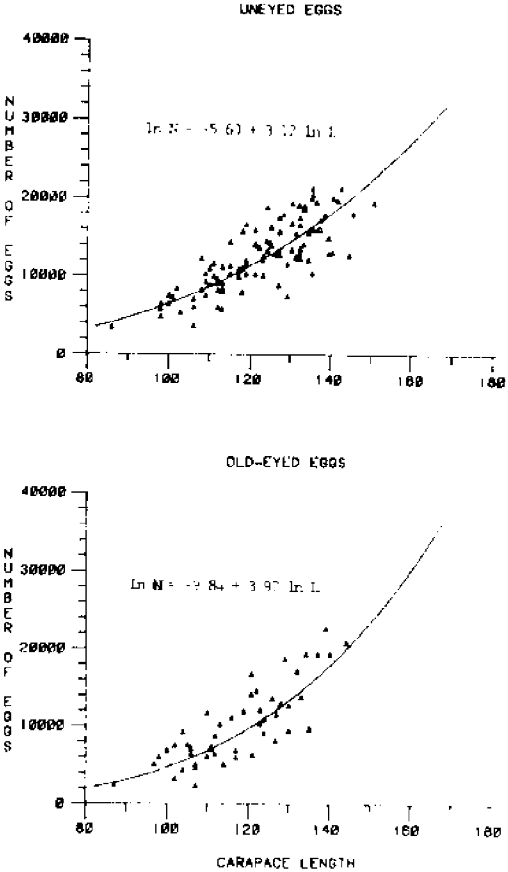

Fig. 6 Relationships between the number of external eggs and carapace length (mm) for golden king crab with full clutches of new uneyed eggs and old-eyed eggs. Regression equations are for transformed data, plots show untransformed data.

however, suggests that their spawning cycle may be similar to that of L. aequispina.

In comparing egg diameters and spawning cycles of Paralithodes and Lithodes, we see that large eggs are characteristic of Lithodes but do not necessarily indicate biennial spawning, and that smaller egg diameters in Paralithodes don't equate to annual spawning. More research on the comparative reproductive biology of both genera is necessary to elucidate the relationship between number and volume of eggs produced and various ecological parameters. It appears that shallow water king crabs (L. antarcticus, P. camtschatica and P. platypus) spawn synchronously in the spring while deep water king crabs (L. aequispina and L. couesi) have protracted spawning periods. Hypothetically, this pattern is probably related to a dependence of larvae of shallow water forms on spring plankton blooms as a food source. Considerable research on larval ecology, particularly of deep water forms, will be necessary to confirm this hypothesis.

From the standpoint of fishery management, it seems likely that the ratio of mature males to mature females is not as critical for L. aequispina as it is for P. camtschatica. By consequence, legal size may be closer to size at maturity for L. aequispina than it is for P. camtschatica. Current size limits are 152 mm carapace width for Aleutian Island golden king crab and 165 mm for red king crab. Growth data provided through tag returns will allow further consideration of optimum legal size.

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Egg number and adult size in *Lithodes aequispina* from northern British Columbia

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Abstract

Size at maturity of fjord-dwelling golden king crabs, *Lithodes aequispina*, from northern British Columbia is 114 mm carapace length (CL) for males, based on chela allometry, and 105.5 mm CL for females, based on the presence of 'eggs' (embryos) or empty egg cases on the pleopod setae. Females carried up to 27,000 'eggs'. Fecundity (F), measured soon after egg extrusion, increases with carapace length according to: F=-18760 + 294 CL. Embryo mortality, from egg extrusion until the appearance of embryonic eyes, decreases from 13% for 110 mm CL females to 8% for 140 mm females. Mean length of external 'eggs' immediately before hatching is 2.4 mm.

Introduction

Lithodes aequispina Benedict occurs throughout the north Pacific from British Columbia to central Japan at depths of 150-900m (Hiramoto and Sato 1970; Otto et al. 1983; Sloan 1985a). In the eastern Pacific, golden king crabs are fished mainly in southeast Alaska, and along the Aleutian Islands and continental slope of the southeastern Bering Sea (Otto et al. 1983; T. Koeneman pers. comm.).

The biology of *L. aequispina* is poorly understood, although some information has been published for populations off central Honshu (Hiramoto and Sato 1970; Suzuki and Sawada 1978) and along western Kamchatka (Rodin 1970). These papers include data on distribution according to depth and size, size-weight relationships, reproductive periods, sex ratios, fecundity, fishing methods and catch.

We abbreviate here the detailed report by Jewett et al. (1985) on the size at sexual maturity and fecundity of fjord-dwelling *Lithodes aequispina* from northern British Columbia and compare the results with *L. aequispina* from different areas.

Materials and Methods

Lithodes aequispina were collected in three fjords, Alice Arm, Hastings Arm and Observatory Inlet, of the Portland Inlet system (55°N:130°W) during October-November, 1983 and February-March, 1984. Sampling was conducted with baited, Alaskan double-entrance king crab pots deployed at depths from 51 to 569m.

Carapace length (CL) of both sexes and right chela (propodus) height of males (illustrated in Jewett et al. 1985) were measured to the nearest 1.0 mm. Males having a right chela that appeared to be regenerating were not measured. In addition, all crabs bearing the externae or scars of the rhizocephalan barnacle parasite, Briarosaccus callosus Boschma, were excluded from the data set. Infected male L. aequispina had smaller right chelae as a result of parasitic castration by B. callosus (Sloan 1985b).

Maturity of males was determined from the height of the right chela relative to the length of the carapace using the Somerton and MacIntosh (1983) technique which assumes that the growth of the chela changes with respect to the growth of the carapace at maturity. When chela and carapace measurements are plotted against each other on log-log axes, the data assume a pattern consisting of two straight lines, one describing the relative growth of juveniles, and the other describing the relative growth of adults. The size at sexual maturity is estimated by determining the intersection point of the two lines.

To estimate the carapace length at the intersection point, a computer technique (MATURE2) was used to iteratively fit two straight lines to the morphometric data until the residual sum of square was minimized.

To estimate the variance of the estimated size at maturity we used a computer technique known as bootstrapping (Diaconis and Efron 1983). In our application of this method, the data was repeatedly subsampled, with each subsample being randomly selected with replacement and equal in size to the original data set. Size at maturity was estimated for each of the 25 subsamples using MATURE 2. Because the distribution function of the estimates appeared to be skewed, they were log transformed before estimating the standard deviation (SD) and the upper and lower 95% confidence intervals (CI). The estimates of SD and CI were then transformed back to a linear scale.

It is assumed that female Lithodes aequispina, as with other crabs of the family Lithodidae (Powell et al. 1973; Somerton and MacIntosh 1983), mate and extrude eggs soon after every adult molt. Therefore, females can be classified as mature or immature based on the presence or absence of 'eggs' (which are technically embryos because they are fertilized immediately upon extrusion) or empty egg cases on the pleopod setae. Large (>100mm CL) juvenile females were examined internally, as well as externally, for any evidence of Briarosaccus callosus parasitism. The percentage of females that were mature was calculated for each 3mm size interval. The size at which 50% of the females are mature (SM50) was then estimated by fitting a logistic equation to the percentage mature by size, using the methods discussed in Somerton (1980), and evaluating the fitted equation to determine the size corresponding to 50% mature. Variance of SM50 was estimated using the technique described in Somerton (1980).

To estimate fecundity, pleopods with attached 'eggs' were removed from females and preserved in buffered 10% sea water formalin. The presence or absence of dark embryonic eyes were noted for each egg mass. Eggs were dried to a constant weight at 60° C, separated from the pleopods, rubbed gently to free them from connective tissue and weighed to the nearest 0.001 g. Two estimates of fecundity were obtained for each crab by dividing the weight of the entire egg mass by the weight of a 200-egg subsample. Fecundity was then estimated as the mean of the two estimates.

Maximum lengths of 50 'eggs' obtained from a single female were measured to 0.01mm using an ocular micrometer. Measured eggs were close to hatching (some embryos in the egg mass had already hatched), and had been stored in 33% isopropyl alcohol after formalin fixation.

Results

Size at sexual maturity

The 395 male L. aequispina used in the analysis ranged from 62 to 188mm CL. The estimated size (± 95% confidence intervals) at maturity for these males was 114.0 ± 11.4mm CL (Figure 1A).

The 780 female L. aequispina used ranged from 59 to 174mm CL. The estimated size (± 95% confidence interval) at SM50 was 105.5 ± 0.7mm CL (Figure 1B). The maximum size of a juvenile female was 129mm, and the minimum size of an adult female was 98mm

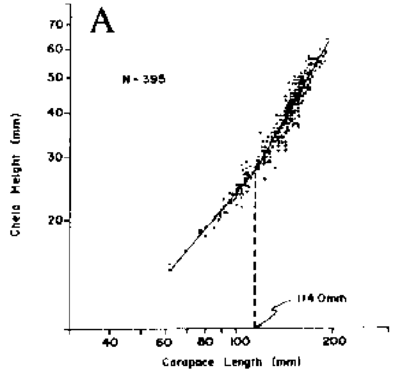

Figure 1(A). Male Lithodes aequispina right chela heights and carapace lengths. The x axis intersection of the two-line model is the estimated size of maturity (114.0 mm carapace length) which is shown by the vertical line. N=sample size.

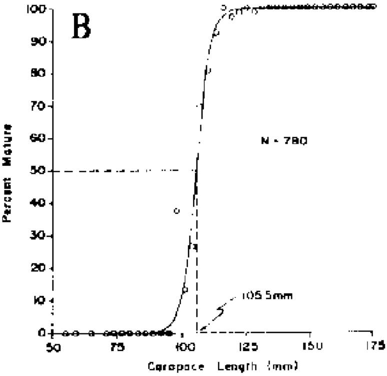

Figure 1(B). A logistic curve fitting the percent of the data classified as adult female Lithodes aequispina by size. The size of 50% maturity (105.5 mm carapace length) is demonstrated. N=sample size.

Fecundity and egg size

The number of uneyed 'eggs' ranged from 10,620 to 27,040 for females (N = 37) ranging in size from 110 to 150mm CL. The number of eyed 'eggs' ranged from 9,329 to 22,656 for females (N = 21) ranging in size from 106 to 139mm CL. To determine whether the size-fecundity was linear or curvilinear, a parabola was fit to the fecundity and size data, considering eyed and uneyed eggs separately. As a parabola did not fit better than a straight line (F test; $P>0.05$), the relationship was, therefore, described by a straight line for both 'egg' conditions (uneyed eggs; $y=-18{,}760 + 294$ CL, $N=21$, $R^2=0.39$: Eyed eggs; $y=-20{,}525 + 294$ CL, $N=37$, $R^2=0.57$). An analysis of covariance was used to determine whether the size-fecundity relationship differed between eyed and uneyed eggs. The slopes of the size-fecundity relationship did not differ ($P > 0.05$) between egg conditions, but the intercepts, assuming a common slope, were significantly different ($P = 0.05$). A significant loss of eggs (embryos) from the uneyed to the eyed stage is indicated by the intercept of the line for uneyed eggs being greater than that for eyed eggs. Crabs with uneyed eggs have, on average, 1765 more eggs than crabs with eyed eggs, regardless of the size of the crab. On a percentage basis this difference is greatest in smaller crabs, decreasing from 13% for females with 110 mm CL to 8% to 8% for females with 140 mm CL. This indicates that 'egg' mortality may be inversely related to crab size.

Eggs of *Lithodes aequispina* that are near hatching have a mean length of 2.39mm (*SD = 0.089, N = 50*).

Discussion

Size at sexual maturity

The use of chela and carapace allometry for estimating male size at maturity appears to be more practical for *Lithodes* spp. than *Paralithodes* spp. Deep-sea king crab *Lithodes couesi* (Benedict) *(Somerton 1981a)* and golden king crab *have a more* pronounced change in chela allometry at the onset of sexual maturity than do red king crab, *Paralithodes camtschatica* (Tilesius) (Somerton 1980) or blue king crab, *P. platypus (Brandt) (Somerton* and MacIntosh 1983). This more *pronounced* change permits greater precision of the estimate of size at maturity. The large (22mm) confidence interval for males is, in part, due to the variability in chela size at a given crab size and this variability could have been increased by the inadvertant inclusion of partially regenerated chela in the sample. Although obviously regenerating chela were excluded from the analysis, chela that are almost completely regenerated are difficult to detect and are likely to be included.

The size at maturity for males and females in the present study is different, with one exception, from the sizes in three continental slope areas of the eastern Bering Sea. Size at sexual maturity and 95% confidence interval for males and females from the Eastern Aleutian Island district was 130 ± 7.8 mm CL and 110.7 ± 1.5 mm CL, respectively. Size at maturity for males and females from the Pribilof Island district were 107 ± 9 mm CL and 99 ± 0.4 mm CL, respectively. Sizes for males and females from the St. Matthew ISland district were 92 ± 4.7 mm CL and 97.7 ± 1 mm CL, respectively (Somerton and Otto in prep.). Males from the Pribilof Island district matured at a similar size to British Columbia male crabs (estimated size at maturity of Pribilof Island crabs fell within the 95% CI of British Columbia crabs). The trend of increasing size at maturity with decreasing latitude apparent for *L. aequispina* in the eastern Bering Sea has also been noted for *Paralithodes camtschatica* (Powell et al 1983) and Tanner crab, *Chionoecetes bairdi* Rathbun (Somerton 1981b). Bottom water temperatures are thought to be the major factor in the regional differences in size at maturity. Perhaps the size at maturity of northern British Columbia *L. aequispina* does not conform to the latitude-related trend seen in the eastern Bering Sea because these crabs come from an isolated population which may be adapted to strictly local conditions in the deep basins of the silled fjords.

Although size at maturity of *L. aequispina* from western Pacific waters is not known precisely, Hiramoto and Sato (1970) reported that 15% of the females at 126 mm carapace width CW (=123.7mm CL as calculated from CW=6,815 + 0.96353 CL; K. Hiramoto pers. comm.) and 60% of the females at 136 mm CW (=134.0 mm CL) were mature. The sizes at which 15% and 60% of the females were mature in the present study were much smaller, approximately 97 and 108 mm CL, respectively. This suggests that females from British Columbia waters (approximately 55°27' N latitude) mature at a smaller size than do individuals from Japan (approximately 35° 00'N latitude).

Information on size at sexual maturity, as well as growth increment per molt and molt frequency, is necessary to set minimum size limits for a crab fishery. A discussion of a proposed minimum legal size for a Canadian *L. aequispina* fishery is presented in Jewett et al. (1985).

Fecundity

The linearity of the fecundity-size relationship of *Lithodes aequispina* is consistent with some studies on lithodid crabs (i.e., *Paralithodes camtschatica* - Haynes 1968; *L. aequispina* - Hiramoto and Sato 1970; *L. antarctica* Jacquinot - Guzman y Campodonico 1972; *L. longispina* Sakai - Hiramoto 1974; *L. murrayi* Henderson - Arnaud et Do-Chi 1977), but different from other studies which display curvilinearity (*P. platypus* - Sasakawa 1975; *L. couesi* - Somerton 1981a). The maximum number of 'eggs' carried by *L. aequispina* was approximately 10 times less than the maximum number reported for *P. camtschatica* (Haynes 1968) and six times less than the number reported for *P. platypus* (Sasakawa 1975). The lower fecundity of *L. aequispina* is consistent with that reported elsewhere for *Lithodes* spp. (Jewett et al. 1985). The 'egg' size of *L. aequispina* in this study was similar to other estimates of mean or median 'egg' size reported for four other *Lithodes* spp. (Jewett et al. 1985). The 'egg' size for *Lithodes* spp. is approximately twice the size found in *Paralithodes* spp. (Haynes 1968; Sasakawa 1975).

Low fecundity and large eggs, as found among *Lithodes* spp. are characteristic of many deep-sea organisms (Somerton 1981a). Somerton discussed the possible advantages to deep-sea crabs of producing few, large larvae able to migrate to the surface, to capture a broader array of food items, or to forgo feeding entirely. He also stated that it is unclear if the larvae of *L. couesi* migrate to surface waters. The behavior of recently hatched larvae of *L. aequispina*, as observed in the survey vessel's darkened sea water holding tank, was more benthic than planktonic. The majority of the several thousand larvae crawled about the tank bottom, although, some actively swam in the water column. We do not know if this behavior is typical in nature.

Comparative information on 'egg' mortality rates is not available for other lithodid crabs. 'Egg' mortality among the majid crab, Chionoecetes bairdi, is reported to increase with crab size from 7% among crabs measuring 80-89mm carapace width to 37% among crabs measuring 109-119mm (Hilsinger 1976). This is in contrast to L. aequispina where 'egg' mortality appears to decrease with increasing size.

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Larval biology of Alaskan red king crab

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ABSTRACT

This review deals with the larval biology of *Paralithodes camtschatica*. The objective of this report was to seek information which may have a bearing on *in situ* survival of the larvae. The literature review revealed a paucity of reports on the subject of *in situ* larval biology. No papers concerning the measurement of *in situ* survival rates of king crab larvae were encountered. One brief Japanese report which correlated historical data for the number of stormy days which occurred during the larval period and the subsequent catch of red king crab nine years later was located. No other reports reviewing physical and environmental factors which affect *in situ* larval survival were found. Very limited data exist for stomach contents of larval red king crab captured at sea; observations on the *in situ* larval period; geographic distribution of larvae and their vertical distribution.

Laboratory experiments on temperature requirements, development rate, prey type, energy consumption, critical period, respiration rate and culture techniques exist. However, in general, these experiments were conducted in conjunction with attempts to commercially culture *P. camtschatica* and did not attempt to simulate natural conditions.

On the basis of this literature survey, it must be concluded that there is virtually no existing information on the recruitment process or the factors which modify ocean survival for Alaskan king crab larvae.

INTRODUCTION

A major problem facing fishery scientists interested in rational management of fisheries is an inability to predict recruitment (Gulland, 1973; Steel, 1970). This is especially true for Alaskan crustaceans where there is very little field work on environmental conditions which affect the survival of planktonic larval forms.

It is generally accepted among fishery biologists that large spawning populations do not ensure subsequent large year classes, and conversely, small spawning populations occasionally give rise to exceptionally large year classes (Hjort, 1926).

There appears to be a strong correlation between sea-surface temperature cycles and subsequent recruitment success for several decapods including *Pandalus borealis* (Dow, 1979), *Penaeus duorarum* (Hettler and Chester, 1982) and the American and European lobsters (Dow, 1978). Sato (1958) has pointed out that the time required for larval king crab to develop to the settling stage is affected by temperature and the amount of food. Paul and Nunes (1983) showed that a one-degree rise in water temperature markedly increases the metabolic energy requirements. Dungeness crab abundance has been tentatively related to upwelling events (Botsford and Wickham, 1975). But no papers were located which identify the major source of mortality for any decapod larvae.

The planktonic larvae of decapods are subjected to similar environmental conditions as planktonic larval fin fishes. Recent studies (see for example, Lasker, 1975) have shown that, for the first-feeding larvae of some species, the density of food must be higher than that usually found at sea in order to obtain even moderate larval fish growth and survival, while other species are well adapted to feeding at prey concentrations normally encountered (Houde, 1974, 1978; Paul, 1983). For an in-depth discussion of the importance of the "critical period" to first-feeding planktonic larvae, see May (1974). Several species of decapod larvae, including that of red king crab, have been shown to have a critical first-feeding period (Anger and Dawirs, 1981; Paul and Paul, 1980). Predation is also an important unstudied factor regulating recruitment success.

The objective of this report is to review the literature existing prior to this symposium which relates environmental factors to growth and survival of the early stages of red king crab, *Paralithodes camtschatica*, which is commercially harvested in Alaskan waters. Information on the following subjects was sought: survival rates and sources of mortality; vertical distribution; prey types; and predators.

RESULTS AND DISCUSSION

No papers reporting measurements of *in situ* survival of red king crab larvae were encountered during the review.

One report which relates the number of stormy days during the planktonic period and subsequent commerical catch of that year class in the Nemuro area of Japan exists (Ishimaru, 1936). The relationship of the total number of stormy days during March through July for 1902-26 and the catch during 1911-35 exhibited a negative correlation, $r^2=0.6$ (Fig. 1). No other reports relating oceanographic conditions to larval survival were encountered.

Stormy conditions during the larval period may affect survival rates in several ways. Mixing from storms may negatively affect the production of prey; disperse prey such that their concentration falls below some critical density; or impede feeding of the crab larvae during a

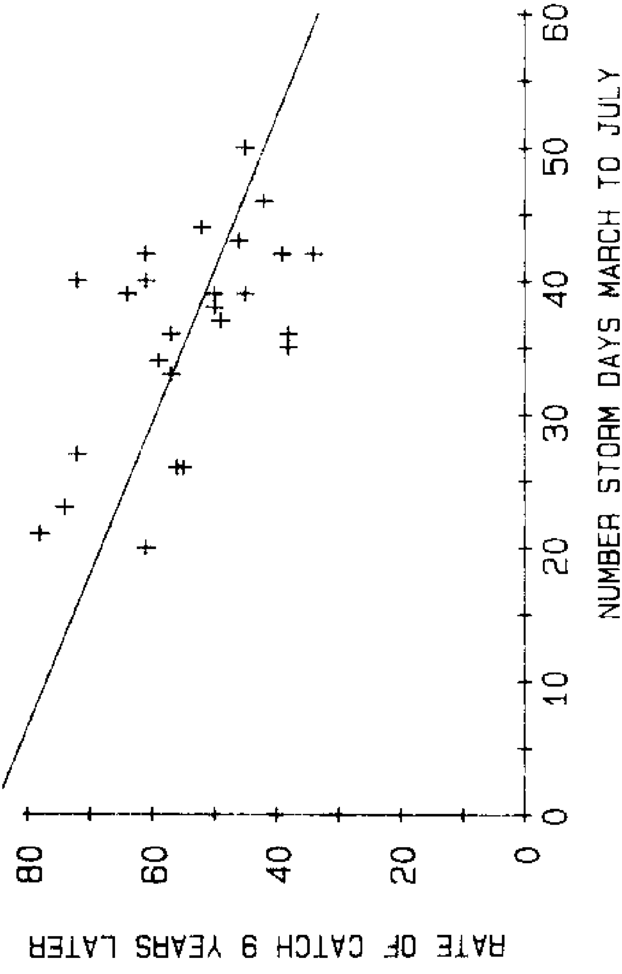

Fig. 1. Total numbers of stormy days from March through July in 1902-1926, and the rate of catch for red king crab for 1911-1935 in the Nemuro area of Japan (Ishimaru, 1936).

critical period. First-feeding king crab larvae can only exist without food at 2-6°C for three days before their ability to capture mobile prey declines (Fig. 2; Paul and Paul, 1980). In culture, survival rates decline if larvae are starved for the first two to four days of life (Kurata, 1959). However, due to lack of study, the extent to which, or the mechanisms through which stormy conditions negatively affect king crab survival is undetermined. Larval year-class strength of *Chionoecetes opilio*, another early spring hatching crab, in the southeastern Bering Sea are also inversely related to the depth of the upper mixed layer during the early hatching period (Incze, 1983)

The vertical distribution of red king crab larvae in the ocean is cursorily described. Takeuchi (1960) reported that more king crab larvae were captured in the southeastern Bering Sea at night surface hauls than during the day. More Stage I zoeae were found at the surface than were Stage II zoeae, with the second stage found to be most abundant at approximately 50 meters. Takeuchi (1960) theorized that king crab zoeae float to the surface at night and make diurnal vertical movements during the planktonic stages. A few MOCNESS samples in the southeastern Bering Sea (Armstrong *et al.*, 1983) determined that most larvae were caught at 0-40 meter depths (sample size = 600 larvae from six stations). Clearly, more study of the vertical distribution of the larvae is needed to determine the interaction of oceanographic conditions and larval survival.

Laboratory studies on the effects of water temperature on the length of the planktonic period and survival of red king crab exist. Kurata (1960) reported a range of 5-10°C as suitable for culture of first zoeae and Sato (1958) had survival of zoeal Stages II-IV at 5.4-18.3°C. Nakanishi (see report in this symposium) reports 8°C is a good temperature to culture king crab larvae. However, these studies were done under laboratory conditions with prey concentrations many magnitudes higher than occur in nature. Paul and Nunes 1983) demonstrated that, for every degree rise in temperature, a first zoeae of *Pandalus borealis* is subjected to an approximately 20% increase in metabolic energy requirements. Thus, under food limited *in situ* conditions, optimal temperature for survival may be lower than that for food-saturated culture conditions. Temperature modification of development rates would also affect the time and place that larvae settle.

In the laboratory, king crab larvae have been reared with *Artemia nauplii*, *Chone teres* (polychaeta) larvae and rotifers (*Brachionus plicatilis*) as food (Nakanishi and Naryu, 1981; Kurata, 1968). The diatoms *Skeletonema* and *Phaeodactylum* have been shown to be of little use as food (Nakanishi and Naryu, 1981; Kurata, 1968). Some decapod larvae can consume larger diatoms like *Coscinodiscus*, but they may only provide a minor source of energy as in the case of *Chionoecetes beirdi* (Incze and Paul, 1983). For other species like *Cancer magister*, diatoms may be an important energy source (see Incze and Paul, 1983 for a review). In culture, the zoeal and post larval stages are commonly cannibalistic (Nakanishi and Naryu, 1981). Paul *et al.* (1979) demonstrated that king crab Stage I zoeae could capture adult *Pseudocalanus elongatus* and *Acartia* spp. Only one report was found that described the stomach contents of zoeae caught at sea. In Cook Inlet, Alaska, diatoms and the larvae of barnacles and the crab *Telmessus* were found in the stomachs of third and fourth zoeal stages of king crab (Bright, 1967). Post larval benthic stages from lower

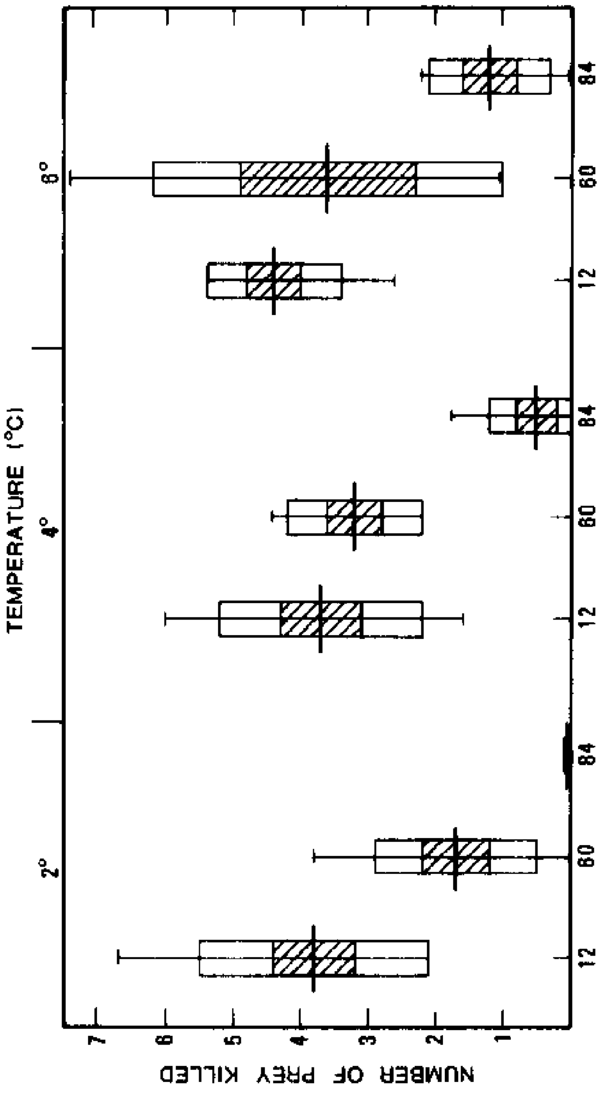

Fig. 2. The number of copepods killed by red king crab Stage I zoeae starved for 12, 60, and 84 hours and held at 2,4, and 6°C: shaded area = 2 SE of the mean; clear area, 2 = SD of mean; vertical line = range; horizontal line = mean (Paul and Paul, 1980).

Cook Inlet, Alaska, consume small crustaceans, especially ostracods and harpacticoid copepods (Feder *et al.*, 1980). It appears that early stages of red king crab are likely to consume diatoms and crustaceans including decapod larvae. However, with the current data base, it cannot be determined which of the components of the pelagic food web are energetically important.

No papers identifying predators or rates of predation on king crab larvae were found.

Respiration values for zoeae Stages II-IV combined are available for 8°C (Nakanishi *et al.*, 1973). Mean oxygen consumption was 21.2 µl per individual per day. The energy expenditure due to respiration, if calculated using a conversion factor of 4.73 x 10^{-3} cal. μl^{-1} O^2 (Crisp, 1971) would be 0.10 cal. per day. Assuming a 60% conversion efficiency, daily consumption would have to exceed 0.17 cal. per day. Additional energy would be needed for growth. Currently, no reports exist which describe energy acquisition by king crab larvae feeding on natural plankton assemblages.

Only one report was located that dealt with settlement areas and habitat requirements of post larval red king crab. Sundberg and Clausen (1977) sampled the benthos in Kachemak Bay, Cook Inlet, Alaska. Post larval king crabs were not found on sandy or muddy bottoms. However, they did occur along the rocky perimeter of the Bay in less than 27 meters of water. In general, the greatest number of crabs were associated with a heavy epifaunal cover of filamentous red algae, sponges and bryozoans (*Flustrella* sp. and *Dendrobeania* spp.). Analysis of the stomach contents of these crab showed that the algae, sponges and bryozoans were not important food items, rather they likely provide habitat (Feder *et al.*, 1980). At the five stations where Sundberg and Clausen (1977) found post larval crab, densities of 1.3-1.5 crab per meter square were observed. That study suggested that there are specific habitat requirements for newly settled king crab and the existence of these nursery areas may be a factor limiting recruitment success.

Even though the red king crab has in the past supported the most valuable crab fishery in the world, little effort has been expended on *in situ* study of larval life history. Currently, it is not possible to determine if differences in interannual survival rates of king crab larvae even occur. Therefore, it is also impossible to determine if variations in larval mortality rates are an important factor in determining recruitment success. Likewise, sources of larval mortality are undescribed. A large scale, long-term study involving physical and biological oceanographers is required to properly examine the recruitment process.

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Oceanographic environment and recruitment

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Abstract

Pelagic larval stages of marine benthic fauna typically comprise a relatively minor component of planktonic communities. However, these larvae occupy a fundamental position in the process of recruitment for their respective species. Knowledge of factors affecting their survival therefore is one of several important steps in the path to eventual understanding of recruitment variability. The physical and biological oceanographic environment of the southeastern Bering Sea is described with respect to processes and events having plausible impacts on larval king crabs and the success of their recruitment through early benthic stages.

Despite the prominence of red king crabs as a fisheries resource, basic studies of their larvae have lagged considerably behind present investigative capabilities and recent progress made with numerous other species. For example, little is known about the feeding requirements or feeding and temperature physiology of the planktonic stages. Nor is much known about planktonic or nektonic predators of these stages. Consequently, even the most basic information about the environment cannot be related to the potential well-being or harm that particular conditions might cause a larval year-class.

Variations in transport during larval development also may be important, but many basic questions are unresolved. For instance, is there a "preferred" depth for settlement, and what characteristics make certain depths better? Are there substantial differences in the availability of appropriate post-larval habitat along the peninsula (food, spatial refuge, regional overlap with major predator populations, etc.)? The transport regime north of the Alaska Peninsula varies substantially over small distances from the coast, so that variability in the location of adult stocks at the time of larval hatching can be expected to have significant influence on larval transport. Factors modifying the adult springtime distribution, the timing of larval hatching and the distribution and suitability of various habitats need to be known in greater detail than they are presently. Variability in transport and its forcing also require additional study.

The list of "unknowns" for king crab appears formidable, but the resources of the eastern Bering Sea are substantial and it is likely that scientific and economic interest in this region will continue. Several of the research needs can be addressed in the laboratory and at field sites more accessible than the Bering Sea.

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Development and decrease in number of eggs attached to pleopods of laboratory-reared king crabs, *Paralithodes camtschatica* (Tilesius)

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Abstract

Observations of eggs laid by laboratory-reared female king crabs, Paralithodes camtschatica (Tilesius), were made to obtain data on egg loss, changes in egg size, embryo growth and histological development, from the time of oviposition to that of hatching. Egg loss during incubation was 13-24 percent in three multiparous females and 53 percent in a primiparous female. Fifty percent of total cumulative egg loss occurred within the first third of the incubation period. Egg loss continued throughout the incubation period but appeared to decrease near the middle of it. Consequently, it is necessary to count the number of eggs just before hatching to obtain a reliable estimate of the zoea produced. There were no changes in the average diameter of the incubated eggs from egg laying to the formation of the early nauplius, egg age 3.5-4 (profile area of embryo 5 percent). Egg diameter increased following that stage, with an accompanying increase in the percentage of profile area and histological development of the embryo. Observations suggest that egg loss is closely related to embryo growth and structural changes in the embryo. The relationship between the number of eggs laid and the effective number of zoea obtained in this laboratory study compared well with similar data taken from field samples.

Introduction

Egg loss during the incubation period occurs in a number of decapod crustaceans (Chionoecetes opilio, Brunel 1962 and 1963; Homarus americanus, Perkins 1971). Egg loss in the king crab (Paralithodes camtschatica) has also been observed (Matsuura et al. 1972, Matsuura and Takeshita 1976). Studies of egg loss are important because they allow better quantification of the effective contribution of female crabs to populations of larvae. In this report, we describe egg loss and its relationship to embryo development for female king crab, collected from the Okhotsk Sea near Kamchatka, and held in the laboratory for three years. During this study we were also able to closely observe molting, mating and growth. One of the male crab used in this study had survived for 13 years in our aquarium.

Materials and Methods

Collections. Crabs for the laboratory study were captured with tangle nets in the waters off the west coast of Kamchatka on July 17, 1972. Upon capture, the crabs were placed in a live box provided with running sea water, and remained there for six days while being transferred to the port of Hakodate. Crabs were then wrapped in moistened, cooled sphagnum moss and placed in polystyrene containers for transfer by air to the Fishery Research Laboratory of Kyushu University.

Laboratory provisions and observations. Each female crab was held in a separate aquarium, (45cm wide, 90cm long and 40cm high) furnished with automatic thermostatic control and continuously flowing fresh sea water of about 5°C at a rate of approximately 150 liters per hour. Male crabs were introduced to the females just after molting. Mating behavior and the process of egg attachment to the pleopods were observed and recorded. The crabs were fed a sufficient supply of mollusks, crustaceans and fish every two or three days. General maintenance procedures were as described by Matsuura and Takeshita (1976).

To obtain developmental stage of embryos within the incubated eggs, 200 eggs were sampled every month from three different parts of the egg mass. Egg lengths and widths were measured and cubic dimensions were calculated. The geometric mean of length and width was considered as the standard egg size.

External observations were made by using a projector and by comparison with histological sections to clarify the stage of embryonic development. The yolked area appeared opaque and the embryo appeared translucent when eggs were observed with a projector. The percentage of the egg occupied by the embryo was obtained by tracing the projected image on paper and weighing the drawn parts. The percentage of the egg occupied by the embryo in profile views had a close relationship to the developmental stage of the embryo when compared with mid-sagital histological sections. Hence the profile area of the embryo by external observation could be used as an easy method to determine the stage of development.

Histological sections of the eggs were prepared by the paraffin method. In the embedding process, terpineol was used in place of xylol to prevent the yolk from hardening. Stage and morphological characteristics of incubated eggs were based on the original descriptions by Marukawa (1933).

For each of the four ovigerous females, lost eggs were counted every few days to estimate the egg loss per day; and the zoea larvae hatched were counted every one or two days to estimate the number of zoea larvae produced per day. Cumulative egg loss was obtained during the incubation period from these data.

The end of the incubation period was chosen as the day when 50 percent of the zoea hatched according the cumulative frequency. The incubation periods lasted from 287 to 374 days depending on crab and rearing year. Incubation periods were divided into 10 equal intervals to compare the eggs from different females. Each interval was considered as a relative measure of the age of the incubated eggs.

The total number of eggs laid was calculated as the sum of the eggs lost, zoea larvae produced and eggs sampled.

Results and Discussion

Molting, mating and egg laying. Molting and mating records for the reared king crabs are shown in Table 1. The female crab with an initial carapace length of 76.4mm used in observation number 1 was a primiparous female which molted to 88.1mm. The male crab of 117.7mm in carapace length was introduced to the primiparous female for mating just after her molting. Female crabs in observations number 2 to 4 were multiparous females and the procedure of mating was the same as in observation number 1. Each female crab laid eggs twice and provided two observations.

Histological stages and age of eggs. The development of incubated eggs was divided into four major stages by histological inspection: cleavage, gastrula - formation of embryonic rudiments, nauplius, and zoea (Table 2).

The cleavage stage: Egg age 0-3. The eggs cleaved in total up to the stage of eight blastomeres before superficial cleavage occurred. A flattened cytoplasm, containing nuclei, was observed and the whole surface of the yolk of the egg was covered with cytoplasm as the result of superficial cleavage by the end of this stage.

The gastrula stage: formation of the embryonic rudiments; egg age 3. Formation of the gastrula begins with the increase in the number of blastodermal cells on one side of the egg.

The nauplius stage: egg age 3-5.5. In the early nauplius stage, egg age 3-4, the embryo occupies 5 percent of the egg area when observed in a projected profile view and eye-stalks become distinct. In the late nauplius stage, 4-5.5, the embryo occupies 17-28 percent of the area and the cephalic lobes are well developed.

The zoea stage: egg age 5.5-10. In the early zoea stage, egg age 5.5-6.5, the embryo occupies 40 percent of the area, compound-eye, black pigment and heart appear. During the late zoea stage, egg age 6.5-10, profile areas are 40-60 percent at egg age 6.5-8; 6 percent at egg age 9; and 90 percent at egg age 10. All visible structures are present at the end of this stage.

Egg size and profile area of embryo. Figure 1 shows the relationship between relative age of incubated eggs and mean egg diameters. Egg sizes were not identical for the four observations but trends were similar, and only the results obtained from observation number 1 are plotted on the graph.

From egg laying to the formation of the early nauplius, egg age 3.5-4, there were no changes in the average diameter (0.88) of incubated eggs. But eggs increased in size following that stage. Up to the early nauplius stage the embryo did not occupy more than 5 percent of the egg

Table 1. Molting and mating records for reared *Paralithodes camtschatica*.

Observation Number	Female						Male	
	Date		Pre-molt		Post-molt			
	Molting	Mating and Egg Laying	CL	CW	CL	CW	CL	CW
1 (No. 1♀ x No. 1♂)	12/04/72	12/04/72	76.4	83.1	88.1	97.0	117.7	134.3
2 (No. 1♀ x No. 1♂)	02/21/74	02/21/74	88.1	97.0	97.1	107.6	133.2	155.7
3 (No. 2♀ x No. 1♂)	04/11/73	04/13/73	96.5	105.9	103.3	114.6	133.2	155.7
4 (No. 2♀ x No. 2♂)	03/27/74	03/28/74	103.3	114.6	108.6	119.1	110.7	128.6

CL = Carapace length in mm.

CW = Carapace width in mm.

Each female crab laid eggs twice and provided two observations.

Table 2. Age and developmental state of incubated eggs of reared *Paralithodes camtschatica*.

Age of Eggs[1]	Days after Fertilization	Month[3]	Diameter of Eggs (mm)[4]	% Egg Loss Between Ages[5]	Cumulative Egg Loss (%)	Profile Area of Embryo (%)[6]	Stage of Eggs and Morphological Characteristics
0							Cleavage Total cleavage in early and superficial in late stage
				17			
0.5							
				4			
1	34	May	0.88		21		Gastrula Invagination and formation of embryonic rudiments
				3			
1.5							
				8			
2	68		0.88		32		
				16			
3	102	Jul	0.88		48	5	Early nauplius Procto-cerebrum and eye-stalk become distinct
				16			
4	136		0.90		64		
				12		17	Late nauplius Cephalic-lobes well developed
5	170	Sep	0.92		76		
				5			
6	204		0.94		81	28	Early zoea Compound-eye, black pigments and heart appear
				5		40	
7	238	Nov	0.96		86	46	
				5			
8	272		0.98		91	60	Late zoea Structure complete
				5			
9	306	Jan	1.00		96	66	
				4			
10	340		1.03 -1.08		100	90	Hatching Zoea larvae

1; The incubation periods lasted from 287 to 374 days, and the periods were divided into 10 equal intervals to compare the eggs from different females with the same criteria. Each interval was considered as a relative measure of the age of the incubated eggs.

2; Incubation period was tentatively defined for 340 days.

3; Date of egg laying was tentatively chosen as April 1.

4; Two hundred eggs from each sample were measured for their lengths, widths and heights - however, height was nearly equal to width in case of incubated eggs - from which the cubic dimension was calculated and the geometric mean was considered as the standardized egg size. Only the results of observation number 1 are presented.

5; Eggs lost by the mother crabs were counted every few days to estimate the egg loss per day. The numbers represent the means of four observations.

6; The yolked area appeared opaque and the embryo appeared translucent when the eggs were observed with a projector. The percentage of the egg occupied by the embryo was obtained by tracing the projected image onto a piece of paper and weighing the drawn parts.

area when observed in a projected profile view. The embryo in the late nauplius stage, egg age 4.5-5.5, occupied 17-28 percent of the profile area with an accompanying increase in egg size to about 0.9mm in diameter. Egg size continued to increase until the late zoea stage, egg age 10 at 1.05mm diameter and 90 percent of profile area, just before hatching.

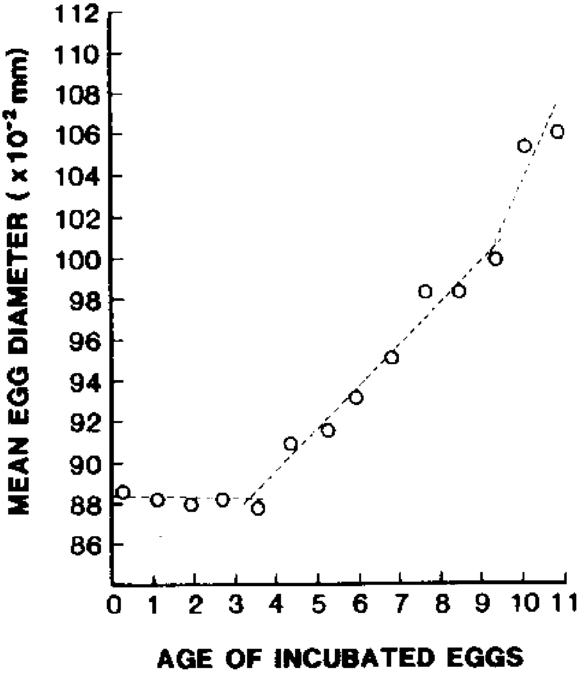

Figure 1. Changes between the age of the incubated eggs and the mean egg diameters of reared Paralithodes camtschatica. Data obtained from observation number 1.

Cumulative egg loss. Figure 2 shows the relationship between cumulative egg loss and relative age of incubated eggs (hatching periods were different for individual crabs). The incubation period was defined as the time between egg laying and the hatching of 50 percent of the eggs. Egg loss varied from 10,000 to 24,000. Loss was greatest at the beginning of the incubation period. The high loss just after egg laying was probably due to unsuccessful egg attachment to the pleopods. Eight percent of the total egg loss occurred within the first day and 9-20 percent of the total egg loss occurred within the first five days. Fifty percent of the cumulative egg loss occurred within the first third of the incubation period, and egg loss appeared to decrease near the middle of the incubation period, egg age 4.5-5.

The structural rudiments of the embryo were developed by the early nauplius stage, egg age 3.5-4, followed by a noticeable change in the structure and size of eggs beginning at the middle nauplius stage, egg age 4. At this point, cumulative egg loss surpassed 60 percent.

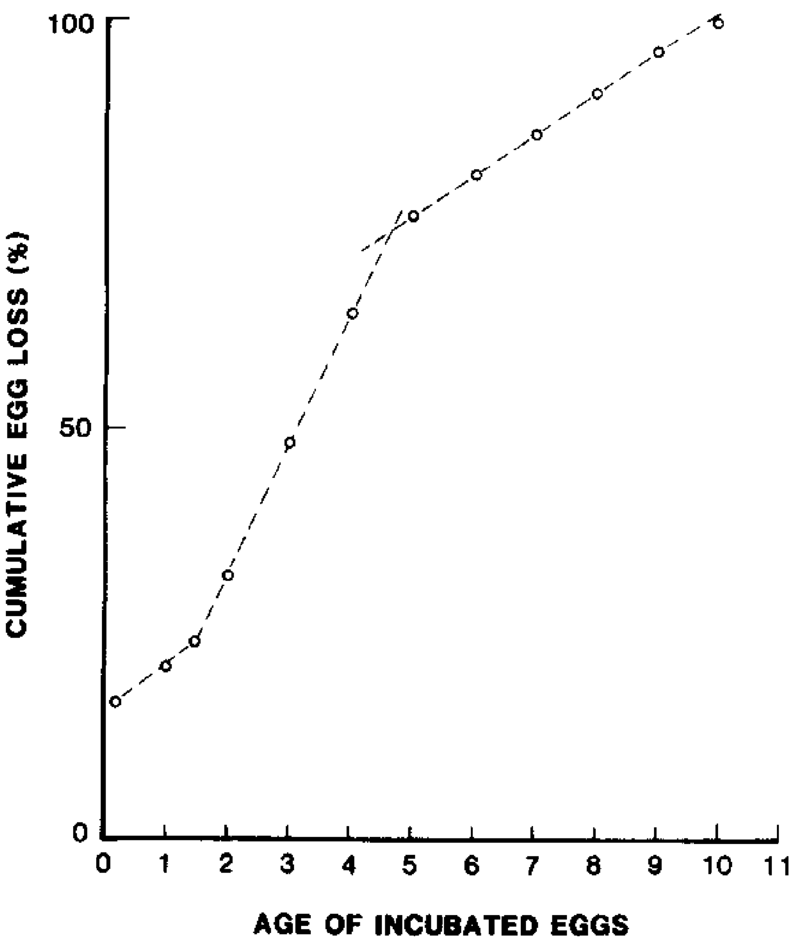

Figure 2. Relationship between egg loss and age of incubated eggs of reared *Paralithodes camtschatica*. Points represent means of four observations.

Deviations and total percentage of egg loss. Deviations from average egg loss also indicated a high loss during the first half of the incubation period with two peaks, one at the beginning, egg age 0-5.5, and one at about a third of the way through the incubation period, egg age 3.5. Deviations in the second half of the incubation period up to hatching, egg age 5-10, were negative (Figure 3).

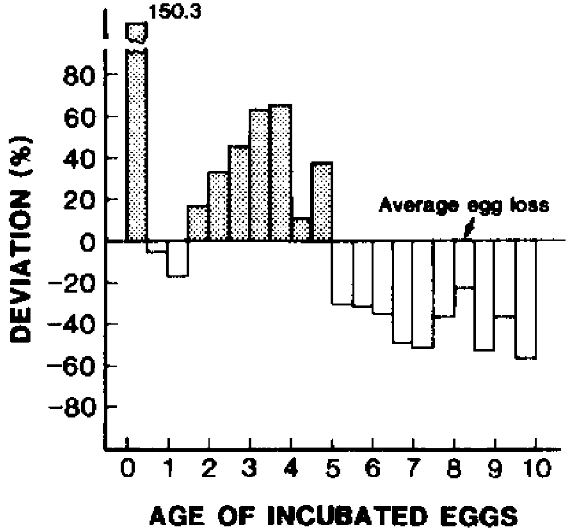

Figure 3. Deviation of egg loss by egg ages from average egg loss during incubated life span of reared Paralithodes camtschatica. Histogram heights represent means of four observations.

Total percentage of egg loss from time of fertilization to hatching was 13-24 percent in three of the multiparous females. The remaining primiparous female had a high loss of 53 percent. A 36 percent egg loss has been observed in the lobster, and egg loss during incubation is a common phenomenon in decapods (Perkins 1971; Brunel 1962, 1963). Therefore, it is necessary to count the number of eggs just before hatching to estimate the effective number of larvae produced.

In conclusion, the results in this study indicate that egg loss is closely related to the age of the eggs, trends in egg growth and structural changes in the embryo.

Number of eggs and zoea larvae. Figure 4 shows the relationship between the carapace width of the parent crab, the number of eggs it laid and the number of zoea larvae it produced (solid circles and open circles, respectively).

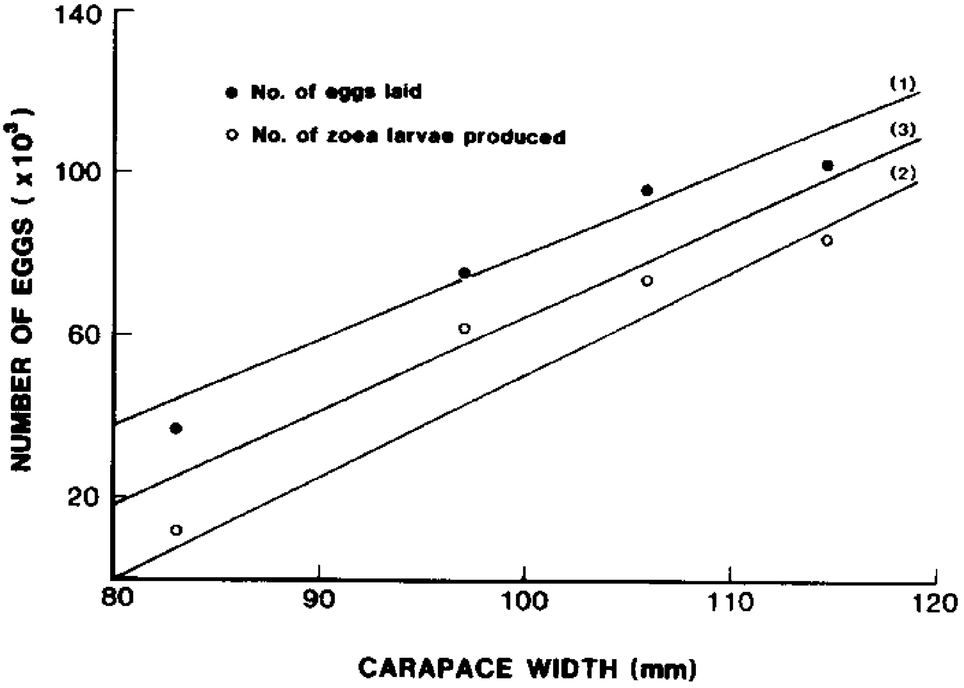

Figure 4. Relationship between the carapace width of reared *Paralithodes camtschatica* and the number of eggs laid and the number of zoea larvae produced. Points were obtained from observations 1 to 4. See text regarding lines (1), (2) and (3).

We previously reported the relationships between the carapace width and the number of mature eggs, the upper line (1), and zoea eggs, the lower line (2), from observations in the field. These results show that the percentage egg loss during the incubation period decreased as the female increased in size. One reason for this phenomenon might be that primiparous females have small, rather flat, brood chambers in which the margins of abdominal segments and thoracic sternites do not fit tightly. On the other hand, multiparous females have a large brood chamber with greater concavity on the inner surfaces of their abdomens and better fittings at the margins. This change in shape may prevent initial egg loss from the brood chamber just after extrusion.

The number of effective mature eggs at 95mm carapace width is equal to the number of zoea eggs at 101mm, which was calculated from published data. From this relationship the number of effective mature eggs at various sizes were obtained based on the assumption that the annual increment of the real fecundity would be proportional to that of the apparent fecundity. The relationship between carapace width and the number of effective mature eggs (Figure 4) was expressed with the middle line, $Y=2.3X-170$ (Matsuura et al., 1972).

The relationship between the number of eggs laid and the effective number of zoea larvae obtained in this laboratory study compared well with similar data taken from field samples.

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The effects of the environment on the survival rate, growth and respiration of eggs, larvae and post-larvae of king crab *(Paralithodes camtschatica)*

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The King crab (Paralithodes camtschatica), Hanasaki crab (Paralithodes brevipes), horsehair crab (Erimacrus isenbeckii) and snow crab (Chionoecetes opilio) are the main species of cold water crabs for which the mass-cultivation of larvae and post-larvae are being studied in Japan. The King crab was one of the most important fisheries in Japan, and there are several studies on larval rearing. Kaai(1940) reared king crab larvae from the zoeal to post-larval stage using in situ chambers and observed four zoeal stages and one glaucothoe. Sato and Tanaka (1949) reared larvae in a laboratory. Kurata (1959 and 1961) reared the first zoeal stage to the ninth post-larval stage in a laboratory, and his studies outlined a method for culturing early stages of king crab. Currently, the kurama prawn (Penaeus japonicus) and the Japanese blue swimming crab (Neptunus pacificus) are both mass cultured in western Japan. Such large-scale rearings demonstrate the possibility of similar production of king crab larvae. In 1970, experiments on crab aquaculture began in Hokkaido, northern Japan (Nakanishi 1976, Omi 1980, Nakanishi and Naryu 1982).

In Japan, studies on rearing of cold water crabs have been conducted mainly since 1970. The studies on the rearing of snow crab larvae were reported by Kon (1980) and Kobayashi(1983), horsehair crab by Omi and Mizushima (1972), and Hanasaki crab by Nakanishi(1981) and Iwamoto et al.(1982). Such mass-cultivations are being conducted at Marine Cultivation Centers under prefectural management and the Japan Sea Farming Association. At present, the numbers of seedlings of king crab and Hanasaki crab exceed 200,000 and there are about 1,000 snow crab seedlings. In these studies, environment effects were examined, and there are several potential environmental conditions which may affect survival of crab seedlings. However, there is not enough information concerning enviromnent effects on the success of the mass-cultivation of crab larvae and post-larvae. Thus, I studied on the effect of environment on growth, survival rate and oxygen consumption in this project.

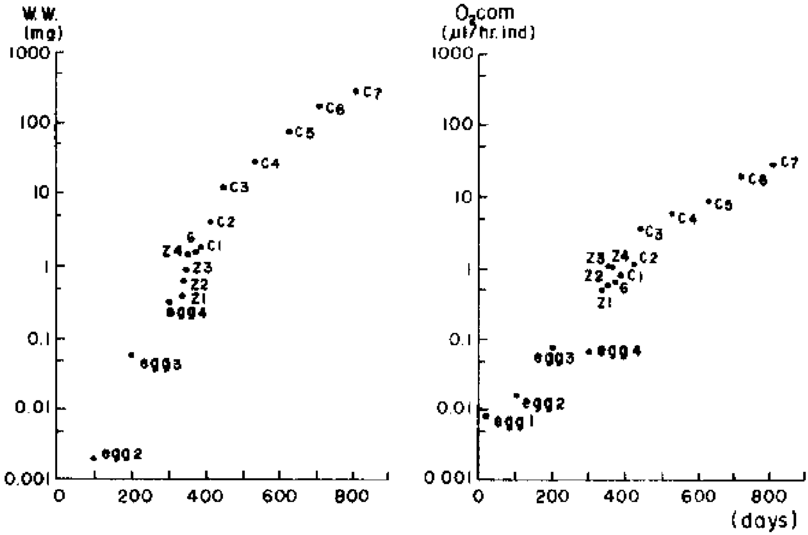


Fig.1 The relationship between the term (days) and the wet weight (mg) of eggs at 3°C and of larvae and post-larvae at 8°C (A), and the relationship between the term (days) and the oxygen consumption (µl/hr. ind.) at 8°C (B).

Life History

Eggs adhere to the abdominal pleopods of king crabs where they are brooded for about 300 days until they hatch at 3°C. There are four planktonic zoeal stages. After approximately 30 days at 8°C, zoeae molt to glaucothoe that have the ability to swim, but whose morphology is crab-like in appearance. The glaucothoe stage molts to become a young, bottom dwelling crab that cannot swim. The egg stage is abbreviated as E (for example, the egg stage at 100 days after the spawning is shown as E-100), the zoeal stage as Z, the glaucothoe stage as G and the young crab stage as C.

When the mass-cultivation is conducted, the data of weight and oxygen consumption is the basic data to calculate the metabolism and the amount of food. Thus, I would like to report the wet weight and oxygen consumption in this section.

Wet weight - The change in size from the egg stage (the embryo) to the young crab stage is indicated by wet weight (Fig.1-A). Wet weight increased exponentially with the time (days). The time (days) during one stage was about 30 days until C-2, but this term during one stage from C-3 was about 90 days, and the regression line was bent at C-3. The king crab molts more frequently, but the growth rate is slower than that of snow crab and horsehair crab. At Z-4, G and C-1, there were large morphological and ecological changes, but the dry weight, wet weight and carapace length at Z-4, G and C-1 was nearly the same (Nakanishi et al. 1974), in other words, there was no growth during these stages.

Oxygen consumption - The oxygen consumption also increased exponentially with the time and this regression line was bent at C-3 (Fig. 1-B). The oxygen consumption of E-300, Z-1, Z-2, G, C-1 and C-2 was under the regression line.

One of the more important enviromental variables affecting marine organisms especially those living in the cold sea is temperature. Thus, the effect of water temperature on the survival, development, respiration and growth rate at eggs, larval and post-larval stage is reported first, and the effect of hypoxia, light and numbers of larvae and post-larvae on the oxygen consumption and the survival rate is reported next.

Effect of Temperature

Egg bearing females cultured at 3 and 8°C - The effect of water temperature on the survival and developmental rate at E was studied by cultivating egg-bearing females at 3 and 8°C respectively in fiberglass flow through (1 liter/min.) tanks with a sand filter. Frozen squid, shrimp and sardines were supplied for food. The experiment started with four crabs at 3°C and with three crabs at 8°C.

Egg clutch volumes at 8°C decreased rapidly from E-40 and were under 10% at E-70, while egg clutch volumes at 3°C decreased gradually, and were 10-80% when the larvae hatched (Fig. 2-A).

The yolk volume at 8°C decreased rapidly from E-120, while the yolk volume at 3°C decreased slowly from E-150 (Fig. 2-B).

The egg bearing females mated in the laboratory were cultured at 3°C, and the developmental stage of their eggs (Fig. 2 -C -d) regarded as a standard egg developmen in order to compare with the development stages of eggs between 8°C and 3°C. The developmental stages of eggs at 3°C were the same as the standard. But those at 8°C were faster than the standard, and there were a lot of fluctuations of the morphological development. The egg development of E-170 at 8°C was the same as that of E-270 - E-300 at 3°C (Fig. 2-C).

Survival rate at egg stages - In order to know the effect of water temperature on the development and survival rates of eggs, eggs removed from the females' pleopods at E-23, E-57, E-166 and E-258, were cultured at -1.8, 3, 8, 13 and 18°C. Culturing was done in a bacteria free petri dish with 30ml sea water for five weeks (Fig. 3). At E-23 and E-57, the survival rate at five weeks was 100% at -1.8, 3 and 8°C, 20-70% at 13°C, and 20-30% at 18°C. At E-166, the survival rate at five weeks later was 100% at -1.8, 3, 8 and 13°C, and 90% at 18°C. At E-258, the survival rate decreased with the rising of water temperature. Fifty percent of the eggs died at 4 weeks later at 8°C, 3 weeks later at 13°C and 2 weeks later at 18°C.

Egg development - Comparisons of egg development between experimental and standard groups are discussed in the same way as reported previously for long term cultivation of egg-bearing females (Fig. 4).

The growth rate increased with the rising of water temperature, but at E-23, the growth rate at 13°C was higher than the growth rate at 18 °C. The size of the embryos cultured at higher temperatures at E - 23, E-57 and E-166 was smaller than the length of the embryo that were cultured at 3°C. There might be no morphological change even if the water temperature increased at E-258, and a lot of larvae hatched out

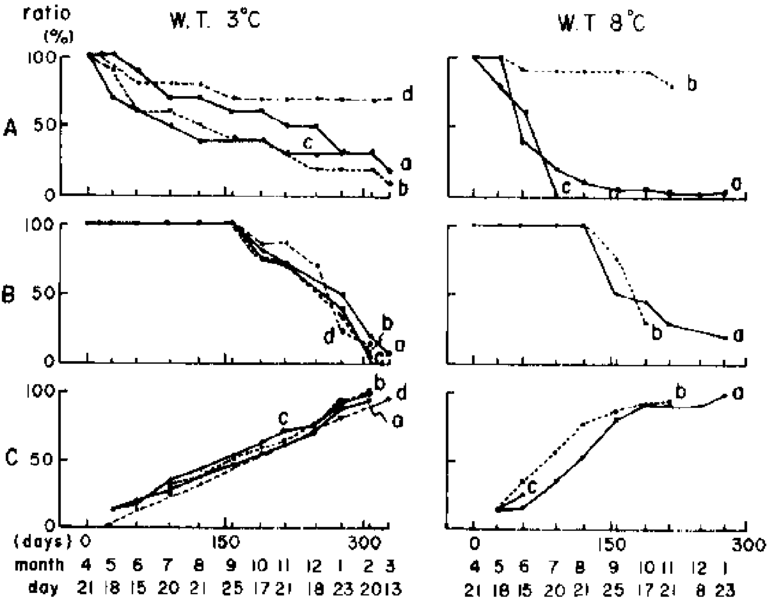


Fig.2 Egg clutch volumes (egg clutch volumes at the start of the experiment were 100%) (A), ratio of volumes of yolk (by the observation fresh sample) (B), and the relationship between the egg development at each experimental condition and the standard one (C-d) (C) at 3° and 8°C.

with the rising of water temperature. But the survival rate of larvae was not satisfactory.

Hatching rate - The effect of water temperature on the hatching rate of eggs was studied as follow. Eggs were removed from females' pleopods at 4 and 18 days before the larvae would have hatched normally at 3°C. These eggs were cultured at -1.8, 3, 8, 13 and 18°C in bacteria free petri dishes with 30ml sea water for 6 days. And the hatching rate of eggs at each water temperature conditions was observed daily. In the experiment of eggs that would hatch in 18 days before the hatching, there was no hatching at -1.8 and 3°C, but at 8°C, larvae hatched at 4-5 days. In the experiment of eggs that would hatch in 4 days before the hatchino,at 8°C larvae hatcehd at 3 days and at 1-2 days at 13 and 18°C. In order to get an equal growth rate, the rising of temperature was an easy method. But the survival rate of post-larvae was low, therefore it was dangerous for eggs to be exposed to warmer temperatures just before hatching.

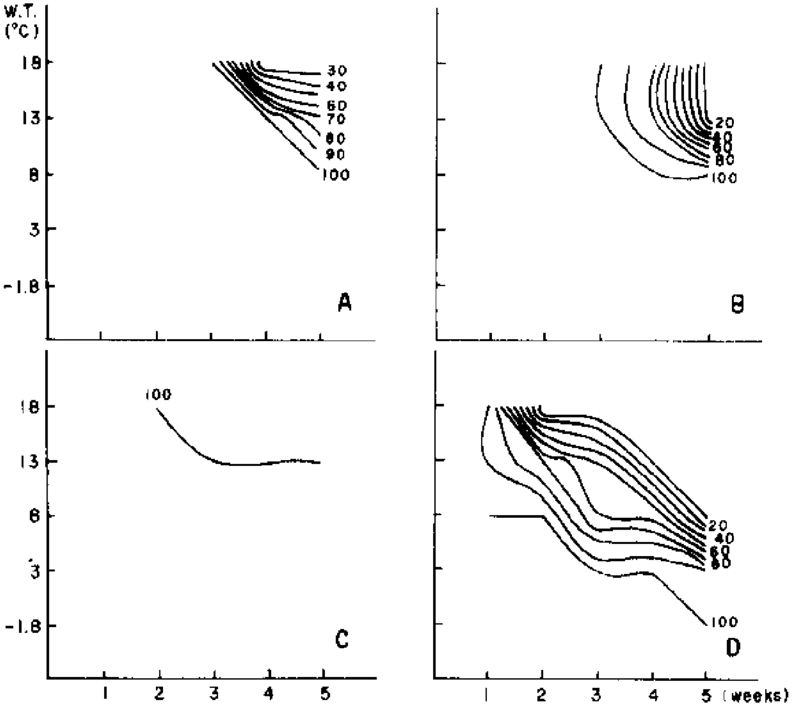
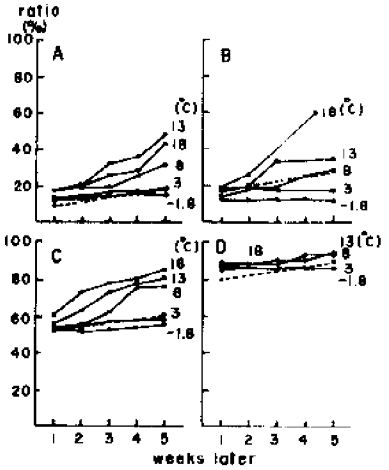


Fig.3 The effect of W.T. on the survival rate of eggs
A - 23 days after the spawning B - 57 days after the spawning
C - 166 " D - 258 "

In air at eggs stage - The survival rate of the eggs at E-250 in the air (100% humidity) was conducted at -1, 3, 8 and 13°C. They survived for over 10 days at -1 and 3°C, but 50% died at 32 hours later at 8°C.

Egg-bearing female cultured from 8 to 3°C - These data suggest that the temperature from 3 to 8°C represents an optimum temperature for the development until the zoea egg stage (about 200 days after the spawning at 3°C), and 3°C represents an optimum temperature from the zoea egg stage. So the egg-bearing female was cultured at 8°C till E-120 and cultured at 6°C till the zoea egg stage. And from this stage the water temperature was decreased gradually to 3°C, and the eggs were cultured at 3°C until the larvae hatched. The egg clutch volume was 80% when the larvae hatched and the survival rate of post-larvae was 20-30% (Fig. 5). This rate was similar to survival rates of post-larvae that were hatched from egg-bearing females cultured at



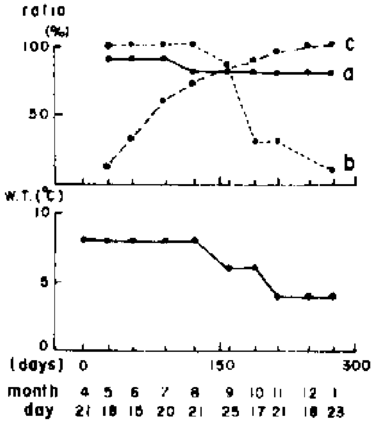


Fig.4 The effect of water temperature on the egg development compared with the standard one. (doted line --- the standard development)

A - 23 days after the spawning.
B - 57 〃
C - 166 〃
D - 258 〃

Fig.5 The egg development reared at 8-6-3 °C.

a - egg mass volumes.
b - volumes of yolk.
c - compare with the standard one.

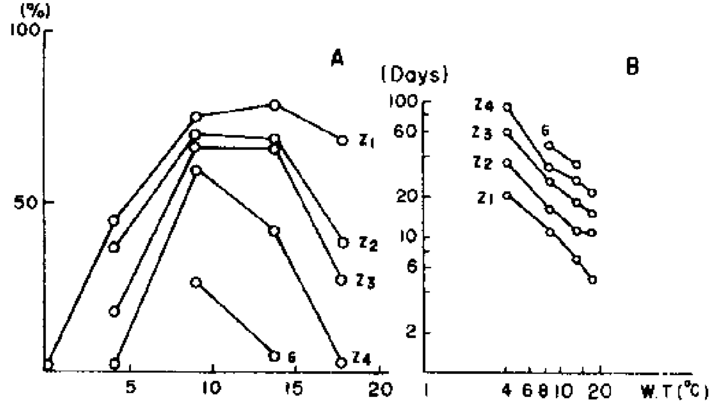


Fig.6 The effect of water temperature on the survival rate of larvae (A), and the relationship between the water temperature and the growth rate of larvae (B).

3°C. This method of controlling the temperature spent less energy than keeping it at 3°C in summer, and hatching could be advanced by 2 months. Therefore, the same tank could be used twice or three times to culture larvae. The first mass-cultivation was conducted with the egg-bearing females that were cultured at 8 or 3°C. The second group of larvae hatched from the egg-bearing females that were cultured at 3 °C or caught in the field.

Survival rate at larval and post-larval stage - The experiment to determine the effect of water temperature on the survival and growth rate was conducted in polyethelene tanks (47 x 30 x 20 (depth) cm) with 5 liters sea water at -1.8. 3, 8, 13 and 18°C. Four tanks were used for each temperature; two tanks with 20 zoeae and the other two tanks with 40 zoeae. When 50% of the zoea developed to the next stage, the former stage was regarded as terminated.

The survival rates at Z and G at 8 and 13°C were higher that those at 3 and 18°C. The glaucothoe molted to C-1 at 8 and 13°C, but all glaucothoe at 3 and 18°C died before molting to C-1. The survival rate from Z-1 to C-1 was 25% at 8°C and 5% at 13°C. It took 40 days from Z-1 to Z-2 at -1.8°C, and all zoeae died before molting to Z-3 (Fig. 6-A). The relationship between the time (days) of each stage and the water temperature applied to the formula logy=blogx+a (water temperature is x (°C) and the time is y (days)) with a high correlation. The variable b was roughly equal to 1, therefore, these regression formulas were regarded as "the total integrated temperature" (xy=c) which was approximately 350°C days at Z (Fig. 6-B).

Carapace length at young crab stage - The relationship between the water temperature and the growth rate of the young king crab in some reports (Kurata 1961; Omi 1976 and 1977 (cited from Omi 1980) and Nakanishi et al. 1974) gave as the formula logy=a+bx (the carapace length is y (mm) and the stage is x) with a high correlation (Fig. 7).

I replaced these regression formulas with the highest value of b (in other words, with the highest growth rate during each stage) (Table 1). The environmental condition of these results is shown from the highest letter b as follows: more than C-4 at 8-9°C > less than C-5 at 8-9°C > more than C-4 at 3°C. The growth rate was higher for higher water temperature and older crabs.

Movement and activity at young crab stage - When seedlings would be released into the field, they exposed to the condition of rapid change of temperature which appeared between the rearing and the field. Therefore, the effect of water temperature on the movement and activity of young crab was studied in the experimental tank (180 x 40 x 40 (depth) cm) that had six partition walls inside the tank to make a wide water tmeperature gradient. Warm sea water (16.5°C) and cold sea water (3°C) was put into each corner of this tank (Fig. 8-A), and thus created a temperature gradient (Fig. 8-B). Young crab at C-4 or C-5 that were cultured at 3, 8 and 13°C were released into the tank at 3, 8 and 13°C. The movement of this crab was observed for 15 minutes at intervals of 30 seconds. In each experimental condition, five crabs were used.

The young crabs that were cultured at 3°C and released at 13°C moved the longest distance at 15 minutes after their release (Table 2-A). The crabs that were cultured at 3°C and released at 8°C moved

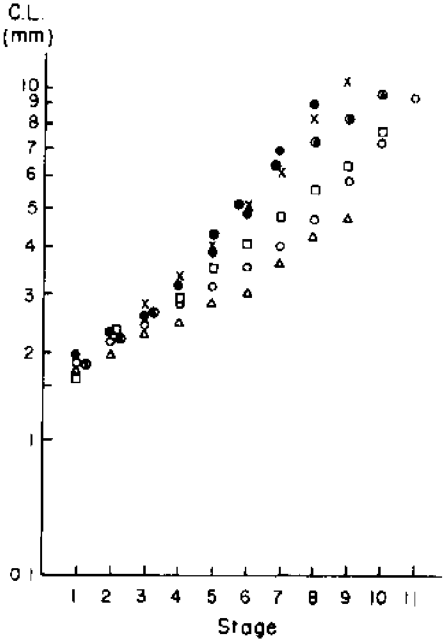


Fig.7 The relationship between the stage and the carapace length (mm) of young king crab. ● - (W.T.8°c). X - (Omi,1977). O - (Omi,1976). □ - (Kurata,1961b). ⊙ - (W.T.3°c). △ - (Kurata,1961a).

Table 1 The ralationship between the stage and the carapace length of each experiment. [log(CL)=a+b(STAGE)] *--different. (p=0.05)

No.		stage	WT(C°)	1	2	3	4	5	6	7	8	9	10	b
1		(>=C5)	8.0	\	·	*	*	*	*	*	*	*	*	0.1236
2 Omi	,1977	(>=C5)	9.2	·	\	*		*	*	*	*	*	*	0.1054
3 Omi	,1976	(C8-12)	9.2	*	*	\	·	*	*	*	*	*	*	0.0991
4 Nakanishi	,1974	(C1-3)	11.4	*	*	·	\	*	*	*	*	*	*	0.0950
5 Omi	,1977	(=<C4)	9.2	*	*	*	*	\	*	*	*	*	*	0.0879
6		(=<C4)	8.0	*	*	*	*	*	\	·		*	*	0.0782
7 Kurata	,1961b			*	*	*	*	*	·	\		*	*	0.0778
8	,1979	(C5-10)	3.0	*	*	*	*	*			\	*	*	0.0733
9 Omi	,1976	(<C8)	9.0	*	*	*	*	*	*	*	*	\	*	0.0570
10 Kurata	,1961a		13-17	*	*	*	*	*	*	*	*	*	\	0.0523

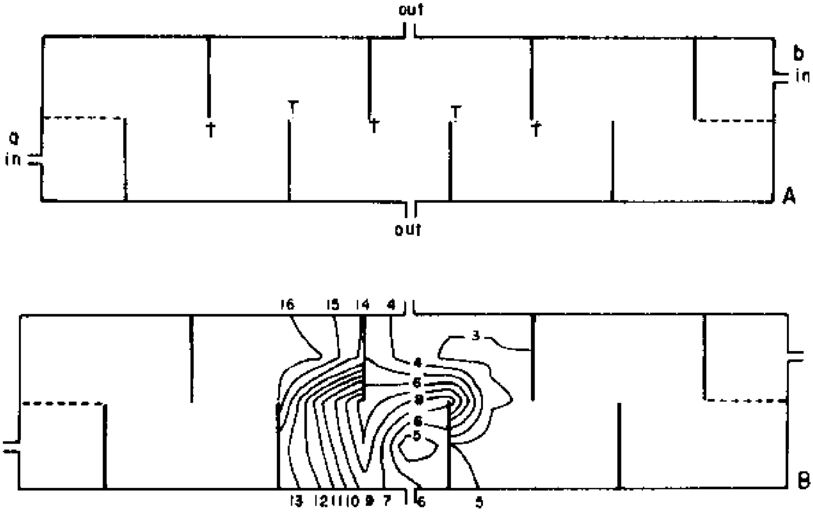


Fig.8 The apparatus to determine the effect of temperature on the movement of young crab (A). a-warm sea water (16.5°C) flow in. b - cold sea water (3°C) flow in. T -- thermometer. And one example of the water temperature in the experimental tank (B).

Table 2-A The water temperature that young king crab were stopped at 15 minutes later.

W.T. (young crab put in)	rearing water		temperature before		the experiment	
	3 °C		8 °C		13 °C	
	3.8	3.5	3.9	3.6	3.0	3.0
3 °C	4.0	4.0	4.0	3.1	3.0	3.0
	4.0		3.0			
	9.8	16.3	7.6	4.8	9.0	9.0
8 °C	8.4	8.7	15.3	7.5	8.4	5.0
	8.1		2.7		4.5	
	9.2	11.5	14.5	16.5	12.9	7.1
13 °C	13.9	14.0	15.0	16.5	7.9	15.5
	12.0		16.1			

Table 2-B The mean and s.d. of the total movement (cm) for 15 minutes of young king crab in the experimental tank.

W.T. (young crab put in)	rearing water 3 °C			temperature before 8 °C			the experiment 13 °C		
	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n
3 °C	29.3	13.00	5	16.5	7.68	5	3.7	3.32	5
8 °C	30.2	24.03	5	43.8	26.37	5	30.2	24.03	5
13 °C	31.7	16.48	4	63.5	30.01	4	36.3	18.57	4

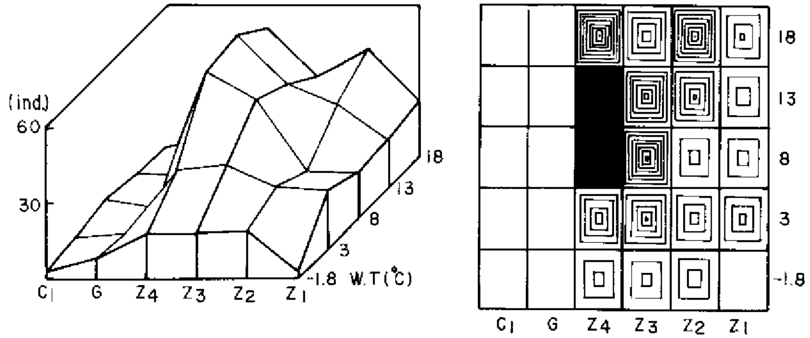


Fig.9 The effect of water tmeperature on the numbers of brine shrimp nauplii eaten by larvae and post-larvae. [right - the above view of the three dimensional graph (left), the dark place was shown the higher place in this 3-D graph].

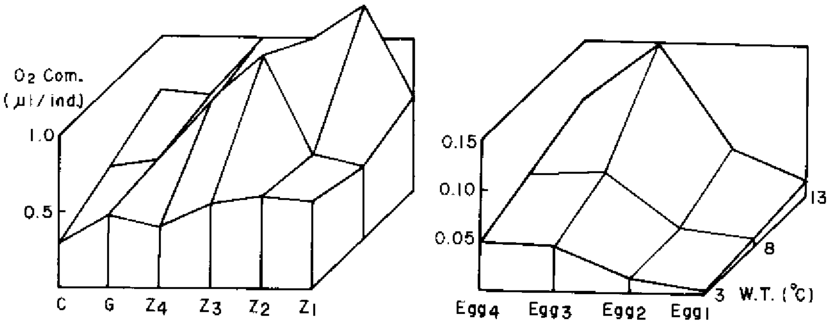


Fig.10 The effect of water temperature on the oxygen consumption of eggs, larvae and post-larvae.

E1 ··· 20 days after the spawning.
E2 ··· 100 "
E3 ··· 200 "
E4 ··· 300 "

the middle distance. The difference between the distances that young crab moved at 3 and 8°C was large. Young crabs that were cultured at 13°C and released at 3°C could not move as if paralyzed. Those that were released at 8 or 13°C moved actively. They had no tendency to move to the same water temperature where they had been cultured, but they distributed throughout locations of various temperatures (Table 2-B).

Food consumption at larval and post-larval stage - The experiments to determine the effect of water temperature on the number of brine shrimp nauplii eaten was conducted at -1.8, 3, 8, 13 and 18°C from Z-1 to C-1 (Fig. 9). Larvae were put into a petri dish with 100 brine shrimp nauplii in 30ml of sea water, and the number eaten was counted under a stereoscopic microscope at 24 hours later. The numbers eaten at Z gradually increased with the developmental stage and rising water temperature, but its increase at Z-4 stopped at 8°C. The number eaten decreased sharply at G and C-1. Perhaps brine shrimp are not a good prey for post-larvae, since in other experiments with five kinds of food at G, no food could be found in their stomachs. Perhaps G stage does not feed.

Oxygen consumption - Oxygen consumption at E-20, E-100, E-200 and E-300, Z, G and C-1 was measured at 3, 8 and 13°C (Fig. 10). The specimens were placed in syringes held in a temperautre controlled water bath. Two water samples (about 0.2ml each) were taken from the syringe at zero time and two more samples from 30 minutes to 4 hours later depending on the temperature and the developmental stage. Oxygen concentration was calculated from oxygen pressure measured by an oxygen meter (Instrumentation Laboratory Co.). In each test, five syringes were containing 20-100 eggs or a single larva was used. From E-20, E-100 and E-200 oxygen consumption (Vo2) increased but Vo2 at E-200 and E-300 was the same. The oxygen consumption at 13°C was the highest, the lowest was at 3°C, and the intermediate at 8°C. The oxygen consumption at Z-1 was about ten times that at E. The oxygen consumption from Z-1 to C-1 at 3°C was almost the same. The oxygen consumption at Z-3 at 8°C peaked and then decreased from this stage.

Effect of Hypoxia on the Oxygen Consumption

The same methods as experiment on Vo2 were used to study the effect of hypoxia on Vo2 at 3, 8 and 13°C (Fig. 11). Different levels of oxygen saturation (Po2) were obtained by passing Nitrogen gas through sea water. The value for Po2 where Vo2 was maintained at the similar rate to Po2 of 90-100% was the lowest at E-100 at 3, 8 and 13 °C. and the highest at G at 3°C and at Z-1 at 8 and 13°C. The normal rate of Vo2 at lower Po2 suggested that there might be a physiological adjustment for taking up oxygen. A homoeostasis of oxygen consumption at E was observed at oxygen saturation higher than 50%, and homoeostasis of oxygen consumption at Z, G and C-1 was observed at oxygen saturation of 70-80% but the gradient at C-1 was above those at Z and G. The effect of water temperature on the oxygen consumption at the hypoxia condition had the same tendency except at G at 3°C.

Effect of Salinity on the Survival Rate

The effect of water temperature and salinity on the survival rate was studied. Eggs that would hatch in about 30 days, Z-1 and Z-2, Z-3 and Z-4, G and C-1 were used in this experiment (Fig. 12). Ten eggs or ten larvae were placed in a one liter beaker and the survival rate after 24 and 48 hours observed. The experimental temperature were at -1.8, 3, 8, 13 and 18°C and 11 salinity conditions ranging from 0 to 67‰. at intervals of 6.7‰ There were 6x11 experiments with paired observations. The area representing the 100% survival rate at 48 hours later in Fig.12 was shown from the largest area as

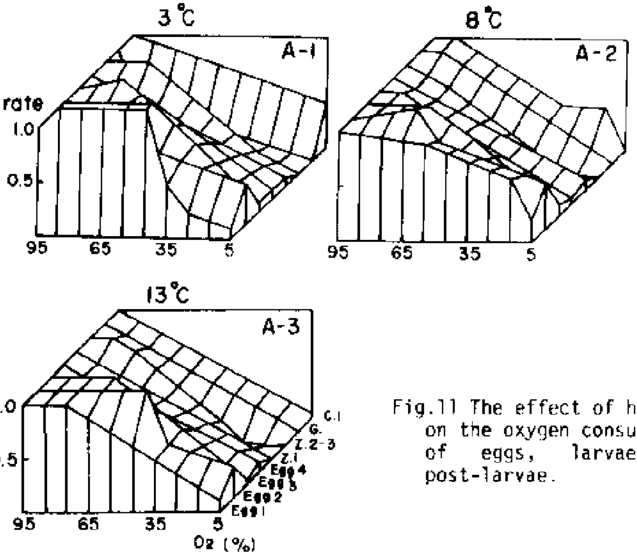


Fig.11 The effect of hypoxia on the oxygen consumption of eggs, larvae and post-larvae.

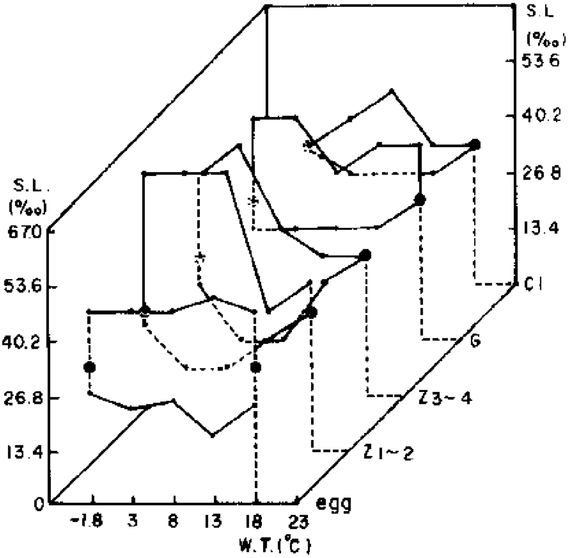


Fig.12 The effect of salinity and water temperature on the survival rate of eggs, larvae and post-larvae.

follows : at Z-1 and Z-2 ❯ at Z-3 and Z-4 ❯ at G ≒ at eggs (about 30 days before the hatch) at C-1. The tolerance to the change of water temperature and salinity at Z is the highest, and it is the lowest at C. The thermal tolerance in 33.5‰, Sea water (approximately the same salinity as natural sea water) was between -1.8° and 18°C. The eggs, larvae and post-larvae have a large short term thermal tolerance.

Effect of Light on the Survival Rate

The effect of light intensity on the survival rate was conducted in one liter beaker with 10 zoeae at 3°C. The range of light intensity was made by the distance of the artificial light from the beaker. Light intensity was 15,000 10,000 5,000 and 2,000 lux at Z-1 - Z-2 (Fig. 13-A) and 15,000 10,000 and 5,000 lux at G (Fig. 13-B) and C-1 (Fig. 13-C). The survival rate decreased with the increase of light intensity and this relationship was linear for light intensity above 5,000 lux.

The effect of period of time of light and dark during one day on the survival rate was conducted in one liter beaker with 10 zoeae at 8°C. The condition of the light-dark term was as follows : 24 hours light, 16 hours light and 8 hours dark, 8 hours light and 16 hours dark and 24 hours dark (Fig. 14). The light intensity was 1,000 lux. There was no effect of light-dark terms on the survival rate. There was no difference of time (days) during each stage.

Effect of the Numbers of Larvae and Post-Larvae on the Survival Rate

Rearing in polluted sea water - The larger the number of larvae in tanks the more polluted the rearing sea water was. There might be some effect of polluted sea water on larval survival. Therefore, the effect of the polluted rearing sea water on the survival rate was studied at 8°C in one liter beaker (Fig. 15). The range of polluted rearing sea water was created by the transfer of larvae as follows. Eleven beaker were prepared with one liter of sea water (these beakers were numbered as B1, B2, B3····· B10 and B11) and ten zoeae were cultured respectively (these zoeae group were numbered as K in B1, J in B2, I in B3;···· B in B10 and A in B11). And the next day, K was transfered to B2, J was transfered to B3, I was transfered to B4, ····· B was transfered to B11. The sea water in B1 was replaced by fresh sea water and A was transfered to B1. At this next day, K was transfered to B3,····· the sea water in B2 was replaced by a fresh one and A was transfered to B2. These transfers were continued once a day, and at 11 days later, 11 ranges of polluted sea water were made (K was cultured in the polluted sea water and the total number of rearing larvae was 100 zoeae, and A was cultured in the fresh sea water). There was a lot of dust, molted carapace and leftover food in the tank at 11 days later, but the P.H. and oxygen saturation was the same as the fresh water. There was no effect of polluted rearing sea water on the survival rate of larvae. Thus, I studied the effect of more polluted sea water on the survival rate. The volume of sea water in each beaker was 200ml and the term of the transfer of larvae was once two days. In this experimental condition, the total number of rearing larvae was 1,000 in one liter beaker in the most polluted condition, but in these conditions there were also no effect of the polluted rearing sea water on the survival rate.

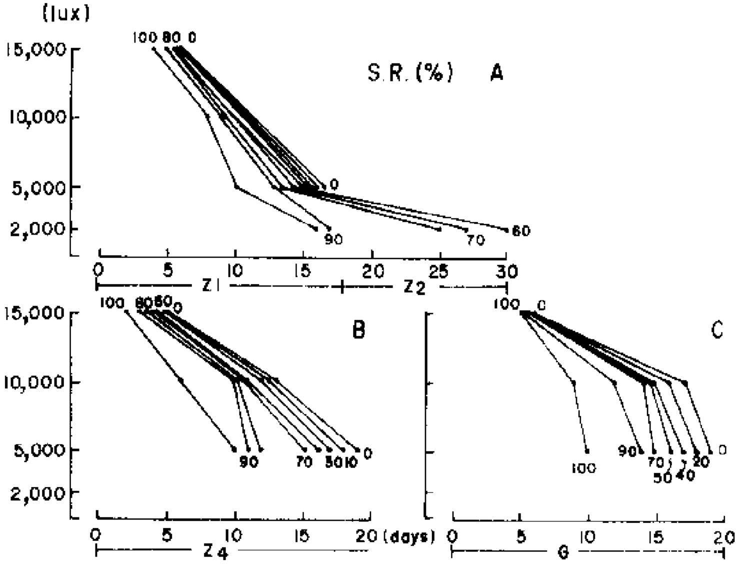


Fig.13 The effect of light intensity on the survival rate at zoeal (A), glaucothoe(B) and young crab (C) stage by 3°C.

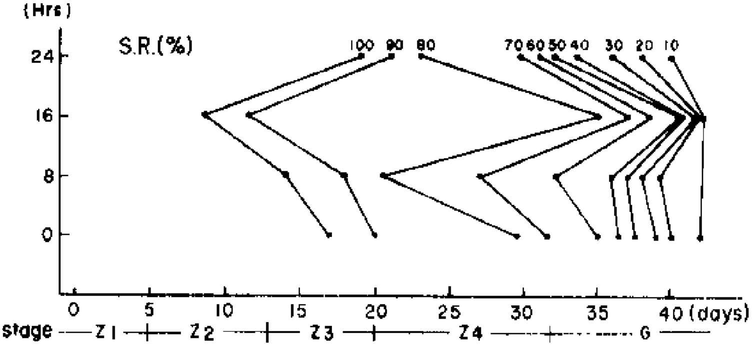


Fig.14 The effect of period of time of light and dark on the survival rate of larvae (8°C).

Number of larvae and post-larvae - The effect of larval density was studied at Z in 1, 30 and 500 liter tanks, and at C-1 in one liter tank. At Z in one liter beaker, the volume of sea water was 200, 400, 600, 800 and 1,000ml with 35 zoeae respectively and 200, 400 and 800ml with 150 zoeae respectively. There was little effect in relation to the volume of water, but there was an effect of density in relation of the number of larvae in one beaker (Fig. 16). The optimum numbers of larvae in one vessel (the survival rate was above 80% from Z-1 to G) was less than 10 zoeae in one liter beaker, 500 in 30 liter tank and 20,000 in 500 liter tank (Fig. 17). At C, there was not a typical effect of the number of young crab on the survival rate, and the distribution pattern of young crabs on the bottom of the tank during the cultivation was at random. The optimum number of young crabs might be under 10 in one liter beaker. These results suggest that at C there may be little effect of density on the survival rate at C, but the main reason of death at C was cannibalism. And cannibalism was also occured many times at Z and G. Therefore, the protection against cannibalism is one of the most important method to succeed the mass-cultivation of king crab seedlings.

Conclusion

These results suggest that there is little negative effect of 8°C warm sea water on eggs until the zoea egg stage (about 200 days after the spawning at 3°C), and 8°C water increases growth rates of eggs and reduces rearing cost (Fig. 18). But from the zoea egg stage, 8°C affected the survival rate and 3°C was the optimum water temperature. The zoeae had a large thermal tolerance, but from the viewpoint of growth and survival rate, 8°C was the optimum water temperature. Glaucothoe had the same characteristics. The thermal tolerance at G was less than that of the larvae, and the growth rate suggested that an optimum water temperature for the cultivation was 8°C. The thermal tolerance of king crab is larger than that of hanasaki crab (Nakanishi 1981), and an optimum temperature is lower than that of snow crab (Kon 1980). It seemed that this characteristics might be one reason for the limit of the main distribution of king crab to more northern Japan than that of snow crab.

The tolerance to hypoxia and salinity, and the optimum condition of light intensity and number of larvae and post-larvae is shown at Fig.19. The optimum light intensity is from 0 to 2,000 lux. But when phytoplankton were put in the rearing tank for food, some light intensity was necessary. Therefore the optimum light intensity might be 2,000 lux or more.

The kinds of food throughout this experiment are shown in Fig.20. These kinds of food were satisfactory to culture the larvae and post-larvae, but the cultivation of rotifer needs the warm water temperature (from 20 to 30°C). The study of optimum food that can culture in the cold sea is necessary. Since 1982, the Japan Sea Farming Association at Akkeshi branch at Hokkaido has been conducting the mass-cultivation of king crab seedlings. The total number at C-1 was 228,400 in 1983 and the survival rate from Z-1 to C-1 exceeded 80% in 20 tons tank (Nagakura et al. 1983). A method of mass-cultivation of king crab seedlings exists, and the experiment of releasing of king crab seedling into the field in preparation. However, there are a lot of unstudied problems in the propagation of king crab, such as optimum place, time and management to release and recapture the king

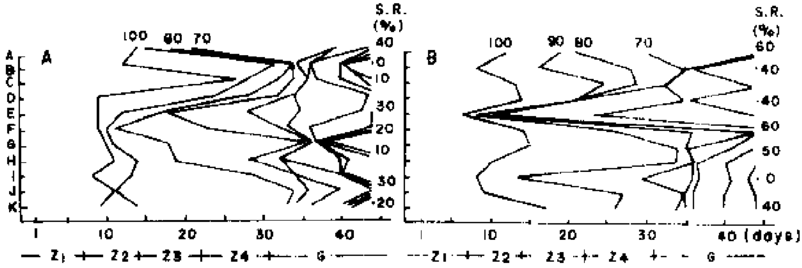


Fig.15 The effect of polluted rearing sea water on the survival rate of larvae with one liter sea water of the Series A and the Series B.

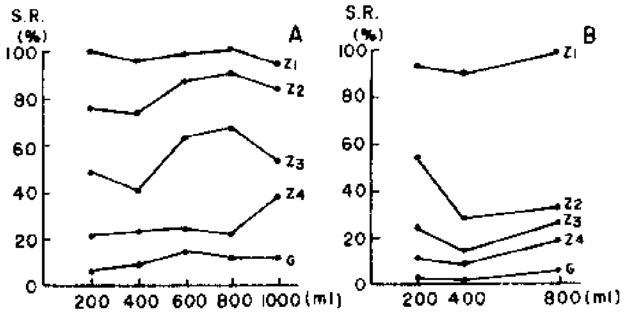


Fig.16 The survival rate (S.R.) of larvae and post-larvae, 35 zoeae at Z-1 in one liter tank with 200, 400, 600, 800 and 1000ml sea water (A) and 150 zoeae at Z-1 with 200, 400 and 800ml sea water.

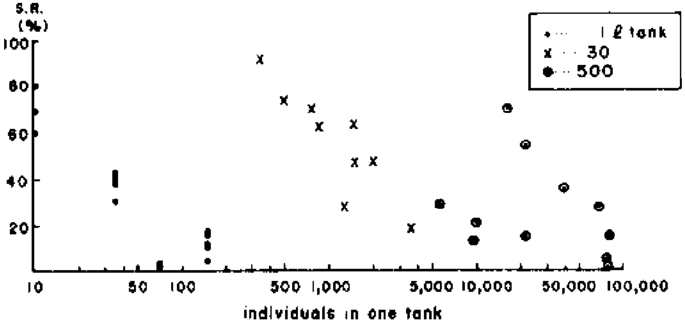


Fig.17 The relationship between the numbers of larvae in one tank and the survival rate.

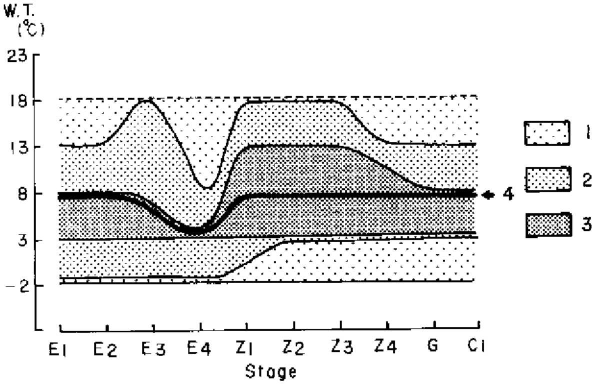


Fig.18 The optimum water temperature for eggs, larval and post-larval stage.
1 - The survival rate at 48 hours later is 100%.
2 - The survival rate at 30 days later at the eggs stage is 100% and juvenile can molt to the next stage.
3 - The normal cultivation is possible.
4 - the optimum temperature for the mass-cultivation.

crab seedlings.

Acknowledgement - I wish to say my hearty thanks to Director A.J. Paul, Seward Marine Center, University of Alaska, for his kind advice and criticism for reading the manuscript. I thank Mrs. N. Naganuma, Japan Sea Regional Fisheries Reserch Laboratory, for writing up the figures.

Abstract

In order to know the optimum environmental conditions for the mass-cultivation of eggs, larvae and post-larvae of King crab, the effects of temperature, hypoxia, salinity, light intensity and number of larvae on the survival rate, growth and respiration were studied.

The optimum temperature from the fertilization to the zoea egg stage is 3-8°C, and from this stage to the hatching out is 3°C. The optimum temperature for the mass-cultivation of larvae and post-larvae is 8°C. The optimum condition of the oxygen saturation is more than 80%, of the salinity is 26.8 - 40.2‰, of the light intensity is 2,000 lux or more and the number of larvae in 500 liter tank is 20,000 and of post-larvae is 1,000 - 2,000.

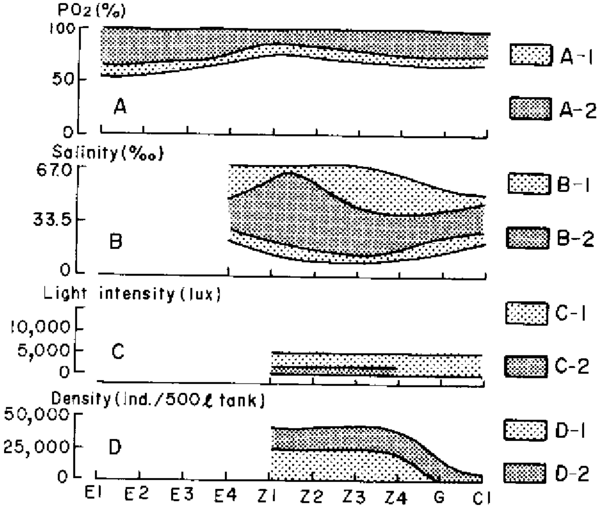


Fig.19 The optimum environment condition.
A - The oxygen saturation (%). A-1 - 80% of the oxygen consumption of the normal rate. A-2 - 90% "
B - The salinity (%). B-1 - 50% survival at 24 hours later. B-2 - 100% survival at 48 hours later.
C - The light intensity (lux). C-1 - 100% survival at 10 days later. C-2 - the optimum light intensity for the rearing.
D - The numbers of juvenile. D-1 - the survival rate was upper 80%. D-2 - the optimum density of juvenile for the rearing.

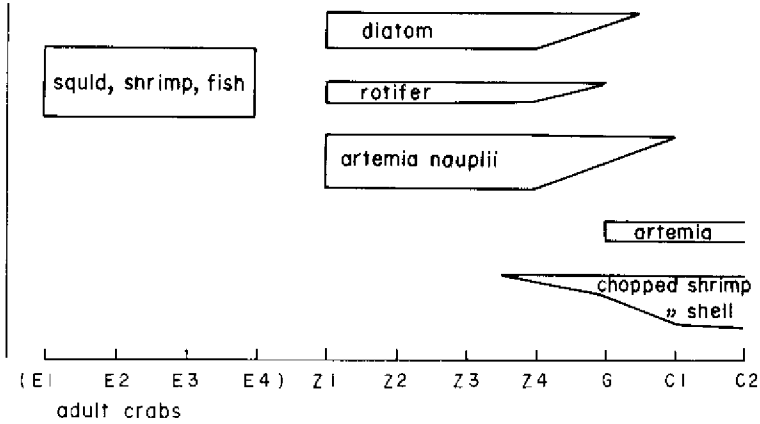
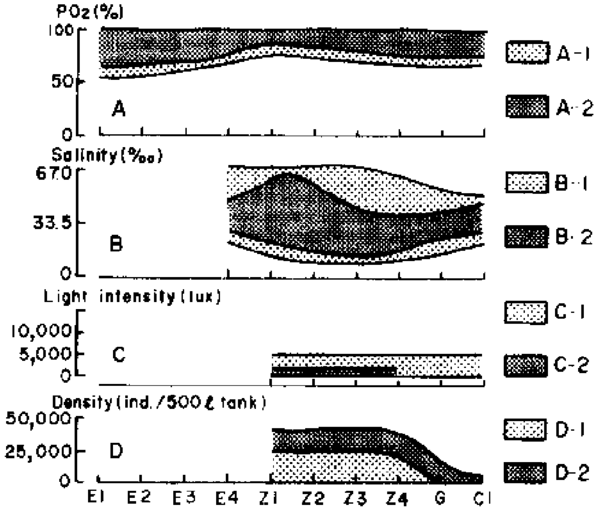


Fig.20 The kinds of food for the cultivation in this experiment.



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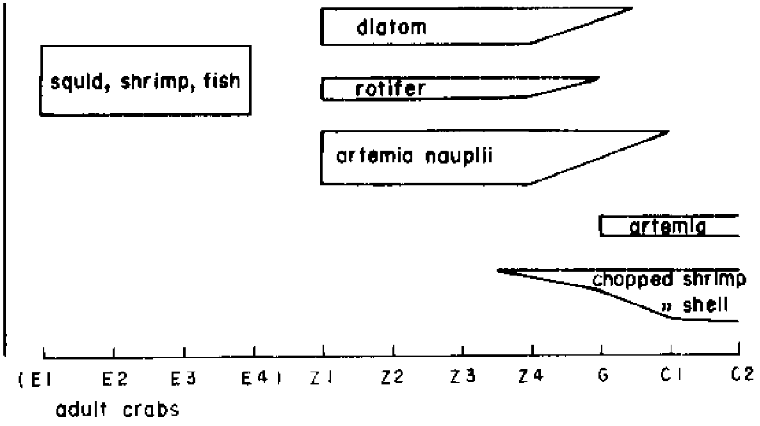

Fig.20 The kinds of food for the cultivation in this experiment.

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Feeding rates, molting success, and survival of juvenile red king crabs at different temperatures

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Abstract

Juvenile (3-4 cm carapace length) red king crabs, Paralithodes camtschatica, were reared for 90 d at 1, 5, 10, 15, and 20°C, to determine the effects of different temperatures on feeding rates, molting frequency and success, and survival. As the temperature increased, food consumption increased linearly. Molting frequency was highest at the middle temperatures. All crabs at 10°C molted at least once.

The survival of crabs during the 90-d study was influenced by both temperature and molting frequency. For non-molting crabs, the survival was 100%; consequently, the extreme temperatures had relatively high survivals because there were very few molting attempts. For molting crabs, the survivals were highest at 5 and 10°C. The poorest survival was at 15°C because there was a relatively high molting frequency, and only 12% of the molting crabs survived.

For long-term rearing of juvenile king crabs, 10°C is best because it allows the most successful molting and reasonable, overall survival. Temporary holding at 0-5°C may be useful because molting frequency is reduced and survival is very high. The lack of successful molting at >10°C suggests that elevated temperatures in the shallow waters normally inhabited by juvenile red king crabs in summer may contribute to population decreases.

Introduction

There are several hypotheses for the decline of the valuable red king crab, Paralithodes camtschatica, stocks in the southeastern Bering Sea, but the data base is too small to support cause and effect conclusions.

Causes suspected of contributing to the decline of red king crab stocks include disease, overfishing, handling mortalities of sublegal crabs during the commercial harvest, increases in other predator or competitor stocks (i.e., cod, halibut, yellowfin sole), and changes in environmental temperatures. Evidence for any one cause over another is lacking.

Changes in the environment are often suspected of affecting commercial fishery stocks, but usually difficult to prove. Sometimes there are correlations of stock changes with average temperature changes, but the effects of temperature changes are too complex for the correlations to be perfect from one year to the next. Temperature will have some direct effects on the species, but generally the indirect effects on food supply are more important to juvenile survival rates. Small changes in juvenile survival rates in the environment are usually too difficult to measure, even though the impact on commercial stocks may be large in the following years. Changes in average temperatures have affected other commercial fishery stocks, and probably have affected the king crab stocks in the southeastern Bering Sea. However, the effect of a shift in average temperature, in either summer or winter, is not known. Any changes in populations during immature life stages would not become evident for several years in stock assessment surveys. It is possible that general warming during the 1983 El Nino contributed significantly to the decline in king crab stocks, either directly or indirectly; however, the general stock decline that began in 1981 cannot be attributed to the El Nino of 1983.

There is little information on the habitat requirements of juvenile red king crab and the effects of temperature on juvenile king crabs. In the southeastern Bering Sea, the yearly stock assessment cruises by the National Marine Fisheries Service have not provided much information on juvenile king crab. The surveys rely primarily on trawl sampling, and the youngest king crabs in the samples are generally the 4-yr-olds. A study of king crabs in Kachemak Bay indicated that pods of juveniles were found in water between 9 and 13°C (Bright et al. 1960). Another field study located juvenile red king crabs in the southeastern Bering Sea, generally in the shallow areas and nearshore, and also measured bottom temperatures in April, June, and September 1983 (McMurray et al. 1984). Juvenile king crabs were found in water ranging from <1°C at the end of winter to >11°C at the end of summer (McMurray et al. 1984). There are some laboratory studies of the effects of temperature and salinity on king crab larvae and megalops, but not on juveniles.

The objective of this laboratory study was to determine the direct effects of temperature on feeding rates, molting frequency and success, and survival of juvenile red king crabs. Juvenile crabs were reared for 90 d at 1, 5, 10, 15, and 20°C. Particular attention was paid to molting success, which is a sensitive physiological process that shows the effects of a stressful environment more clearly than do either feeding or survival rates.

Methods

Two-year-old red king crabs (3-4 cm carapace length) were collected from a single pod in Auke Bay, Alaska, during April 1984. The crabs were held in running seawater (7-10°C) in the laboratory, until temperature tests began. To identify individuals, we glued (Permabond

910 cyanoacrylate adhesive) a numbered, plastic fry tags (3 mm x 6 mm) to each carapace. Tags were collected from the cast exoskeletons of molted crabs and replaced when new carapaces had hardened.

A short-term temperature tolerance test was used to determine the maximum rearing temperature for the 90-d test. Twelve crabs were held in 10°C water that was increased 1°C/d until all crabs died. In the short-term test, the first crabs died at 23°C, and 50% died by 25°C. The maximum temperature selected for the long-term test was 20°C.

The long-term (90 d) rearing at different temperatures took place in five rectangular, fiberglass tanks divided with screens into three sections each. Each section (54 cm x 48 cm; 40 cm deep) held 8-9 crabs in running seawater, for a total of 26 crabs per tank.

When the study began, the water in all tanks was 10°C. Over a 7-d period, the tanks were gradually adjusted to 1, 5, 10, 15, and 20°C. These temperatures were maintained to within ±1°C, by heaters and chillers with thermostats.

All crabs were weighed (live wet weight) and measured (carapace length, from eye socket to center rear) at the beginning and the end of the 90-d exposure to assigned temperatures. All molts and deaths were noted daily. Crabs were fed Pacific herring fillets. At the midpoint of the test, feeding rates were determined for 15 consecutive days, by weighing the fillets before feeding and 24 hr later when the uneaten portions were removed.

Results

Food consumption increased linearly with increased temperature (Table 1). At 1°C, crabs ate a daily average of 0.09 g of fish, and at 20°C, 1.0 g. Although eating more, crabs at 20°C were generally more lethargic than the mid-temperature crabs.

Table 1. Average food consumption of juvenile red king crabs at different temperatures.

Rearing temperature (°C)	Grams of herring eaten: Per crab per day	Grams of herring eaten: Per gram of crab per day
1	0.09	0.003
5	0.39	0.011
10	0.53	0.012
15	0.84	0.026
20	1.00	0.032

Molting frequency was highest at the middle temperatures (Table 2). At 10°C, all of the crabs attempted to molt at least once during the 90-d study, and 15% molted twice. No crabs at other temperatures molted more than once. The fewest molting attempts were at the extreme temperatures of 1 and 20°C.

Table 2. Molting frequency of juvenile red king crabs at different temperatures.

Rearing temperatures (°C)	Attempted one molt (%)	Attempted two molts (%)
1	8	0
5	46	0
10	100	15
15	62	0
20	19	0

All non-molting crabs survived the 90-d test at all temperatures, but the survival of molting crabs was affected by different temperatures (Table 3). The highest survivals of molted crabs were 75% at 5°C and 65% at 10°C. Survival of molted crabs was only 12% at 15°C, and no crabs survived molting at either 0 or 20°C. Temperature was directly responsible for many of the unsuccessful molts at 1, 15, and 20°C; the dead crabs were not eaten. Cannibalism was responsible for many deaths of crabs at 10 and 15°C; they were eaten before completing the molt extrication.

Table 3. Percent survival of molted and non-molted juvenile red king crabs at different temperatures.

Rearing	Survival of crabs		Overall
temperature (°C)	Non-molting (%)	Molting (%)	survival (%)
1	100	0	92
5	100	75	88
10	100	65	65
15	100	12	46
20	100	0	81

During the 90-d study, overall survival of crabs was influenced by both temperature and molting. The extreme temperatures, 1 and 20°C, had high (92 and 81%) survivals (Table 3), even though the crabs had no success in molting. The high survivals resulted from the fewest (8 and 19%) molting attempts (Table 2). The second highest survival was 88% at 5°C (Table 3) because the crabs had a moderate (46%) amount of molting attempts (Table 2) and the highest (75%) molting success. Survival at 10°C was good (65%), especially considering that all the crabs at this temperature molted once and 15% molted twice. Survival at 15°C was poor (46%) because a high percentage of crabs attempted molt (65%) and survival of molting crabs was only 12%.

We attempted to measure the effects of temperature on growth after molting, but not enough crabs survived molting at temperatures of

1, 15, and 20°C. Although growth of crabs was slightly greater at 10°C than at 5°C, differences were not significant. Crabs (32-34 mm long) at 5 and 10°C grew an average of 15%, and their weights (25-29 g) increased an average of 41%.

Discussion

Molting is always a vulnerable time in the life history of crustaceans. Not only are crabs subjected to predation during the soft-shelled stage after molting, but they must also survive molt extrication. Smaller juveniles are probably more vulnerable to problems associated with molting success because their frequency of molting is greater than that of larger juveniles and adults. In juvenile red king crabs, temperature affects the molting frequency and survival during molting.

The optimum temperature for long-term rearing appeared to be 10°C, which allowed the most successful molting. Survival at 5°C was slightly better than at 10°C, but molting frequency was less than half that of crabs at 10°C. Temporary holding of the crabs at 0-5°C may be useful because molting frequency was reduced and survival was high.

Although survival at 20°C was high, crabs attempted few molts, and none survived molting. The crabs fed well, which suggests that crabs could grow at this temperature. However, the conversion of food to tissue at this temperature was probably poor, as indicated by the relatively few molt attempts.

Environmental temperatures can affect the survival of molting juvenile crabs, and the general warming during the 1983 El Nino may have affected the survival of molting crabs in Bristol Bay. McMurray et al. (1984) found juvenile red king crab in areas of Bristol Bay where the bottom temperatures were >11°C at the end of summer in 1983. Our study indicates that the best survival of molting crabs is at <10°C and high molting frequency with very poor survival occurs at 15°C. There is no direct evidence that elevated temperatures in 1983 caused massive numbers of juvenile and subadult red king crabs to die during the molting process. However, like other hypothesized causes of red king crab mortalities, elevated summer temperatures could have contributed directly to greater than normal mortalities.

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Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands

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Introduction

The eastern Bering Sea shelf is one of the greatest producers of commercial shellfish and fish of the world (Bakkala 1981), and include some of the richest U.S. crab fisheries until recent times (Otto 1981; Hayes 1983).

In order to evaluate and predict possible changes in the ecosystem which may impact in these important fisheries, it is necessary to have reliable information on species composition, abundance and distribution to assess the extent of any alterations and to help in management decisions.

Published studies of the benthic communities of the Bering Sea cover enormous areas and may be based on relatively few samples. Thus, assumptions about the spatial homogenecity of the benthos must be made which have not been tested in detail although complete coverage has been given to Bristol Bay and the northern Bering Sea/Chukchi sea (Mc Donald et al. 1981; Mac Intosh and Somerton 1981; Jewet and Feder 1981). These studies have found large areas to be rather homogeneous and characterized by a few dominant species. In contrast, the Pribilof Islands constitutes an exception to most of the shelf because of a varied nearshore substrate of gravel, rock and shellhash that represents a unique habitat for juveniles of various species seeking refuge from predators. The blue king crab (Paralithodes platypus) is exemplary of juvenile substrate dependence and warrants study because of the increased importance of its fishery as that for red king crab declined, and because of the very insular distribution of blue king crab about the Pribilof and other islands.

This work is an attempt to characterize blue king habitat and accompanying fauna through the use of numerical classification techniques. Special consideration is given to adult-juvenile distribution and habitat preferences.

Methods

A substantial variety of fish and invertebrate species was collected during cruises in May and August, 1983. The species list was reduced to its dominant species to facilitate detection of ecological communities based on certain intrinsic characteristics such as relative abundance and co-occurrence in space and time. Frequency-of-occurence was the criterion used for this selection and all species or taxanomic groups present in less than 3.5% of hauls (see Armstrong et al this proceedings for description of gear) were disregarded as being too rare. To better focus the analyses, some groups were eliminated that had not been identified consistently during both cruises. Hermit crabs, for example, were excluded although they were among the 10 dominant groups both as no./ha and kg/ha, but during the May and August cruises they were never identified to a level lower than family (Paguridae) and evidence from a third cruise in April 1984 suggests species-specific distribution. Future analyses of these data will clarify the relationsihp of different hermit crab species within benthic communities. Finally, some species were grouped into higher taxonomic categories like genera or families to assure a coherent classification. From these processes, the species list was reduced to a maximum of 57 (Table 1).

Numerical classification techniques (cluster analyses) were used to analyze biological associations and distribution patterns. The computer facilities and programs needed for these analyses were kindly provided by the Northwest and Alaska Fisheries Center (NWAFC). Software consisted of four programs: "Cluster/Start"; "Cluster"; "Cluster/Map" and "Cluster/Draw". The program "Cluster/Start" prepares the data matrix to be used on program "Cluster", based on the haul file, the catch file, and the list of species to be used in the analysis. The data matrix consists of catch-per-unit-of-effort (CPUE) values for the species considered at each sample station. CPUE was calculated as species densities (no/ha) based on area swept because it was considered a more reliable measure than weights which were not always taken, and avoided underestimating the importance of some small organisms in the communities.

The program "Cluster" performs the analysis itself, calculating the similarity (or dissimilarity) values and combining the entities according to these values. This program is very flexible and allows the user to execute several transformations and standardizations of the data matrix, along with a wide option of similarity coefficients and clustering strategies. It also allows a choice between "normal" or "inverse" classifications, that is, clustering by stations or by species. The last two programs, "Cluster/Draw" and "Cluster/Map" give graphic representations of the clusters produced, in the form of dendograms and geographic maps showing the location of different sites or species clusters.

Data put through these programs was not transformed or standardized because such processes are often used to reduce the effect of very abundant catches at some sites and for our purpose outstanding catches

Table 1. List of fish and invertebrates used in the cluster analysis.

Class Anthozoa

Sea anemones

Class Stelleroidea

Asterias amurensis
Evasterias troschelli
Gorgoncephalus caryi
Henricia sp.
Leptasterias polaris
Lethasterias nanimensis
Pteraster tesselatus

Class Echinoidea

Echinarachnius parma
Strongylocentrotus droebachiensis

Class Holothurioidea

Cucumaria sp.

Class Gastropoda

Fusitriton oregonensis
Natica spp.
Neptunea spp.
Nudibranchs

Class Bivalvia

Chlamys sp.
Clinocardium spp.
Mytilidae (*)
Pododesmus macrochisma

Class Cirripedia

Balanus sp.

Class Malacostraca

Order Decapoda

Argis spp.
Crangon dalli
Pandalus spp.
Spirontocaris spp.
Cancer oregonensis
Chionocetes spp.
Dermaturus mandtii
Erimacrus isenbeckii
Hapalogaster grebnitzkii
Hyas coarctatus
Hyas lyratus
Oregonia gracilis
Paralithodes camtschatica
Paralithodes platypus

Class Osteichtyes

Order Pleuronectiformes

Atherestes stomia
Hippoglossoides elassodon
Hippoglossus stenolepis
Lepidopsetta bilineata
Limanda aspera

Order Scorpaeniformes

Agonus acipenserinus
Agonids
Aspidophoroides bartoni
Gymnocanthus spp.
Hemilepidotus jordani
Liparis spp.
Psycrolutes paradoxus
Sarritor frenatus
Triglops spp.

Order Gadiformes

Theragra chalcogramma

Order Perciformes

Ammodytes hexapterus
Bathymaster signatus
Bathymasteridae
Stichaeidae

Order Ophidiiformes

Zoarcidae

(*) over 90% of the mussels caught were *Modiolus modiolus* may have important ecological implications such as propitious habitats.

As a first approach the 'inverse' clustering technique (by species) was used to look for species associations and, in turn, ecological communities. From the two coefficients of similarity available, the Canberra-metric and the Bray-Curtis, we chose the latter because of its wide use in marine ecology (Field 1969; Lay et al. 1971; Chance and Deutsch 1980; Walters and McPhail 1982; Davis et al. 1983) and because it is more sensitive to occasional large values (e.g. CPUE; Clifford and Stephenson 1975, p. 58).

Two clustering strategies were attempted: group average and flexible sorting, the latter with several different values applied for the coefficient. The group average strategy fuses each entity with the cluster formed to that point which gives the lowest average dissimilarity value for each entity. This strategy is considered 'space conserving' and has been used in many ecological works (Pritchard and Anderson 1971; Loya 1972; Walters and McPhail 1982).Flexible sorting is a strategy developed by Lance and Williams (1967) which allows different clustering intensities according to the value of the coefficient: with positive values it act as a space-conserving strategy; if is 0 it causes a space-conserving effect and negative values yield a space-dilating clustering. However, in the NWAFC program, is constrained to negative values limiting the flexibility to a (variable) space-dilating strategy.We chose the flexible sorting strategy with a value of -0.5 since this method produced better structured dendograms. With this coefficient, the program acted as a moderately space-dilating strategy; that is, the chance that an individual element (station or species) will act as the nucleus of a new group rather than join a pre-existing one is increased.

After each run of the programs, the resulting dendogram was studied for species composition of the clusters at different dissimilarity levels and for consistency of these groupings. Each method seemed to yield different results except for a few species which appeared to be highly associated. This procedure was deemed too subjective and consequently we examined a different approach. Working with the 'normal' classification (by stations) we repeated the process described above obtaining more consistent dendograms. With station groups defined we then looked at the species caught at the stations that constituted each major cluster. Data from May and August was treated separately since notable differences were observed in the catches of the two cruises. August data was further divided according to gear type (beam trawl, BT, and rock dredge, RD, hauls) because of the different fishing performance of each during comparative hauls. This was not considered necessary for the May data as the number of rock dredge stations was very low (25) and there was no overlapping use of both gears at the same station as was commonly done in August.

Results

Dendograms were examined at different levels of dissimilarity and the level adopted in each case was the one believed to make ecological sense in terms of species assemblages and substrate type. For this reason the May dendogram, as an example, was truncated at two different levels of dissimilarity (Fig. 1; see Clifford and Stephenson 1975, p.

134 for discussion of the technique).
In all three cases (i.e. May both gear, August BT and RD) three major clusters were defined that grouped stations with similar biological characteristics (Figs. 1, 2 and 3). In these figures, each vertical line at the zero dissimilarity value represents a single station and they are linked in larger groups as their similarity decreases (the dissimilarity increases).

A paramount question at issue is the abiotic attributes common to the stations within each cluster, particularly bottom types.

Stations grouped in cluster 185 are located around the two main islands, most of them within the 60 m isobath (Fig. 4 a). The nature of substrate of these stations is predominantly rocky (44%) and shellhash (33%). The importance of these substrates in defining cluster 185 is enhanced by the fact that 71% of the rock stations and 75% of the shellhash stations from the May cruise were included in this cluster. Also, 22% of the stations in the cluster have a mud-sand substrate, but this represents only 9% of the total number of such stations sampled in May (Table 2). It is important at this point to remember that the only attribute used to form the clusters was the species composition of the catch (in no./ha) at each station, rather than bottom type. The dominant species at these stations were sessile invertebrates like anemones and sea urchins (Strongylocentrotus droebachiensis); mussels, scallops (Chlamys sp.) and Pododesmus macrochisma; and some crabs such decorator crab (Oregonia gracilis), juvenile blue king crab and Cancer oregonensis.

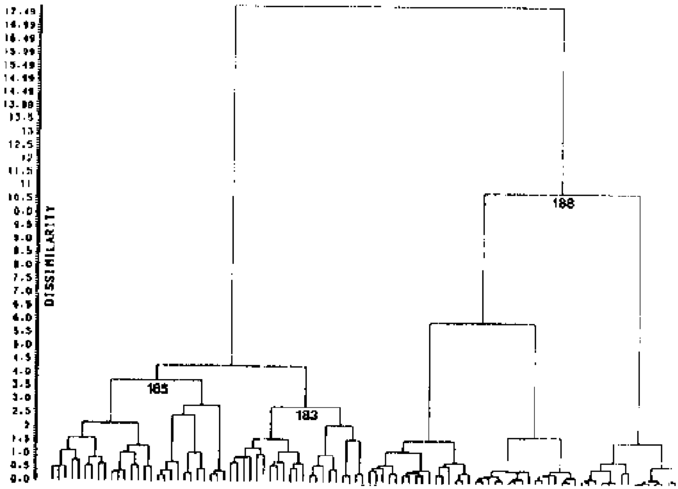


Figure 1. Dendogram showing the relationship between the stations of the may 1983 cruise. Each vertical line at the bottom of the figure represents a different station.

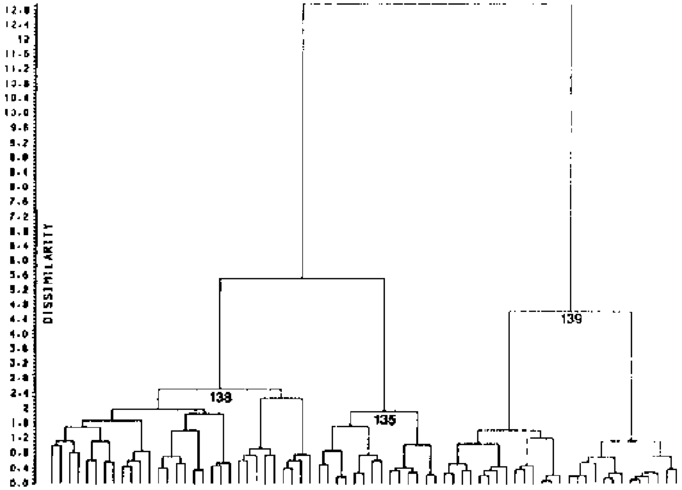


Figure 2. Dendogram of the beam trawl stations of the August 1983 cruise. Each vertical line at the bottom of the figure represents a different station.

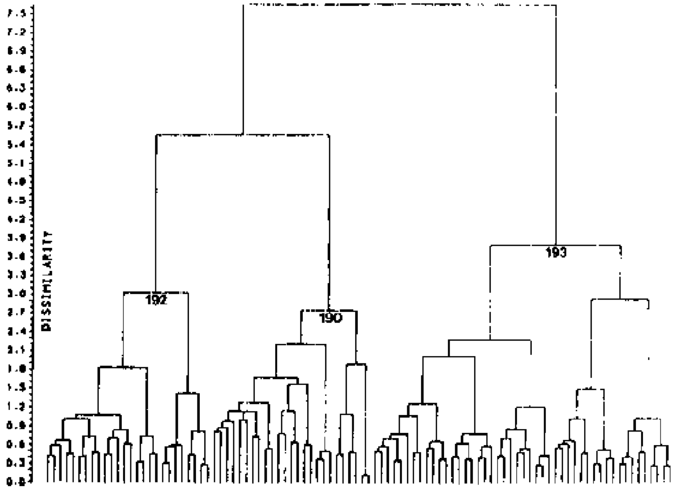
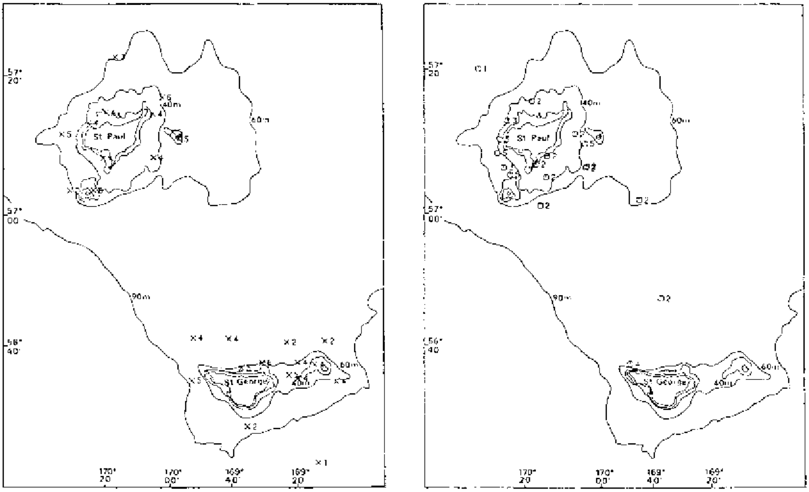
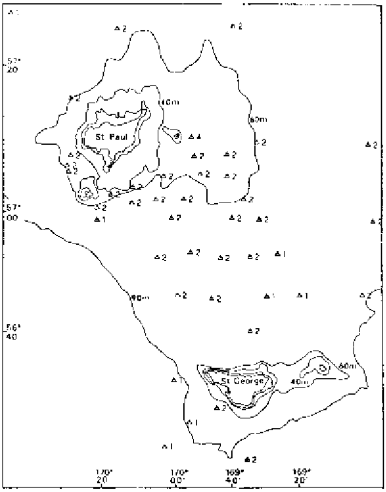


Figure 3. Dendogram of the rock dredge stations of the August 1983 cruise. Each vertical line at the bottom of the figure represents a different station.



A) Cluster 185

B)Cluster 183



C) Cluster 188

Figure 4. Location of the May 1983 stations A) Stations included in cluster 185; B) stations in cluster 183; C) stations in cluster 188.

Cluster 183 included stations with an average depth of 50 m and a geographic distribution very similar to cluster 185 (Fig. 4 b). However, there are certain differences in substrates types with a preponderance of mud-sand stations (67%) and less rock (19%) and shellhash (14%) (Table 2) that makes this cluster more similar to cluster 188. In both abiotic and biological characteristics, this group of stations appears to be a transition between the other clusters 185 and 188. Most of the dominant species in this cluster were also found in cluster 185 or 188 with greater frequency or abundance. The total biomass values of cluster 183 are noticeably low relative to those of clusters 185 and 188.

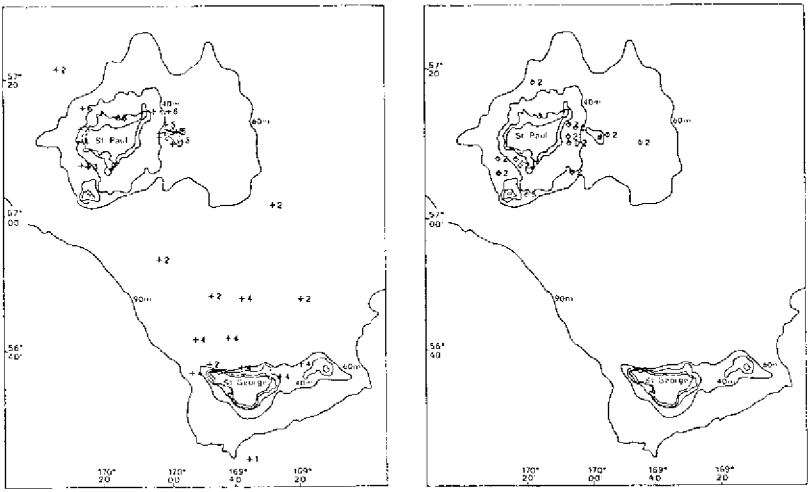
Cluster 188 comprises deeper offshore stations mostly in the basin between the two islands (Fig. 4 c). The substrate type is almost exclusively mud-sand (Table 2) and the average depth is 71 m. The dominant species included most

Table 2. Summary of the substrate characteristics of the stations that constituted each of the major clusters.

		Number							Percentage																		
		of stations							Within clusters									Between clusters									
May - Both gears																											
	Substrate *	1	2	3	4	5	6	T	1	2	3	4	5	6	1-2	3-4	5-6**	1	2	3	4	5	6	1-2	3-4	5-6**
Cluster	Average depth(m)																									
185	59	1	5	1	11	7	2	27	4	19	4	41	26	7	23	44	34	7	10	25	85	70	100	9	71	75
193	50	3	11	3	1	3	0	21	14	52	14	5	14	0	67	19	14	20	22	75	8	30	0	21	24	25
183	71	11	35	0	1	0	0	47	23	74	0	2	0	0	98	2	0	73	68	0	8	0	0	70	6	0
T		15	51	4	13	10	2	95																		
August - Beam trawl																										
	Substrate *	1	2	3	4	5	6	T	1	2	3	4	5	6	1-2	3-4	5-6**	1	2	3	4	5	6	1-2	3-4	5-6**
Cluster	Average depth(m)																									
138	60	1	8	3	9	7	2	30	3	27	10	30	23	7	30	40	30	17	20	75	100	78	100	19	92	82
135	44	0	13	0	0	1	0	14	0	93	0	0	7	0	93	0	7	0	32	0	0	11	0	28	0	9
139	77	5	20	1	0	1	0	27	19	74	4	0	4	0	93	4	4	83	49	25	0	11	0	53	8	9
T		6	41	4	9	9	2	71																		
August - Rock dredge																										
	Substrate *	1	2	3	4	5	6	T	1	2	3	4	5	6	1-2	3-4	5-6**	1	2	3	4	5	6	1-2	3-4	5-6**
Cluster	Average depth(m)																									
192	54	2	4	2	4	9	5	26	8	15	8	15	35	19	23	23	54	50	33	33	10	64	23	36	13	39
190	55	2	6	4	7	1	3	25	8	32	16	28	4	12	40	44	16	50	67	67	18	7	14	63	24	11
193	40	0	0	0	29	4	14	47	0	0	0	62	9	30	0	62	38	0	0	0	73	29	64	0	63	50
T		4	12	6	40	14	22	98																		

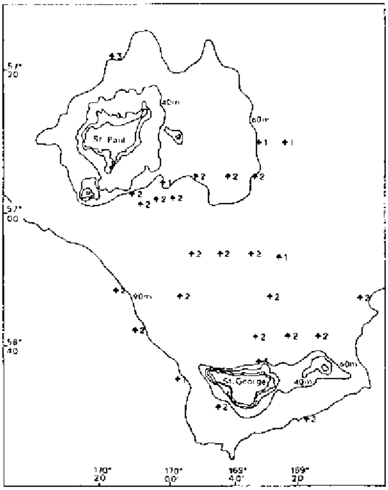
* Substrate type: 1=mud; 2=sand; 3=gravel; 4=rock; 5=shellhash I (whole shells); 6=shellhash II (broken shells)

** Substrates of similar composition grouped to better highlight the dominant types within the cluster.



A) Cluster 138

B) Cluster 135

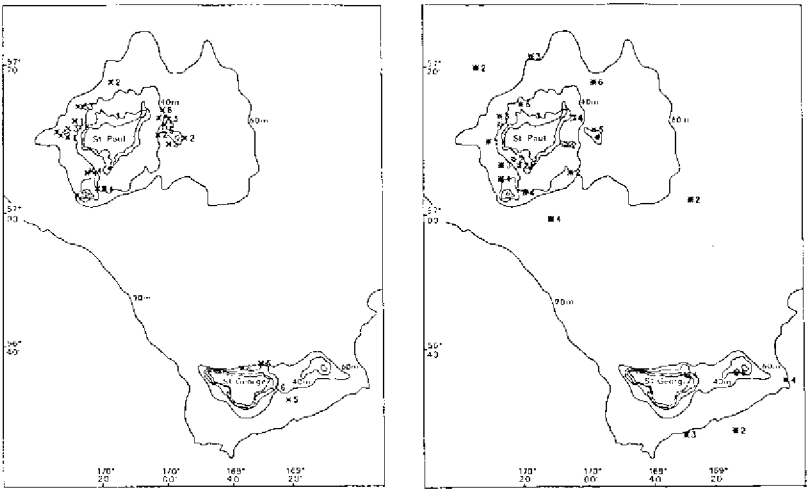


C) Cluster 139

Figure 5. Location of the August beam trawl stations. A) Stations included in cluster 138; B) Stations in cluster 135; C) Stations in cluster 139.

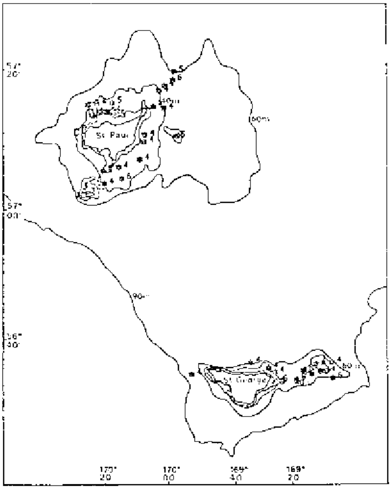
of the fish, adult blue king crab, tanner crab (Chionocetes sp. and Korean hair crab (Erimacrus isenbeckii) and large gastropods of the genus Neptunea spp..

Beam trawl hauls done in August grouped in a pattern similar to those in May (Figs. 4 and 5). Cluster 138 included rocky substrate at 40% of the stations which represented 92% of the total beam trawls on this substrate. The remaining stations were equally divided between shellhash and mud-sand, but the shellhash represented 82% of this kind of substrate while sand only 19% (Table 2). Most of these stations are nearshore around the islands but some of the deep off shore sandy stations were included in this cluster (Fig. 5 a). Biologically, these stations are analogous to those of cluster 185 in May and dominant species include sea urchins, anemones, scallops, juvenile blue king crabs, decorator crabs, C. oregonensis, sea cucumber



A) Cluster 192

B) Cluster 190



C) Cluster 193

Figure 6. Location of the August rock dredge stations. A) Stations included in cluster 192; B) Stations in cluster 190; C) Stations in cluster 193.

(Cucumaria sp.) and pandalid shrimp (Table 4).

Clusters 135 and 139 both include 93% of stations on mud-sand substrate (Table 2). However, stations in cluster 135 are grouped nearshore around St. Paul at an average depth of 44 m, while cluster 139 is comprised of offshore deeper stations in the basin between the islands at an average depth of 77m (Figs. 5 b and c). Dominant species lists denote further differences between these two groups: decorator crabs, Asterias amurensis, Korean hair crab (Erimacrus isenbeckii), rock sole (Lepidopsetta bilineata) and juvenile halibut (Hippoglossus stenolepis) were more frequent and abundant at cluster 135, while tanner crab, Lethasterias nanimensis, arrow toothflounder (Atheresthes stomias), yellowfin sole (Limanda aspera) and flathead sole (Hipoglossoides elassodon) prevailed at cluster 139.

Rock dredge stations from August

did not form such well defined clusters in terms of substrate type as found for the preceding groups. Perhaps the main reason for this is the selective use of this gear based on side scan sonar traces available during the August cruise which allowed us a choice of fishing gear according to the substrate type. Thus, the rock dredge was used almost exclusively on hard bottoms or small sand and shellhash areas surrounded by rocks which precluded the use of the beam trawl. The geographic location is then very similar for all 3 clusters and restricted to the near shore waters around the islands (Figs. 6 a, b and c). Still, some contrasts of substrate and species assemblages are possible.

Cluster 192 is composed of 23% mud-sand stations, 23% rock and 54% shellhash (Table 2) at an average depth of 54 m. Dominant species at these stations included pandalid shrimp, Hyas lyratus, tanner crab and blue king crab, scallops and Clinocardium sp. and starfish Asterias amurensis.

Cluster 190 consists of 40% mud-sand, 44% rock and 16% shellhash stations. 63% of the sand stations sampled with the rock dredge were included in this cluster. Except for the tanner crab and Korean hair crab, all other species were more frequent or abundant in the other two clusters.

Cluster 193 did not include any mud or sand stations; 62% were rocky substrate and 38% shellhash. Biologically, this cluster is analogous to cluster 185 (May) and 138 (August - beam trawl). Dominant species were sea urchins, sea cucumber, mussels, P. macrochisma, Fusitriton oregoncensis and barnacles.

Discussion

The dominant species at the stations that constituted each cluster is given on Tables 3, 4 and 5. It is clear from these tables that frequency of occurrance alone or CPUE (in numbers or weight) by itself is not enough to determine the dominance and spatial distribution of the species. In the May clusters, the blue king crab is found most frequently (47%) in cluster 188 and the average CPUE (145 kg/ha) is about 12 times larger than in cluster 185 (37% and 12 kg/ha respectively), but based on individual average weight there is a clear segregation by size. Although cluster 185 consists mostly of rock dredge stations and cluster 188 is composed of beam trawl stations, we do not consider the difference in the gear behavior and catch to be a misleading factor in this case. The rock dredge proved unsatisfactory for catching adult king crabs, but we did not catch them with the beam trawl when fishing on nearshore rocky and shellhash substrates. A similar segregation of blue king crab life history stages is seen in the August beam trawl data (Tables 3 and 4) and station locations for clusters 138 and 139 (Fig. 5 a and c). Although the beam trawl did not sample juveniles as well as the rock dredge, the mean weight per individual is 56g and 314g in clusters 138 and 139 respectively. As noted, a high percentage of stations in cluster 138 were nearshore on rock and shell, while those of cluster 139 were offshore over mud-sand.

The importance of these results is to highlight habitat requirements of different life history stages of P. platypus and the importance of recruitment to shallow areas around the Pribilof Islands. Juvenile blue

Table 3. List of the dominant species, frequency of occurrence, average CPUE (in no/ha and kg/ha) and average individual weights at the stations that constituted each of the major clusters from the May cruise.

	CLUSTER 185 (27 st.)					CLUSTER 183 (21 st.)					CLUSTER 188 (47 st.)				
	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g
Chlamys sp	15	55.6	4622	38.1	8.2	5	23.8	75	0.47	6.3	4	8.5	34	0.15	4.4
Mytilidae	12	44.4	1494	94.5	63.3	3	14.3	41	2.4	58.5	0	0.0	--	---	---
S. droebachiensis	15	55.6	404	19.8	49.0	5	23.8	126	9.8	77.8	1	2.1	3	0.17	56.7
C. oregonensis	17	63.0	402	0.89	2.2	6	28.6	30	0.08	2.7	6	12.8	4	0.004	1.0
P. macroschisma	18	66.7	271	123.1	454.2	3	14.3	23	8.9	387.0	2	4.3	16	1.10	68.8
F. oregonensis	10	37.0	191	13.6	71.2	2	9.5	77	10.9	141.6	2	4.3	0.7	0.01	14.3
B. signatus	8	29.6	104	19.6	188.5	3	14.3	3	0.02	6.7	11	23.4	3	0.30	100.0
O. gracilis	23	85.2	742	1.2	1.6	13	61.9	208	2.0	9.6	14	29.8	50	0.06	1.2
Nudibranch	13	48.1	296	0.78	2.6	9	42.9	71	0.08	1.1	27	57.4	36	0.06	1.7
Anemone	11	40.7	163	29.2	179.1	9	42.9	87	28.2	324.1	19	40.4	29	18.10	624.1
P. platypus	10	37.0	196	12.1	61.7	6	28.6	12	1.8	150.0	22	46.8	119	145.50	1222.7
Pandalus sp.	7	25.9	2172	1.8	0.8	6	28.6	35	0.02	0.6	25	53.2	193	0.17	0.9
Chionocetes	10	37.0	1464	3.9	2.7	15	71.4	321	5.6	17.4	47	100.0	4369	66.50	15.2
A. bartoni	5	18.5	50	0.06	1.2	8	38.1	23	0.03	1.3	17	36.2	5	0.01	2.0
A. amurensis	2	7.4	10	0.79	79.0	7	33.3	250	42.4	169.6	18	38.3	65	70.90	1090.8
E isembecki	5	18.5	151	90.4	598.7	11	52.4	242	1.4	5.8	21	44.7	9	2.20	244.4
Neptunea sp.	4	14.8	22	1.9	86.4	7	33.3	118	9.7	82.2	27	57.4	67	11.20	167.2
H. jordani	4	14.8	17	5.4	317.6	9	42.9	32	15.4	481.3	19	40.4	9	4.40	488.9
L. bilineata	4	14.8	43	0.6	14.0	14	66.7	186	8.3	44.6	33	70.2	377	19.80	52.5
T. chalcogramma	0	0.0	--	--		5	23.8	58	0.39	6.7	17	36.2	9	0.15	16.7
S. frenatus	3	11.1	38	0.28	7.4	1	4.8	1	0.01	10.0	18	38.3	6	0.07	11.7
			12846	458.0				2019	147.9				5403	340.9	

Table 4. List of the dominant species, frequency of occurrence, average CPUE (in no/ha and kg/ha) and average individual weights at the stations that constituted each of the major clusters from the beam trawl hauls in the August cruise.

	CLUSTER 138 (30 st.)					CLUSTER 135 (14 st.)					CLUSTER 139 (27 st)				
	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	W/N g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	W/N g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	W/N g
Chlamys sp.	17	56.7	373	5.50	14.7	2	14.3	8.0	0.25	31.3	5	18.5	5	0.07	14.0
Cucumaria sp.	11	36.7	62	36.60	590.3	3	21.4	3.0	3.80	1 56.7	1	3.7	0.1	0.10	1000.0
S. droebachiensis	21	70.0	643	15.80	24.6	3	21.4	1.7	0.33	19.4	3	11.1	16	0.07	4.4
C. oregonensis	16	53.3	28	0.06	2.1	1	7.1	1.4	0.002	1.4	6	22.2	16	0.02	1.3
Nudibranch	23	76.7	46	0.71	15.4	5	35.7	5.0	0.01	2.0	7	25.9	73	3.60	49.3
Pandalus sp.	13	43.3	790	0.92	1.2	4	28.6	188.0	0.22	1.2	2	7.4	4	0.01	2.5
A. bartoni	11	36.7	12	0.06	5.0	1	7.1	0.3	0.001	3.3	14	51.9	4	0.004	1.0
Anemone	15	50.0	180	23.60	131.1	3	21.4	1.6	0.06	37.5	14	51.9	288	36.50	126.7
P. platypus	15	50.0	17	0.96	56.5	2	14.3	3.0	0.001	0.3	18	66.7	21	6.60	314.3
M. alassodon	5	16.7	50	0.38	7.6	0	0	0	0	--	14	51.9	26	1.40	53.8
Triglops sp.	19	63.3	231	0.78	3.4	8	57.1	235.0	0.73	3.1	14	51.9	178	0.19	1.1
O. gracilis	26	86.7	549	6.30	11.5	11	78.6	370.0	2.10	5.7	13	48.1	27	0.02	0.7
L. bilineata	19	63.3	334	5.10	15.3	14	100.0	1697.0	40.4	23.8	22	81.5	245	27.60	112.7
Cyclopteridae	20	66.7	30	0.13	4.3	10	71.4	167.0	0.32	1.9	19	70.4	104	0.63	6.1
H. stemolepis	7	23.3	23	0.38	16.5	12	85.7	234.0	0.59	2.5	6	22.2	8	0.01	1.3
H. lyratus	16	53.3	95	1.30	13.7	6	42.9	291.0	5.90	20.3	18	66.7	15	0.04	2.7
E. isembecki	11	36.7	19	4.50	236.8	11	78.6	190.0	22.10	116.3	12	44.4	29	7.30	251.7
A amurensis	11	36.7	140	16.30	116.4	6	42.9	179.0	104.60	584.4	13	48.0	90	13.20	146.7
A. acipenserinus	5	16.7	6	0.04	6.7	5	35.7	16.0	0.04	2.5	12	44.4	6	0.03	5.0
Chionocetes sp	13	43.3	56	0.90	16.1	10	71.4	781.0	5.90	7.6	27	100.0	3792	12.60	3.3
L. nanimensis	15	50.0	54	4.70	87.0	5	35.7	10.0	2.20	220.0	15	55.6	37	11.80	318.9
T. chalcogramma	4	13.3	21	0.04	1.9	3	21.4	8.0	0.01	1.3	16	59.3	9	0.03	3.3
A. stomias	9	30.0	6	0.14	23.3	2	14.3	0.6	0.01	16.7	20	74.1	40	2.40	60.0
C. dalli	3	10.0	5	0.01	2.0	5	35.7	87.0	0.18	2.1	17	63.0	183	0.19	1.0
L. aspera	3	10.0	5	1.50	300.0	0	0	0	0		20	74.1	70	6.70	110.0
Neptunea sp	2	6.7	1	0.16	160.0	1	21.4	9.0	3.40	377.8	18	66.7	39	3.50	89.7
			3776	126.90				4487.0	193.0				5275	134.10	

Table 5. List of the dominant species, frequency of occurrence, average CPUE (in no/ha and kg/ha) and average individual weights at the stations that constituted aech of the major clusters from the rock dredge hauls in the August cruise.

	CLUSTER 192 (26 st.)					CLUSTER 190 (25 st.)					CLUSTER 193 (47 st.)				
	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g	FREQ n	FREQ %	$\bar{N}$ No/Ha	$\bar{W}$ Kg/Ha	$\bar{W}/\bar{N}$ g
H. lyratus	22	84.6	2202	6.10	2.8	6	24.0	63	0.17	2.7	20	42.6	143	0.45	3.1
P. platypus	21	80.8	1642	2.70	1.6	7	28.0	462	1.10	2.3	26	55.3	474	0.07	0.1
Chlamys sp.	21	80.8	2775	29.40	10.6	5	20.0	36	0.84	23.3	25	53.2	131	1.00	7.6
Clinocardium sp.	12	46.1	450	2.30	5.1	5	20.0	337	0.17	0.5	7	14.9	35	0.14	4.0
Anemone	17	65.4	987	20.10	20.4	8	32.0	124	7.80	62.9	20	42.6	82	2.90	35.4
A. amurensis	17	65.4	1154	104.60	90.6	7	28.0	121	15.70	129.8	13	27.7	63	6.90	109.5
Nudibranch	13	50.0	130	0.35	2.7	7	28.0	18	.02	1.1	19	40.4	45	0.26	5.8
Pandalus sp.	17	65.4	2243	2.40	1.1	5	20.0	73	0.06	0.8	17	36.2	467	0.40	0.9
Cyclopteridae	17	65.4	318	0.39	1.2	8	32.0	78	0.05	0.6	25	53.2	146	0.28	1.9
C. oregonensis	18	69.2	1453	2.40	1.7	7	28.0	39	0.04	1.0	42	89.4	661	0.91	1.4
O. gracilis	22	84.6	2333	10.10	4.3	13	52.0	1327	1.00	0.8	46	97.9	1481	5.60	3.8
E. isenbecki	20	76.9	3987	3.20	0.8	11	44.0	7622	4.30	0.6	17	36.2	134	0.18	1.3
Chionoecetes sp.	10	38.5	463	1.70	3.7	13	52.0	569	0.34	0.6	4	8.5	103	0.09	0.9
H. grebnitzkii	10	38.5	224	0.23	1.0	4	16.0	56	0.07	1.3	22	46.8	246	0.15	0.6
Argis sp.	5	19.2	79	0.06	0.8	2	8.0	639	0.09	0.1	11	23.4	58	0.12	2.1
Mytilidae	15	57.7	432	13.00	30.1	2	8.0	650	52.50	80.8	30	63.8	1283	120.60	94.0
P. macroschisma	13	50.0	652	54.30	83.3	4	16.0	982	53.10	54.1	41	87.2	1013	60.10	59.3
S. droebachiensis	20	76.9	848	42.20	49.8	6	24.0	205	5.40	26.3	41	91.5	1148	57.90	50.4
Cucumaria sp	6	23.0	55	39.70	721.8	3	12.0	43	42.90	997.7	21	44.7	119	91.10	765.5
D. mandtii	9	34.6	132	0.22	1.7	5	20.0	40	0.04	1.0	29	61.7	559	0.54	1.0
F. oregonensis	5	19.2	75	5.70	76.0	4	16.0	48	3.00	62.5	15	31.9	737	4.90	6.6
Henricia sp	4	15.4	70	0.35	5.0	2	8.0	22	0.08	3.6	20	42.6	98	0.27	2.8
Cirripedia	4	15.4	94	2.50	26.6	1	4.0	24	0.93	38.8	18	38.3	103	12.10	117.5
			22798	344.00				13598	189.7				9329	367.30	

king crab (<30 mm carapace length) were found predominantly at nearshore, rocky and shellhash stations, while male and female adults had a high occurrance offshore on deeper mud-sand substrates. This distribution pattern indicates a strong dependence of the juveniles on substrate that affords refuge from predators, and their survival may be seriously compromised if they fail to settle on appropriate substrate. Shellhash is a key material for refuge and thus the survival is ultimately linked to certain molluscs that are also abundant within the species assemblage that characterize the blue king crab habitat. Based on May, 1983 data and resultant clusters 165 and 188, Mytilidae (*Modiolus modiolus*), *Chlamys sp*, *Pododesmus macrochisma* and *Fusitriton oregonensis* were all dominant species with juvenile *P. platypus* in cluster 185. The empty shells of these molluscs become refuge substrate for the crab and is a material that is scarce offshore in cluster 188 where adults are the dominant life history stage of blue king crab.

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Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands

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Introduction

Interannual variability and recruitment in year class strength of commercial decopod Crustacea has received increased attention in recent years, particularly as substantial fluctuations and decreased trends in fisheries stocks have affected several major U.S. fisheries (Armstrong 1983; Harding et al. 1983; Hayes 1983). While considerable attention has been given to the impact of physical oceanographic events on larval early life history and population dynamics as a cause of fluctuation (Lough 1976; Rothlisberg and Miller 1982; Sulkin and Van Heukelem 1982; Incze 1983; Rothlisberg et al. 1983; Epifanio et al. 1984), or to analyses and trends in fisheries landings as bases for hypotheses on year class variation (Botsford and Wickham 1978; McKelvey et al. 1980; Reeves and Marasco 1980; Harding et al. 1983), relatively little effort has been directed toward population dynamics and ecology of newly settled juveniles and the influence of environmental factors as another source of interannual year class variation.

Based on studies to date it is apparent that newly metamorphosed juvenile stages of several commercial decapods are critically dependent on refuge habitat for optimal survival following settlement to the benthos. Descriptions and importance of nursery habitat in estuaries has been described for blue crab (Callinectes sapidus), Dungeness crab (Cancer magister), and species of penaeid shrimp (Weinstein 1979; Zimmerman et al. 1984; Heck and Thoman 1984; Stevens and Armstrong 1984; Armstrong and Gunderson 1985). However, little work has been done on habitat requirements and nursery areas for decapod species that recruit directly to offshore locations.

In the southeastern Bering Sea, major U.S. crab fisheries have historically targeted on two species of king crab, the red king crab

(Paralithodes camtschatica) and the blue king crab (P. platypus), the former being the most important until recent years (see review by Otto 1981). The rich red king crab fishery began to decline in 1981, and by the 1982-83 season the catch of blue king crab at the Pribilof Islands (4.7 million lbs) exceeded the catch of red king crab from the entire Bristol Bay area (2.7 million lbs; ADF&G 1983). But by 1984 the National Marine Fisheries Service (NMFS) annual groundfish survey indicated that stocks of legal male blue king crab had declined percipitously and were only 0.6 million males around the Pribilof Islands compared to 3.1 million legal male red king crab throughout Bristol Bay (Otto et.al. 1984).

Although included in the annual NMFS groundfish survey, blue king crab has been little studied to date throughout its distribution from the Gulf of Anadyr through the southeastern Bering Sea. Most biological investigations have focused on the very intriguing reproductive biology of this species (eg., Sasakawa 1975; Somerton and MacIntosh 1985). Almost no attention has been given early life history, ecology and population dynamics of larvae and juveniles of this very insular species. In addition to the importance of such basic biological information for fisheries management there is concern that expanded oil and gas development throughout the southeastern Bering Sea could pose a substantial threat to the highly restricted populations of blue king crab in the area of the Pribilof Islands (Curl and Manen 1982; Armstrong et al. 1984); thus mitigation for and management of such development must be based on good ecological data for P. platypus.

The research program partially described in this paper was undertaken to study the early life history of P. platypus around the Pribilof Islands, the spatial and temporal relationship of spawning females to their larvae and newly settled juvenile stages, and to describe location and habitat type of major aggregations of juveniles during several periods of the year.

Methods and Materials

Sample area and timing.

Three cruises of about 2.5 weeks each were made to the Pribilof Islands in May and August, 1983 and April 1984. During the first cruise stations were systematically arranged on transect lines radiating from St. Paul and St. George Islands. Additional stations were placed in areas of high crab abundance as found during the course of the cruise (Fig. 1). This array was designed to afford both broad scale coverage with stations up to 76 km offshore (40 nautical miles = NM), but also detailed coverage in areas of certain substrate composition. In reality however, this coverage was still somewhat hit-and-miss since stations arbitrarily selected on the basis of nautical charts were largely situated on sand or mud substrates. Thus relatively little effort during the first cruise was directed toward cobble and rock substrate that was subsequently found, along with certain types of shell, to be of prime importance to juvenile stages of blue king crab. On the second and third cruises grid patterns of stations were used to randomly select areas that were first surveyed with sidescan sonar (SSS) to map bottom type, and then with that information to direct sampling effort on specific substrates (Fig. 2). In general, the areas selected for intense field effort were nearshore of each of the two Pribilof Islands based on long term surveys

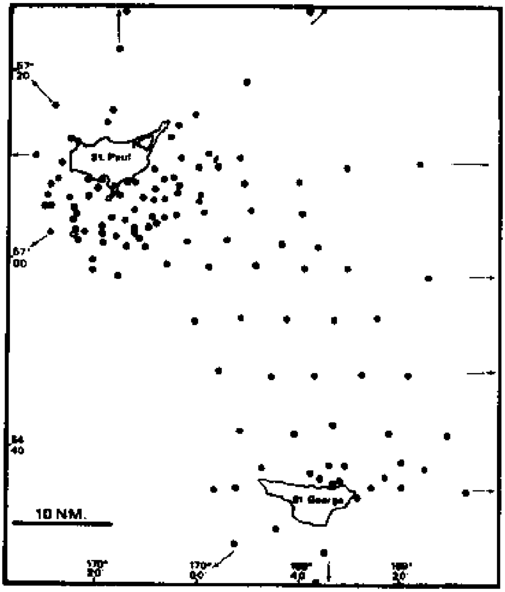

Fig. 1. Pribilof Island survey area and an example of station locations May 1983. Arrows indicate additional stations on transect lines up to 76 km (40 NM) from each island in various directions. On each of three cruises at least 125 combined benthic trawl and rock dredge samples were taken.

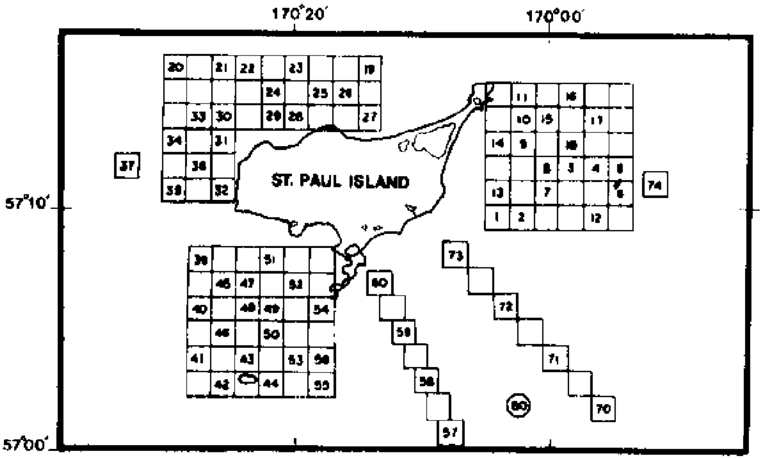

Fig. 2. An example of a side scan sonar grid pattern used to survey substrates in August 1983. Based on groundtruthing, major substrates were mapped as shown in Figs. 4 and 5.

conducted by NMFS that indicated relatively limited and insular distribution of adult stages of this species of crab (eg. Otto et al. 1984). We expected most crab to be around St. Paul island somewhat to the east and northeast. Because juvenile crab are rarely caught during the NMFS survey, the majority of effort was also directed nearshore within the 60 m isobath of each island in areas assumed to be largely composed of cobble, rock, and shell material.

Sampling gear and Methodology.

Plankton. Zooplankton samples were collected with twin 60 cm diameter bongo nets with 505 μ mesh equipped with flow meters and fished according to standard CALCOFI procedure (Armstrong et al. 1983; Incze 1983). Larval samples were also taken with a 1m Tucker trawl and a modified Sameoto neuston net for information on vertical distribution. Sampling for king crab larvae was limited to the May 1983 and April 1984 cruises.

Benthic juveniles and adults. Epibenthic sampling was done primarily with either a 3m beam trawl or a 1m biological rock dredge. Both pieces of gear had to be substantially reinforced and modified for use around the Pribilof Islands due to very rocky substrate in certain areas. The effective fishing width of the beam trawl (a modification of that described by Gunderson et al. 1985) was 2.3m. The net was knotted mesh of 15 mm lumen (unstretched; 28 mm stretched) with a cod-end liner of 5.5 mm. The 1m rock dredge had a net of about 1.8 m length and was a 6 mm knotless mesh throughout. Each gear was used to target on different life history stages, the beam trawl for larger juveniles and adults, the rock dredge for small juveniles, particularly those located in areas where the beam trawl was unsuitable. Trawls varied from 5 to 10 minutes and usually covered a distance of about 0.4 to 0.7 km.

Sidescan sonar and substrate.

Because the primary objective of this program was to study the distribution and population dynamics of small juvenile king crab, a SSS was added for the second and third cruises in order to identify certain substrate types and map their distribution around the Pribilof Islands. A 500 kh SSS (Kline Assoc. Model 422S-001E) was used in a grid pattern depicted in Figure 2. Each sonar trace covered a distance of 1.8 km (1 NM) and a width of about 150 to 200m. Such traces were used for two purposes: first, to map the general distribution of various materials after groundtruthing and; secondly, to direct sampling effort to specific substrates found in the area. On a single 1.8 km tract, the beam trawl was often used in an area of relatively flat sand, small cobble and shell, whereas the rock dredge was used in areas of larger cobble, thick shell cover, and rocks. Because of the very patchy and heterogeneous nature of the nearshore substrate, the rock dredge and beam trawl were frequently interchanged to sample large and small crab over short distances. Patterns of bottom materials seen on the SSS traces were identified through a combination of Shipek and VanVeen benthic grabs as well as by material excavated with the rock dredge. In general, very different substrate categories of sand-mud, gravel-cobble, shelf or large rock, and shellhash were reliably identified from the SSS trace.

Shell was the substrate of paramount importance to juvenile king crab and thus throughout the cruise each station was characterized as to presence or absence of shell, and whether it fell into one of two categories: Shelltype I was described as relatively intact shell often with an epiphytic covering of diatoms, bryozoans and algae (Fig. 3). Shelltype II on the other hand was pulverized to small, finely polished fragments with no epiphytic layer.

Data analyses.

All crabs were counted, measured, sexed and the data entered according to standard NMFS survey protocol. Data collected on all species were transferred to the NMFS Burroughs computer in Seattle and programs used to calculate crab density at each station as well as population estimates based on geographic and substrate strata mapped by computer and used for extrapolation of individual station densities to larger areas. Length-frequency programs were used to describe size composition and an assortment of statistical and clustering programs were used to describe community structure (Palacios et al. this proceeding).

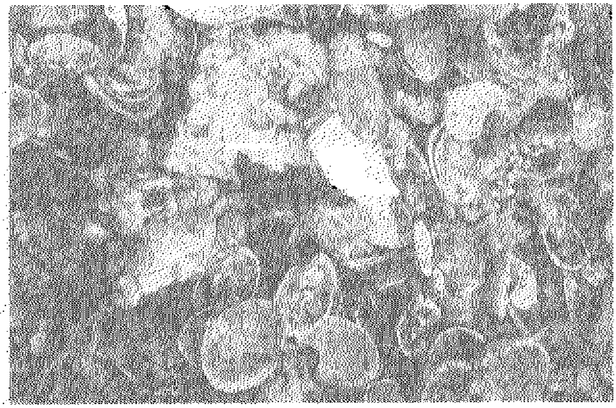

Fig. 3. Example of Shelltype I from east of St. Paul Island. Most shell is intact and covered with epiphytic growth. Pictured primarily are _Serripes_ sp. and _Spisula_ sp.

Results

Water temperatures.

Bottom water temperatures differed between St. Paul and St. George Island (61 km apart) and were colder at northerly St. Paul in both May 1983 and April 1984. In May temperatures ranged from 2° to 4.5°C on the bottom and 2° to 4°C at the surface. By August of 1983 bottom water temperatures were about 8°C around St. Paul, but only 5.5°C at St. George whereas surface water was generally about 8.5°C over the entire area. The spring of 1984 was particularly cold and by mid-April sea ice still extended to the north shore of St. Paul Island which prevented sampling most stations in that vicinity. Surface and bottom water were almost always isothermal throughout the study region and ranged from about 1.5 C near St. George to nearly -1°C around St. Paul Island.

Substrate.

Although a number of sediment analyses were performed for standard grain size parameters, the most useful classification of bottom sediment for the purpose of describing juvenile crab distribution was based on broad categories of sand, cobble, gravel, and rock (Fig. 4) or shellhash which often overlaid several of these substrates in various regions (Fig. 5). The highest densities of juvenile blue king crab as determined with the rock dredge were found most consistently to the east and west of St. Paul Island in areas of cobble and gravel, frequently covered with Shell I (Figs. 4 and 5); similar substrate configurations were found to the east of St. George Island. In all nearshore regions, bottom type was very heterogeneous, frequently alternating between major substrate categories over a distance of a hundred meters or less; for this reason SSS was a very useful tool to direct sampling effort on specific substrates. The shelf area between the two main islands showed much less heterogeneity in the SSS records and was verified to be a relatively uniform sandy bottom based on a large number of grab and dredge samples. In total, data from over 400 benthic trawls and dredges was used to form a composite of bottom type throughout the Pribilof Islands study area during the three cruises.

Shelltype I was the most important epibenthic substrate for juvenile blue king crab and was composed primarily of four species of bivalves (*Serripes groenlandicus*, *Spisula polynyma*, *Chlamys sp.*, *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were generally intact or in large pieces and usually covered with profuse epiphytic growth including feathery bryozoans, barnacles, anemones, ascidians etc. Both the rock dredge and beam trawl used in areas east of St. Paul and St. George Islands frequently caught several hundred pounds of pure shell per haul, or shell such as *Pododesmus sp.* and barnacles adhering to cobble (see Palacios et al., this proceeding for a discussion of community composition relative to substrate type and juvenile crab distribution).

Adult female distribution and abundance.

Mature female blue king crab (carapace length >90 mm) were most abundant to the southeast of St. Paul Island in May 1983 as determined

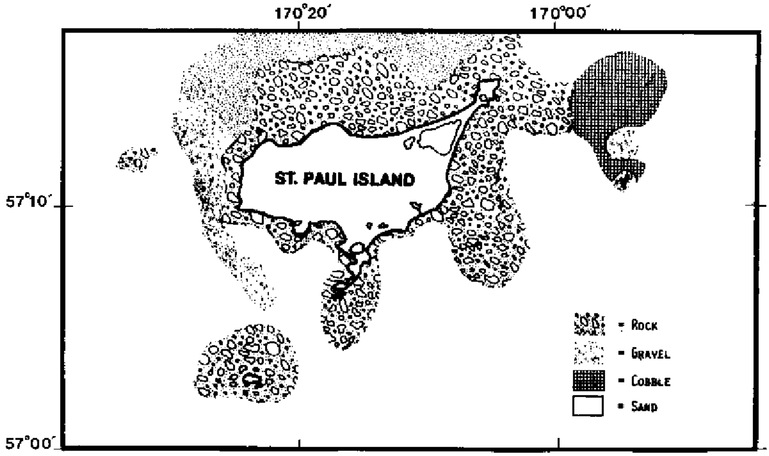

Fig. 4. A composite map of major substrates around St. Paul Island based on side scan sonar, trawl and grab samples. Such areas around and between both islands were digitized on computer and used as strata to group stations for estimation of population abundance.

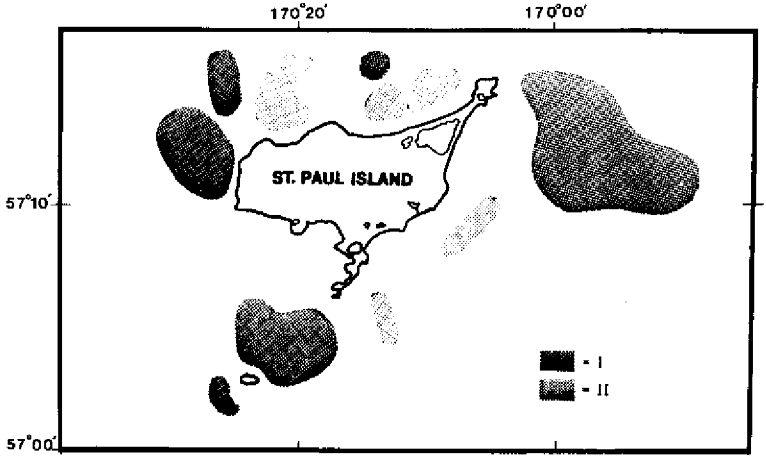

Fig. 5. Distribution of shellhash around St. Paul Island. Shelltype I (darker shade) was material generally intact covered with epiphytic growth and supported high densities of juvenile blue king crab. Type II was pulverized, polished and had no biological growth nor associated king crab.

by beam trawls (Fig. 6). Females were generally within 25 km (14 NM) of St. Paul Island on a mixed sand/mud substrate with a high prevalence of gastropod shells (see Palacios et al., this proceedings). Female density ranged from zero at many stations not pictured in Figure 6 (refer to Fig. 1 for the extent of trawl sampling stations) to 50/ha in the area of greatest abundance southeast of St. Paul; no female crab were caught around St. George Island. Based on the standard units used by NMFS, this would equate to about 13,000 to 17,000 crabs/NM^2; a very high density compared to most years of data from the NMFS groundfish survey (eg., see Otto et al. 1984). Using a

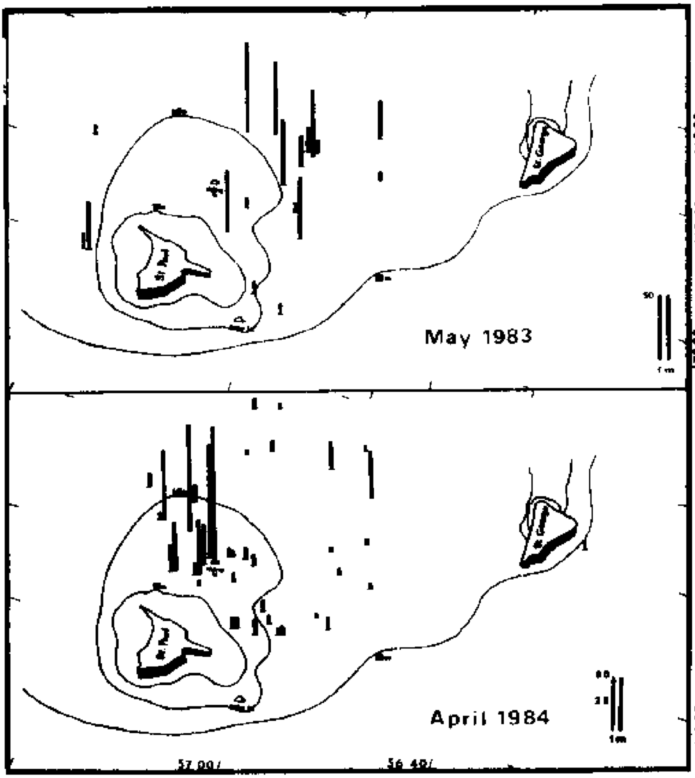

Fig. 6. Distribution and abundance (no./ha) of adult blue king crab in spring of 1983 and 1984. Refer to Fig. 1 for the extent of sampling to appreciate the rather restricted distribution of females.

NMFS program to estimate population abundance, 6.2 million mature females were calculated for an area of about 8,840 km (2,600 NM) extending from about 25 km north of St. Paul Island down toward St. George Island along the 80 m isobath to the west. Considering the extent of our sampling around the Pribilof Islands as well as that of in the same year (Otto et al., 1983), the preponderance of the mature female population was situated relatively near St. Paul Island as larval hatch occured. By August of 1983 mature females were much more broadly distributed around the Pribilof Islands, primarily in the basin between St. Paul and St. George and their population estimate was less than one-third of that calculated for May of the same year. In April of 1984 female crab were again abundant nearshore and to the east of St. Paul at densities up to 120/ha (Fig. 6).

Larval distribution and abundance

In spring of both 1983 and 1984 blue king crab larvae were judged to have hatched in mid to late April. During May 1983 larvae were predominately stage I zoeae (greater than 80%) during the first portion of sampling beginning May 10, and were a composite of stage II and stage III zoeae (35-60%) during the latter part of that cruise about May 25. From these data a development rate of about 2.5 to 3 weeks per zoeal stage at prevailing water temperatures was calculated. During mid to late April 1984 all blue king crab larvae caught were stage I zoea and all were found just south of the 0° isotherm midway between St. George and St. Paul Islands (Fig. 7). Egg hatching was evidently occuring during the cruise since a large number of females were caught in the vicinity with nearly empty egg cases or full clutches of eyed eggs in the process of hatching.

In May 1983 larvae were found distributed primarily south and southeast of St. Paul Island, frequently in waters of depths between 40 to 60 m (Fig. 7). Larval densities averaged around 4,000/100m^2 of sea surface in the vicinity of St. Paul Island with peak values between 13,000-18,000/100m^2. Virtually no larvae were found near St. George Island, nor were larvae generally found at distances in excess of 18 km to the north and west of St. Paul Island (Fig. 7). In April 1984 larvae were only found midway between the two islands in waters >0°C, although a large number of females bearing mature eggs were caught east of St. Paul Island (Fig. 6) near Walrus Island and are assumed to have hatched larvae soon after the termination of the cruise in late April and/or possibly when water temperatures warmed from the -1°C average of that area.

Juvenile distribution and abundance.

Juvenile P. platypus were considered those up to a carapace length (CL) of 30 mm based on consistent size frequency patterns throughout the three cruises (see size frequency section). In May 1983 relatively low densities of juvenile blue king crab were caught primarily east of both St. Paul and St. George Islands, but in general most of the 130 stations sampled had zero to very low densities of crab probably because the beam trawl was used much more than the rock dredge. In marked contrast, large populations of juvenile crab were found in August of 1983, likely for two primary reasons: first, settlement of large numbers of young-of-the-year (YOY) juveniles had occured by this time and second, more extensive use was made of the rock dredge as a sampling tool.

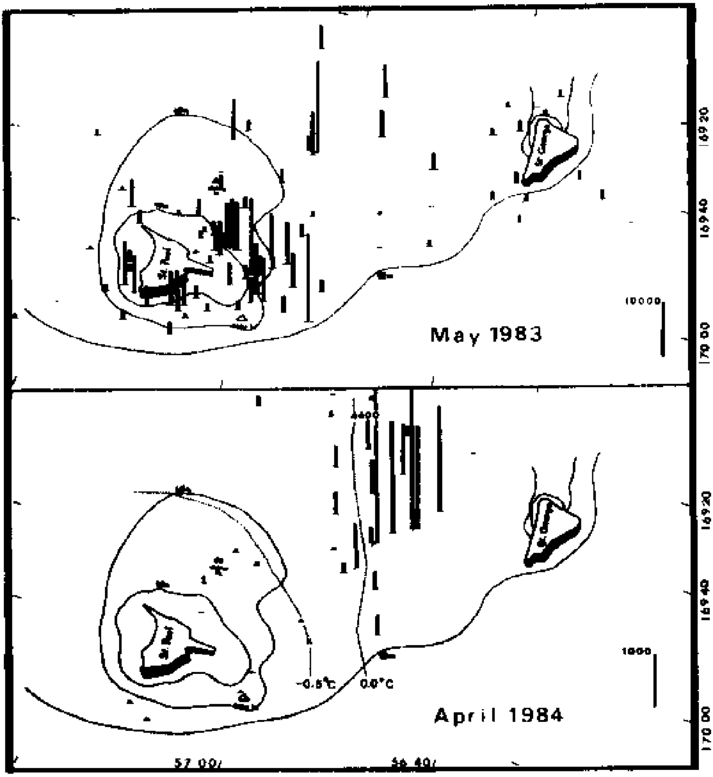

Fig. 7. Distribution and abundance (no./100m^2) of blue king crab larvae in spring 1983 and 1984 at the Pribilof Islands. (Note the 10x scale change between years).

Juvenile blue king crab were located in many areas around St. Paul Island primarily between the 40 and 60 m isobath (Fig. 8) on substrates that were composed of gravel, cobble and Shelltype I material. Extensive populations also occured east of St. George Island despite the lack of females or larvae distribution in that area (Fig. 8; refer to Figs. 1 and 2 for substrate distribution). Striking in the distribution pattern was the virtual absence of juveniles over the sand/mud shelf between the two islands and in any direction from the islands beyond the cobble/shell substrate. In areas of dense aggregation crab densities were exceedingly high, often in excess of

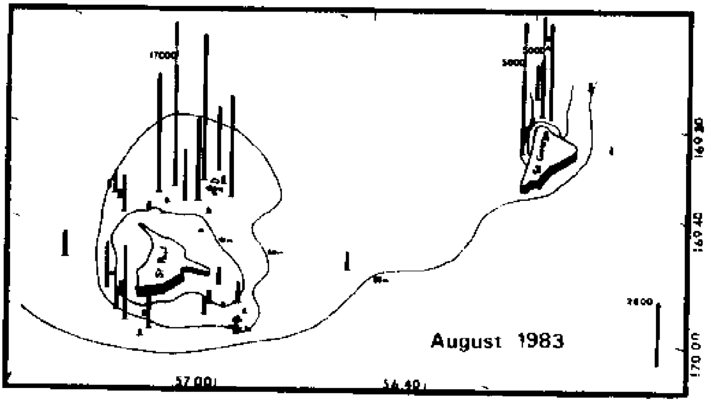

Fig. 8. Distribution and abundance (no./ha) of juvenile (< 30 mm CL) blue king crab caught by rock dredge in August 1983. Refer to Figs. 4 and 5 for a sense of the spatial association with certain substrates.

2,500/ha (Fig. 8). Station densities of 5,000 to 17,000/ha (Fig. 8) equate to densities of 1.7 to 5.4 million/NM^2 (NMFS survey units; 1 NM^2 = about 343 hectares). Population estimates of juvenile blue king crab in August 1983 were derived for an area of 2820 km^2 (830 NM^2) between the 15 to 60 m isobaths around each island (a more restricted area for juvenile distribution and population estimates was considered than used for adults). In that region 282 million animals were estimated based on rock dredge data, but in contrast the juvenile population estimate derived from beam trawl data and extrapolated to the same area was only 4 million animals.

Size frequency distribution.

A wide variety of size frequency analyses were performed on groupings of crab according to geographic or sediment composition strata, as well as according to cruise date and gear type (rock dredge or beam trawl). A great majority of juvenile crab caught in August 1983 were judged to be YOY first instar juveniles with a mean CL of 2.8 mm (Fig. 9). Based on size frequency analyses of the August data, our preliminary impression is that juvenile blue king crab grow very slowly and we selected as size ranges for age classes the following: 0+ = 2.8-10.0 mm, 1+ = 10.1-17.0 mm, 2+ = 17.1-24.0 mm, 3+ > 24.1 mm carapace length. By April 1984 crab that were judged to be 0+ (approximately 8 months old since a settlement date of August 1983)

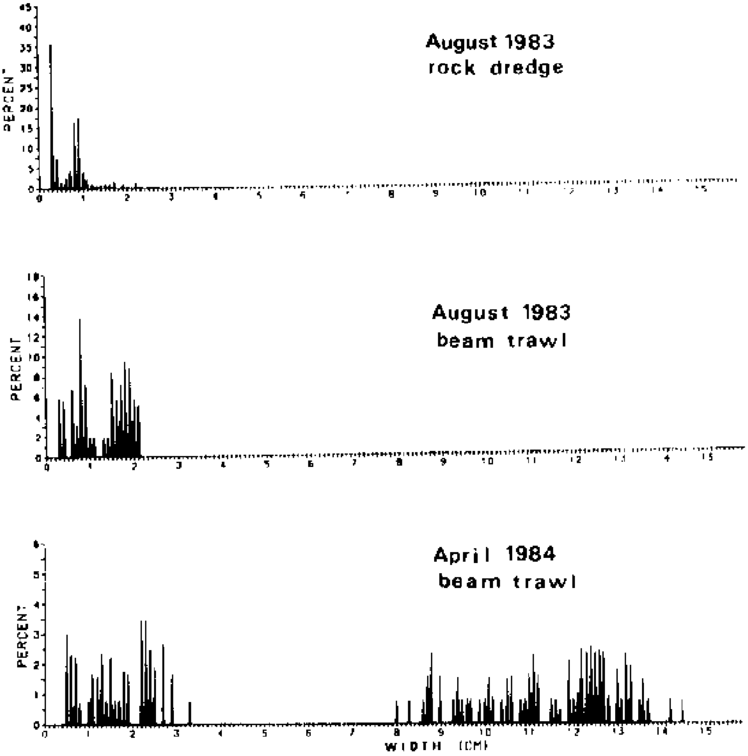

Fig. 9. Example size-frequency plots of blue king crab caught on a combination of gravel, cobble and Shelltype I. In August 1983 note the strong spike of first instars (3mm) at settlement. Note also the suggestion of several age groups under 30 mm and virtual absence of crab between 30 to 80 mm which was consistent on all three cruises.

still had a strong size mode between 5 to 7 mm and first instars were also found on that cruise. (Size/age interpretation is considered

preliminary and analyses are being continued at this time).
In general, two interesting features have emerged to date from such analyses:

1) The virtual absence of any size class of crab between approximately 30 to 85 mm CL for any cruise and gear type considered (Fig. 9), despite approximately 400 benthic beam trawl and rock dredge samples taken over an extensive area around and between the Pribilof Islands.

2) The apparent occurrence of up to three age classes (or four?) within a size range of 30 mm CL would indicate a relatively slow growth rate compared to that of red king crab (Weber 1967).

Discussion

The insular distribution of adult blue king crab shown by the annual NMFS groundfish survey was reinforced in the present investigation of nearshore species ecology. Much more so than adults, juvenile stages of P. platypus are restricted to nearshore areas around the Pribilof Islands and the bulk of the population can be found within 10-15 km of St. Paul and east of St. George. The high degree of association between juvenile blue king crab and shellhash was unexpected, and yet may provide an important explanation of the limit of species distribution and range. The habitat needs of juveniles of several species of commercial decapods have been investigated, usually within the context of estuarine nursery areas. Stevens and Armstrong (1984) found that juveniles of Dungeness crab (C. magister) were much more abundant in eelgrass beds of coastal estuaries than on open intertidal flats or in subtidal channels that did not provide some form of epibenthic cover. In a more recent study, Armstrong and Gunderson (1985) found that YOY juvenile Dungeness crab were critically dependent on shellhash, principally that of oyster and Mya arenaria; this the only other reported instance of a close association between juvenile crab and shellhash of which we are aware. Juvenile penaeid shrimp in estuaries along the Gulf states are most commonly found in vegetated areas where Spartina provides cover and habitat. Zimmerman et al. (1984) reported densities an order of magnitude greater in vegetated areas within a Galveston salt marsh than found over open mud and sand flats. In estuaries of North Carolina (Weinstein 1979) and in Chesapeake Bay (Heck and Thoman 1984) marshes and eelgrass (Zostera marina) support much higher densities and biomass of juvenile stages of blue crab (Callinectes sapidus) and penaeid shrimp than occur in open unprotected areas.

Relatively little work has been done on habitat requirements of juvenile stages of coastal commercial decapods with the exception of several species of lobster. Pottle and Elner (1982) demonstrated a distinct preference of juvenile Homarus americanus for gravel when given that as a choice along with silt-clay. Juveniles were able to excavate burrows in gravel which they occupy during daylight to avoid predators. Howard (1980) hypothesized that the size composition of lobster populations (Homarus gamarus) along the English coast is controlled by substrate size and composition as well as by nearbed current speeds which, if too fast, augment juveniles' need for rocky outcrop areas (Howard and Nunny 1983).

Only very limited work has been done specifically on the distribution and habitat requirements of young stages of juvenile blue and red king crab in the southeastern Bering Sea and Gulf of Alaska. Sundberg and Clausen (1979) documented higher incidence of juvenile red king crab in rocky areas of lower Cook Inlet than elsewhere on more open unprotected bottom. Jewett and Powell (1981) described general nearshore ecology and breeding biology of king crab around Kodiak Island and describe a similar propensity of small juveniles to occupy rocky niches in that area as well. In the southeastern Bering Sea McMurray et al. (1984) presented the results of a broad scale survey of juvenile distribution from Unimak Island through Bristol Bay, and reported a higher incidence of small juveniles (<28 mm CL) on substrates of gravel or cobble, usually in association with biological material that provides a three dimensional habitat. Such invertebrates as stalked ascidians (*Holtenia ovifera*), bryozoans and colonial tube dwelling polychaetes were frequently associated with small king crab found inshore of the 50 m isobath.

In the present study small YOY and somewhat older age classes of juvenile *P. platypus* were consistently associated with a gravel to cobble substrate, but more so with various forms of shellhash around both St. George and St. Paul Islands. It is assumed that such shell material is the principle form of refuge afforded newly metamorphosed and small sized juvenile crab that are otherwise predated by a variety of other invertebrates and fish. The strict association with shell may in part explain the limits of species distribution, particularly in contrast to that of the red king crab. Small juvenile red king crab are from metamorphosis much more spherical than are blue and have an exceedingly spinose morphology that, assumably, helps to decrease predation. Coupled with the physical attribute of spines to desuade predation is the well known behavioral process of podding that is also viewed as an anti-predator component of early life history (Powell and Nickerson 1965). In marked contrast, juveniles of *P. platypus* are compressed dorsoventrally and have virtually no appreciable spinose pattern to the carapace at all. The low, rather flat matrices in stacked shell, particularly of the several bivalves that dominate shellhash around the Pribilof Islands, probably serves as a very effective habitat for small juvenile stages of this closely related (to *P. camtschatica*) but anotomically different species.

In general, the exceedingly thick cover of shellhash found around the Pribilof Islands may be peculiar to such insular habitats. Large populations of bivalves that produce the shellhash were found around the islands, and current patterns in the vicinity may be such that empty shell is retained in the area. Elsewhere in the southeastern Bering Sea, particularly along the North Aleutian Shelf from Unimak Island to Kvichak Bay and west to Cape Newenham, we have never observed, despite numerous trawls and rock dredges, similar aggregations of shellhash as seen at the Pribilofs although large infaunal populations of certain bivalves exist in the area (McDonald et al. 1981). The very restricted distribution of juvenile king crab around the Pribilof Islands and apparent dependence of this early life history stage on particular benthic material makes the overall life history of this species somewhat precarious. Females are apparently situated nearshore at the time of egg hatch in the spring and larvae (based on our two cruises in May 1983 and April 1984) are certainly distributed in greatest density nearshore around the islands or at least in the open water between them. However, given the extended larval period of this species, which is estimated to range from about 3.5 to 4 months (Armstrong et al., unpublished data), and the very limited benthic habitat to which they must settle and metamorphose for successful juvenile survival, it seems likely that this species may experience year class failures in certain years.

Summaries of current patterns in the southeastern Bering Sea, and particularly in the vicinity of the Pribilof Islands, show a general northwest direction and slow speeds along the shelf break past the islands (Kinder and Schumacher 1981; Schumacher and Reed 1983). On the local scale of the Pribilof Islands there must, however, be current patterns and eddies that normally retain larvae nearshore to enhance settlement on the limited refuge substrate found in the area. However, in certain years it seems quite probable that anomolous events may cause transport of larvae well beyond the Pribilof Islands which results in settlement and metamorphosis of megalopae on substrates where survival is exceedingly low. It is striking that after several hundred benthic trawls and rock dredges over a relatively wide area around each of the islands, no juveniles between approixmately 30-85 mm carapace length were caught, a size range that probably encompasses several age classes.

Uncertainties of annual recruitment success, the strict dependence of early life history stages on nearshore habitat around the Pribilof Islands, the unique reproductive biology of this species (biennial spawning of females, Somerton and MacIntosh 1985; Jensen et al. this proceeding) and the uncertainties concerning growth rate are all issues that should be considered and studied for better management of the fishery. Of further interest to us is the relationship between juvenile king crab and their shell habitat, particularly population dynamics of the molluscan species themselves, their frequency of recruitment and age at death, as well as age of shells before physical and biological processes reduce them to sizes suitable as crab habitat. Importance of gastropod shell to benthic communities that are comprised of hermit crabs, octopus and fish has long been recognized and the impact of reduction in shell supply and/or configuration has recently been reviewed by McLean (1983). Future crab research should include studies of the dynamics of molluscan populations that supply refuge for juveniles of this commercial crab species.

Acknowledgements

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Southern king crab, *Lithodes antarcticus*, of the Magellan Region, Chile

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INTRODUCTION

Fishing for Lithodidae in Chile is centered on harvesting the southern king crab (Lithodes antarcticus) "centolla" and, to a lesser extent, false king crab (Paralomis granulosa) "centollon". As far as Lithodes murrayi is concerned, there is not much information, except for some reports about its presence in the far southeastern region of the Pacific Ocean (Campodonico and Guzmán, 1972).

The exploitation of the southern king crab is one of the main economic activities in the southern part of the country, after cattle raising and mining. Fishing for this resource is limited to the Magellan Region, between 49° and 56° latitude south, with an area of 132,000 sq. km. Human population density is one inhabitant per sq. km and the region is isolated from the rest of the country by 400km of mountains, glaciers and channels, in such a way that the region can be reached from Chilean territory only by sea or air.

The distribution of Lithodes antarcticus in the Pacific Ocean extends from the latitude 38°48'S (Valdivia) down to the far end of South America, although sometimes it has been seen near Talcahuano (36"41'S) (Fig. 1). Its bathimetric distribution goes from shallow waters to depths reaching 600m, and is always associated with low temperatures.

Historic Summary

The exploitation of the southern king crab began in 1928. In 1934, without any previous studies, some fishing regulations were implemented. Thus, the minimum legal size was set at 120mm carapace length; the harvesting of females with external eggs was prohibited; and a closed season for its fishing was fixed between February 1st and June 30th of each year. Of all these regulations, only the minimum

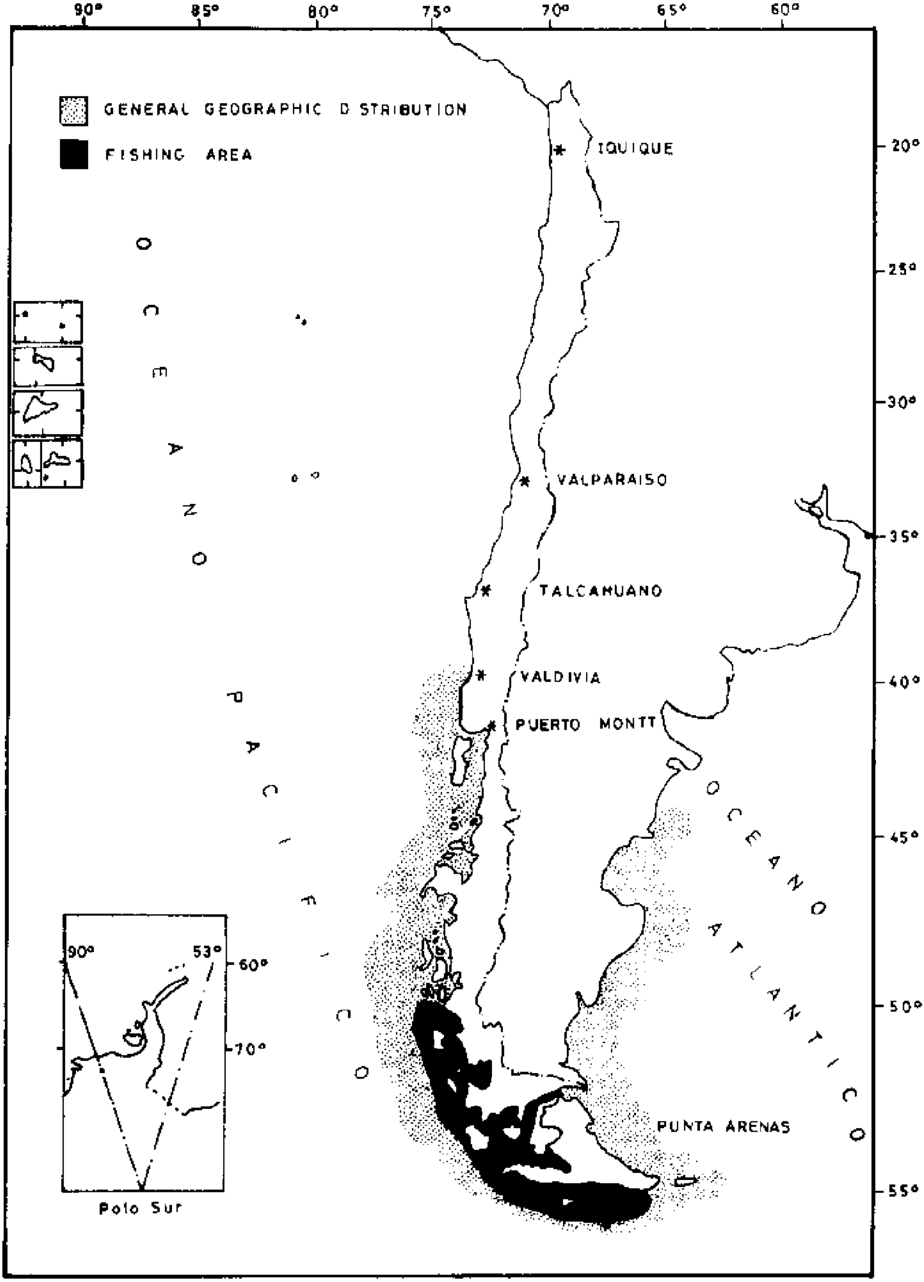

Figure 1. General geographic distribution and fishing area of southern king crab Chile.

legal size is still in effect. The regulation regarding females was not strictly adhered to since they carry eggs most of the year. This resulted in the prohibition of harvesting or transporting females in the Magellan region in 1973. The regulation now calls for female crabs to be returned to the sea in the same place they were captured. Later, this regulation was set as a standard for the whole country. Finally, since 1982 the harvesting of the southern king crab has been allowed throughout the year. This was instituted only on the condition that the fishing industry test the feasibility of operation in the months previously prohibited. A regulatory change to protect the mating period will probably be implemented in 1985. A closed season will be set between December 1st and January 15th.

The first biological study of the southern king crab resources was made 35 years after the industry began. Some of the conclusions obtained at that time are still valid, such as the reproductive migrations and the molting time. Campodonico (1981) presents a review of the investigations done on southern king crab through 1979.

A fisheries biology project was begun in 1979 and is still active. As a result of the investigations, some changes in resource regulations were implemented. That is why the use of tangle nets has been prohibited since 1980, allowing only the use of pots. This has been difficult to enforce because of the limited means available, due to the vast extent of the fishing areas. It is believed that a relatively high number of tangle nets still operate illegally.

In October 1981, the Porvenir area was closed for a period of four years. This area had been fished since the industry began, and was considered overexploited due to diminishing relative abundance indices and average sizes of males and females. In this area, the harvesting of females was a constant violation.

There are still several aspects of the fisheries that have not been studied, i.e. physiochemical, oceanographic and ecological relationships; determination of some population parameters, stock evaluation in terms of real abundance, etc.

Life History

Marking experiments in the Magellan Strait area have shown that the southern king crab does not make any significant horizontal movements (Geaghan, 1973), but does make vertical migrations correlated with the reproductive cycle (Stuardo and Solis, 1963). Around the first part of spring, the *Lithodes antarcticus* migrate to shallow waters and after mating (December and part of January), they return to deeper waters. This fact is demonstrated by the changes in the sex ratio in commercial catches (Campodonico and Hernandez, 1981).

Except for the case of the Admiral Montt Gulf area, where the process of liberation of the larvae and spawning occurs a month earlier than the other areas studied (Sanhueza, 1976), (in the Magellan Region the liberation of the larvae occurs after 10 to 11 months of incubation), the process begins in mid-September and ends in early November. During most of November, all the mature females are without eggs, but at the end of November or the beginning of December, it is possible to find some females with new eggs.

Spawning occurs immediately after molting, when the carapace is still soft. The highest intensity spawning occurs in December, but the whole process extends until approximately mid-January.

The larval development comprises three stages of zoea and one of megalopa; the planktonic zoeal life is less than a month and depends on the water temperature (Campodonico, 1971).

All the information on sexual maturity is being updated and analyzed by the Patagonian Institute, since significant variations have been found between areas relatively near one another. Until recently, the information had been analyzed using large geographic areas.

As to fecundity, there are differences among the small areas and among the number of eggs that females of the same size carry. Fecundity varies; between 2,000 and 60,000 eggs are attached to the pleopods. In comparison with Paralithodes camtschatica, the fecundity of Lithodes antarcticus is low, a fact that is consistent with the larger size of the eggs and the shorter period of larval development (Campodonico and Hernández, 1983).

The population is parasitized by the rhizocephalan Briarosaccus callosus, but the incidence of parasitism varies between areas and localities. Although single infestations are the most common, specimens with up to four parasites have been found. The percentage of infested crabs markedly diminishes as the size of the crabs increases. One of the possible explanations for this situation might be a high mortality among the host crabs (Campodonico and Hernández, 1981). The right chela of infested males is smaller than those of non-parasitized individuals, and mature-size female hosts do not carry eggs on the pleopods. The maximum percentage of parasitism recorded to date is 15.3 percent of the population of a location in Ano Nuevo Inlet; a quantity that considerably exceeds any other samples in the region.

Structure of the Population

The studies of male:female ratio in the commercial captures show, in general and especially during spring and summer, the existence of a predominant quantity of males over females. However, this is not a clear and definite reflection of the real relation of sexes in those environments. The higher proportion of males would be due to the female behavior associated with the spawning process. On the other hand, the smaller size of the females would allow them to escape more easily. It is also suggested that the crabs congregate by sex and that the fishermen make the selection. All these factors have been extensively analyzed by Geaghan (1973), Sanhueza (1979) and Campodonico and Hernández (1983).

Sex ratio is also a function of size and generally fits into the "anomalous" pattern as described by Wenner (1972), but seasonal fluctuations in the ratio are evident. These variations are attributed to a reproductive migration as well as to a change in the vulnerability of the fishing gear (Campodonico and Hernández, 1983). The size structure for males, as well as for females, shows variations between areas, seasons, and as a result of commercial exploitation (Figs. 2 and 3).

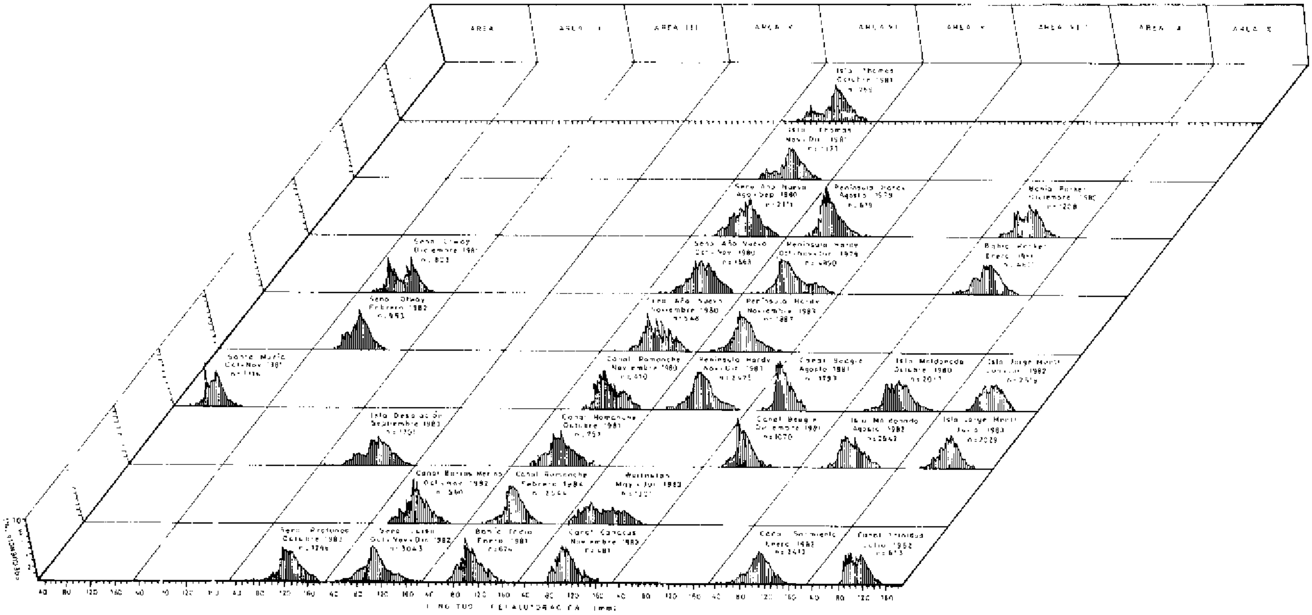

Figure 2. Size composition for males of southern king crab, sampled between 1979 and 1984.

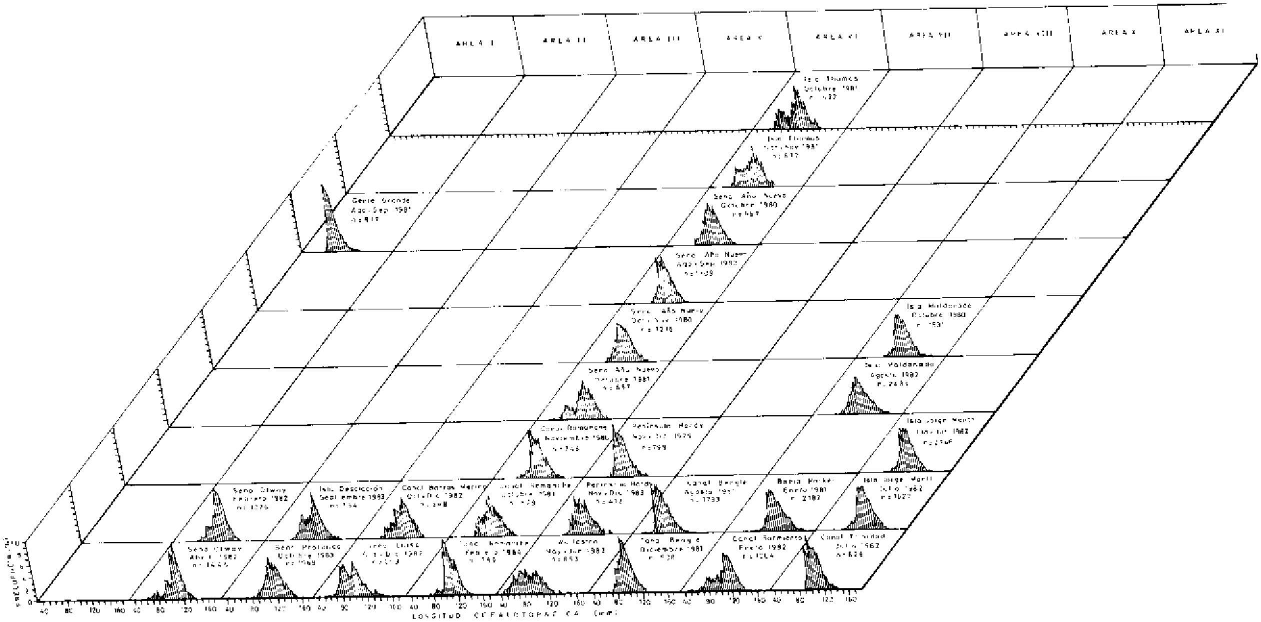

Figure 3. Size composition for females of southern king crab, sampled between 1979 and 1984.

Comparisons among the size frequency distributions of crabs from small areas and for different times of the year showed significant differences between the curves. An increase in the average sizes from winter to summer is related to spawning migrations and linked to an increase in the proportion of larger samples. After the reproductive period, large crab probably return to deeper water where the fishing gear is less effective.

Comparing size-frequency distributions from various small areas generally showed differences between locations that are relatively near one another. Cases where this situation can be observed for both sexes could be attributed to the existence of different environmental conditions, which produce different growth and mortality ratics, including, in the latter, the effects of fishing (Hernández et al, 1984).

Size ranges observed between 1979 and 1984 in the commercial catch was 34-184mm carapace length for males and 36-173mm for females. The average size for the landed males was 128-134mm carapace length, which represents a live weight of 1.5-1.8kg per king crab. Even though the controls have been intensified, landings of king crab caught below the minimum legal size, especially between the sizes of 110mm and 119mm carapace length, still exist.

Exploitation

Fishing for southern king crab was centered for almost 50 years in the Magellan Strait and nearby areas. Only since 1974 has the Beagle Channel been exploited. In 1976, the Cape of Horn Archipelago (55° 40'S) was added, this being the southern limit for fishing. In 1979, the harvest in the Ano Nuevo Inlet began and from 1980 on, the fishing industry has extended north to Nelson Strait (51°40'S). In 1982, fishing was as far as the Trinidad Channel (50°S), the maximum northern latitude reached so far. Figure 4 shows a clearer view of the expansion experienced since 1979. It can also be observed that the geographical area suffers variations between seasons, due to the incorporation of new areas and the abandonment of others.

The harvesting and processing of the southern king crab began in Chile about half a century ago. In 1928, the first canning industry was installed, joined by others later on. The development of fishing was rather slow up to the 1950s. The industry operated mainly between October and December, being closed for the rest of the year. Until then, the landings did not surpass 150 tons and were distributed only in the national market.

With the exception of the start of the frozen southern king crab industry in the 50s, there have been no other major changes during this period. This is why the Magellan Strait area remains the main industrial center and the market maintains a domestic character. The landings in the period fluctuated between 200 and 400 tons, figures that were maintained in the first three years of the 70s. However, it was in the 70s that growth occurred, as clearly shown from 1974 onward (Fig. 5). In that period, there was an important technological development in the industrial sector, coinciding with the exploitation of the southern area of the region.

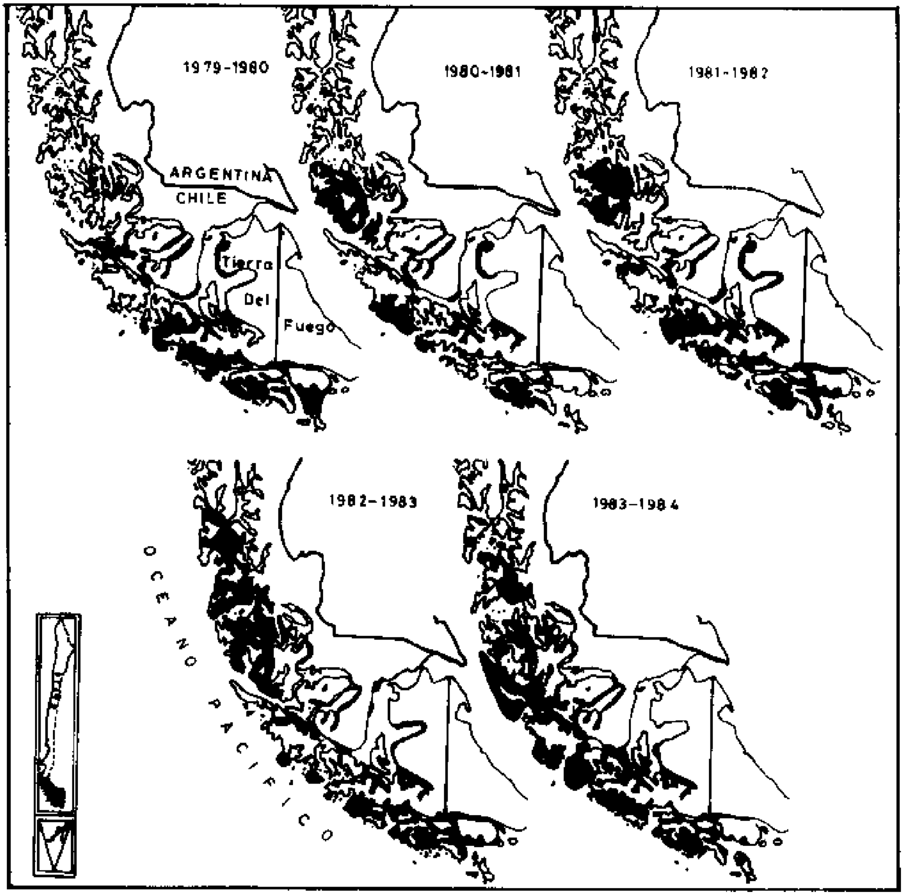

Figure 4. Fishing areas of southern king crab between July 1979 and January 1984 in Magellan.

In 1976, exporting began, the fishing industry increased its volume, and the mechanization of the industry was improved. From 1976 to 1979 there was an increase in the volume of landings, due to increased fishing effort and to the exploitation of new areas.

In 1980, a general decrease in industrial activity and production was caused by a considerable fall in orders and prices paid for the Chilean king crab, at that time fully dedicated to the European market in a variety of canned foods. For this reason, the landings fell very remarkably between 1979 and 1980. In 1981, there was a slight rise caused by the opening of the North American market to the frozen line. This started a reorientation of the fishing industry toward frozen products. Since then, the frozen line has surpassed the canned food production.

In the second half of 1982, market conditions got better and reactivated the local fishing activity, leading to a significant increase in industrial activity in 1983. Historically, the highest fishery landing was recorded in 1983, reaching 2,633 tons. There was a slight reduction in 1984 (2,571 tons). Rivalry among companies and failures in commercialization have not allowed Chile to maintain a stable market.

Generally speaking, the king crab fishery can be defined as a fishery in the process of development. In a decade, the landing has quintupled, new fishing areas have been exploited, and the harvesting and processing capacity has increased annually. The industry has become highly developed but, at present, the processing capacity considerably exceeds the total harvesting capacity. This means that the growth of the fishery should be planned on major fleet development and especially on optimization of its quality.

The fleet is composed of a large number of small vessels, mainly wood-hulled; many of these do not have mechanized systems to operate pots. The length of these vessels varies between 7m and 22m, although more than 50 percent are in the 8-17m range. Only a small proportion of the fleet belongs to the industry; it is mainly of low tonnage gross register, without proper navigational and communications systems, and with weak facilities to maintain the raw material.

Vessels less than 9m long generally have a beam that does not exceed 2m, compared with the base of the pots commonly used in the fishery, which are approximately 1.6m in diameter. It is clear that most of these vessels work with tangle nets.

Pots in use are round-based, not more than 60cm high. Pots are hauled down in sets of 10 to 20 pots per line. The most common bait is fish, although some mammals and sea birds are used illegally.

For statistical purposes, the region was considered as a whole until 1978. After that time, it was divided into 12 areas, whose limits were mainly based on fishery development. Figure 6 shows a map of the region separated into the 12 different areas.

Since 1982, harvesting throughout the year has been allowed. However, the fishery maintains its historic behavior, registering higher landings in November and December. In Figure 7, the evolution of the landings and the number of vessels is shown; the curves are similar.

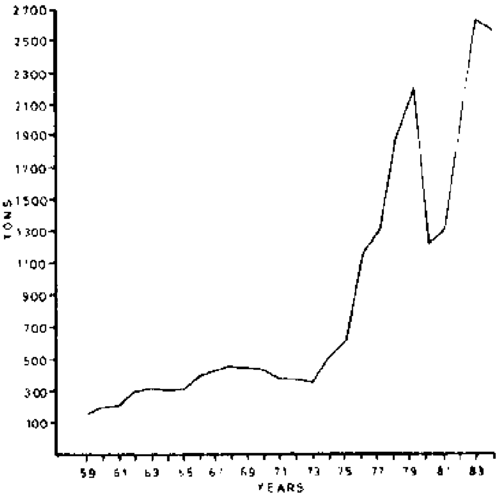

Figure 5. Southern king crab landing (Chile) between 1959 and 1984.

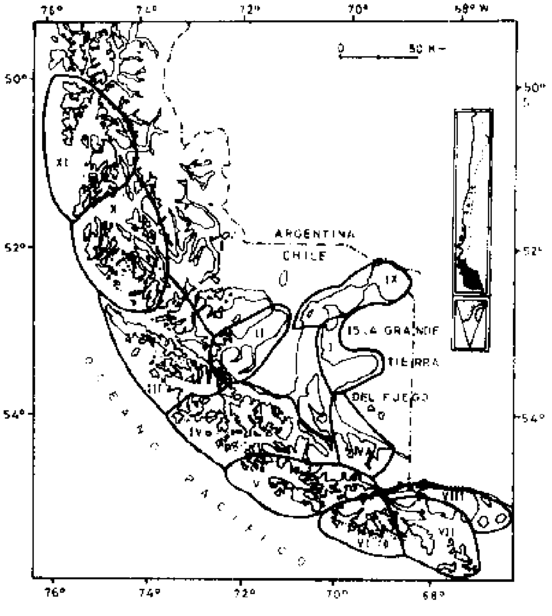

Figure 6. Southern king crab fishery studies areas.

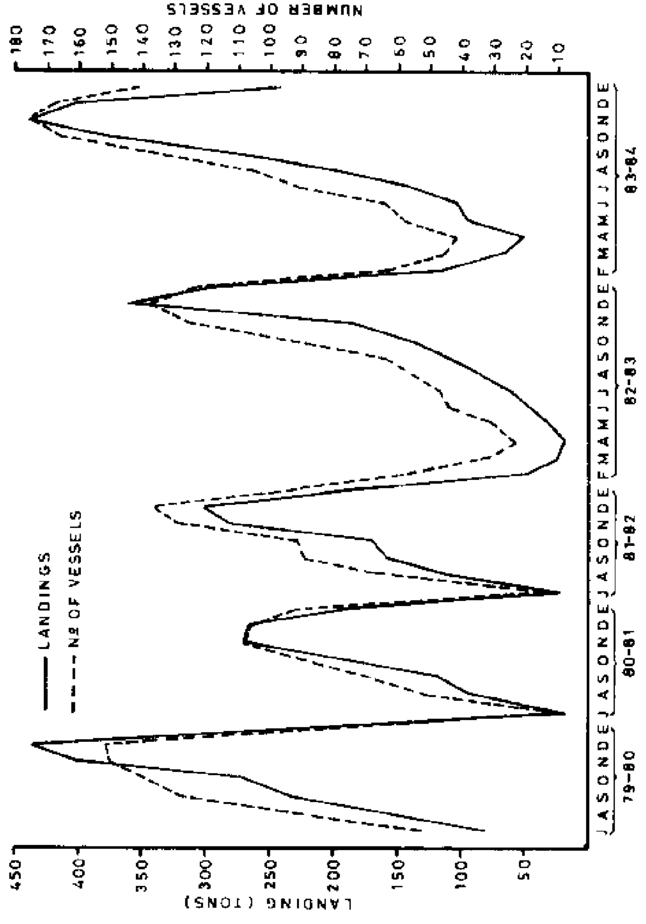

Figure 7. Monthly variation of the number of vessels and landings, July 1979 to January 1984.

A statistical analysis showed a high degree of association between the variables.

The feasibility of conducting the commercial fishery from February to June is unequivocal. Lower capture rates during other months is basically the result of limiting the effort. To date, this has been on the increase. The landings recorded for the period from February to June 1984 reached 603 tons, which represents more than 200 percent of the harvest recorded the first time this season was opened in 1982. The noticeable limiting of effort in April is probably due to the condition of the king crab and to the decrease of the yield produced by the male molting process (Hernández et al, 1984).

In Table 1, the landings per fishing area in each season is shown, as well as the contribution of each to the total landings of the five-year period, 1979-1984. It shows that the areas VI (Año Nuevo Inlet) and V (Balleneros Channel) contribute the highest percentage to the total, followed by VII (Cape of Horn Archipelago), III (Clarence Island) and X (Maldonado Island). These five areas produced 58 percent of the accumulated total landings. The area that contributed the highest proportion to the total landings can also be seen. The changes in each season are basically due to the industry operation system and to the incorporation of new fishing areas.

Table 2 compiles the fishing effort estimated in number of pots. It can be seen that the 1979-1980 season (running from July to January of the following year) is the one contributing the highest effort. In the following season, effort diminishes by 55 percent. Later on, it increases in a slow but sustained way. In the 1983-84 season it reaches an amount corresponding to 81 percent of that recorded at the beginning of the five-year period.

The relative abundance indices, expressed as crabs per pot, show fluctuations between seasons in the different areas, which are in some cases due to the utilization of more productive locations within each area, as for instance the incorporation of locations of better yield near the Pacific Ocean.

The average catch per pot of legal males varies from a minimum of 0.5 to a maximum of 2.2 crabs per pot (Table 3). Considering that the catch per unit effort reflects the relative abundance of the resource, the region can be divided into areas of higher or lower productivity.

Area VIII (the Beagle Channel) presents a significant deterioration in the relative abundance indices. This is a result of considerable landings of king crab smaller than legal minimum size. Fishing now depends on the recruits incorporated each year.

General Considerations on the Protection of Southern King Crab

At present, there is a management plan waiting to be passed by the government (Hernández et al, 1984). Its main objectives are:

- to reduce the risk of overexploitation and the failures in recruitment.
- to promote better utilization of the resource, dependent on the biological conditions of the stocks.

Table 1. Landings of southern king crab (tons). Period of 1979-80 and 1983-84.

	Period								
Area	1979-80*	1980-81*	1981-82*	1982**	1982-83*	1983**	1983-84*	Total	%
I	144.1	24.2	29.5	--	0.3	--	--	198.1	2.4
II	160.5	62.0	26.7	14.0	33.8	46.7	105.1	448.8	5.4
III	10.8	5.1	4.5	19.7	93.8	46.3	243.0	423.2	5.1
IV	256.2	156.8	188.3	12.7	94.5	27.4	271.0	1,006.9	12.1
IV-A	--	2.7	53.0	7.8	87.6	77.4	186.3	414.8	5.0
V	327.4	14.4	295.7	17.6	341.9	2.3	255.6	1,254.9	15.1
VI	400.8	365.6	169.5	--	67.7	68.7	270.1	1,342.4	16.2
VII	381.7	--	246.7	10.0	93.1	9.9	295.8	1,037.2	12.5
VIII	57.6	74.6	57.3	3.1	40.2	3.0	59.4	295.2	3.6
X	--	428.1	162.4	41.7	147.1	75.0	132.8	987.1	11.9
XI	--	--	--	43.9	190.2	66.5	93.5	394.1	4.7
Indet.	51.2	7.0	43.2	15.5	169.5	34.5	178.7	499.6	6.0
TOTAL	1,790.3	1,140.5	1,276.8	186.0	1,359.7	457.7	2,091.3	8,302.3	

(*) July - January
(**) February - June

Table 2. Effort estimated (number of pots). Period of 1979-80 and 1983-84.

Area	Period							Total	%
	1979-80	1980-81	1981-82	1982*	1982-83	1983*	1983-84		
I	157,945	21,833	27,090	--	181	--	--	207,049	3.9
II	198,389	101,027	27,418	19,035	37,276	60,938	100,793	544,876	10.2
III	13,186	3,745	2,914	15,692	60,307	24,721	88,146	208,711	3.9
IV	323,721	143,670	138,540	12,596	70,930	25,500	147,811	862,768	16.2
IV-A	--	1,660	35,638	5,940	57,103	59,473	132,774	292,588	5.5
V	239,331	11,108	149,043	18,347	187,622	1,929	126,573	733,953	13.7
VI	200,341	116,696	68,152	--	26,256	34,228	95,033	540,706	10.1
VII	229,638	--	152,286	6,571	62,425	7,271	174,158	632,349	11.8
VIII	39,867	42,347	52,595	3,381	33,279	3,779	47,852	223,100	4.2
X	--	202,632	80,017	32,243	84,064	69,561	89,916	558,433	10.5
XI	--	--	--	35,508	120,197	59,063	61,042	275,810	5.2
Indet.	41,364	4,769	462	1,900	84,011	18,930	107,768	259,204	4.9
TOTAL	1,443,782	649,487	734,155	151,213	823,651	365,393	1,171,866	5,339,547	

(*) February - June

Table 3. Catch per unit effort (crabs per pot). Period of 1979-80 and 1983-84.

Area	Period						
	1979-80*	1980-81*	1981-82*	1982**	1982-83*	1983**	1983-84*
I	0.62	0.86	0.83	--	--	--	--
II	0.55	0.48	0.60	0.58	0.62	0.64	0.82
III	0.55	--	--	1.03	0.99	1.31	1.73
IV	0.56	0.69	0.80	0.77	--	0.78	1.10
IV-A	--	--	1.06	1.03	1.02	--	--
V	0.90	0.89	1.23	0.68	1.07	--	1.34
VI	1.36	2.15	1.54	--	1.68	1.52	1.91
VII	1.13	--	1.07	0.99	0.97	1.02	1.17
VIII	0.98	1.34	0.81	0.67	1.01	0.62	0.96
X	--	1.39	1.33	1.08	1.19	1.08	1.23
XI	--	--	--	1.01	1.12	0.99	1.16

(*) July - January
(**) February - June

- to develop a permanent information exchange about fishing and species.

It is proposed that the king crab fishery should consider the following options:

1. To maintain the regulations in effect. These concern the minimum size, type of pots, and prohibition of female landings.

2. Setting of a closed season time. The mating and spawning periods, which are from December to mid-January; must be protected. The intense fishing activity engaged in during these months not only causes unnecessary harm or mortality to females, due to their vulnerability because of molting, but also disturbs the reproductive behavior of the species and affects the success of reproduction. It is during this period that the use of tangle nets is higher due to their efficiency.

3. Temporary closing of small areas. As the size of commercial stocks has not been estimated so far, and as many of the areas have recently been incorporated, there is not enough information about capture and effort to estimate a quota on the basis of maximum sustainable yield. Besides, due to economic reasons, it seems highly improbable that a routine program for stock evaluation would be feasible.

The decision to have closed areas and the duration of the closures should be based on size composition, relative abundance indices, and the state of the female population, as much as on an estimate of the future condition of the resource (pre-recruit fraction).

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The fishery biology of Beagle Channel king crab *(Lithodes antarcticus)*

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Introduction

The fishing of the southern king crab -"centolla"- (*Lithodes antarcticus*) in the Argentine region of the Beagle Channel between Lapataia Bay and the Frontón Gable (SACB), south of the Isla Grande de la Tierra del Fuego (Figure 1), started in an artisanal way in the decade of1930. In spite of this, there are practically no statistic reliable registers, neither were they systematically obtained. It is only since 1973 that some investigations on the biology of the king crab in that region were made, although unfortunately very spottedly or partial (Scelzo et al, 1974; Fenucci et al, 1974; Boschi et al, 1975, 1976; Boschi, 1976; Boschi et al, 1981; Vinuesa, 1982; Vinuesa et al, 1982).

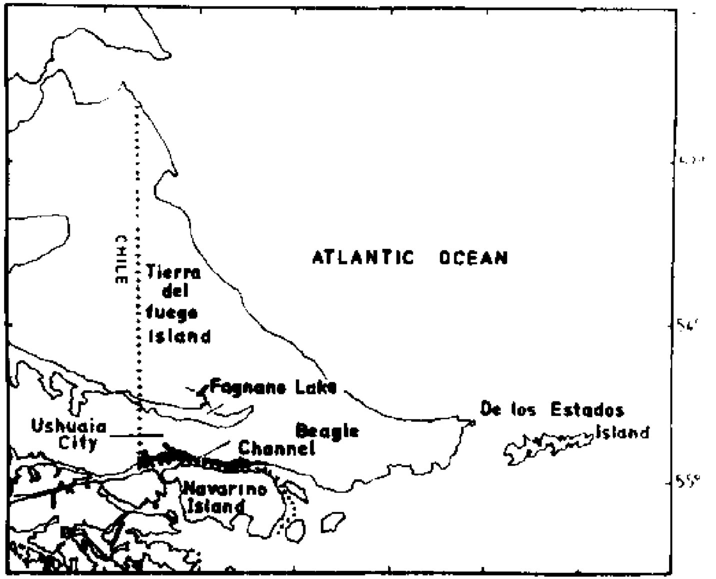
In 1980 an agreement was signed between the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) of Mar del Plata City and the three king crab processing industries settled in Ushuaia City, in order to determine the resource's situation, since there was alarm owing to the low yields. From August 1980 until December 1981, a research program was carried out with only a precarious framework loaned by the fishery industries. Some of the results obtained are presented in this communication.

The Fishery of King Crab in the Argentine Region of the Beagle Channel

The first commercial catches were realized with crab nets. Some years, nets more than 50 km long have been used. In 1975 it was determined that the only fishing gear allowed would be the pot. The length of vessels operating in the region does not exceed 15 m and generally have no navigation equipment. The crew of each vessel is composed of one cockswain and two sailors, and fishing usually takes one day. The pots have the form of a truncated cone and their skeleton is composed of three iron hoops united by eight crossbars of thinner iron rods. The framework is 1.30 m high. The mouth's diameter is 1.50-1.80 m The structure is covered by net of variable mesh size, 70-115 mm long and 55-95 mm wide between knots. The mouth of the pot is guarded by a circular plastic band which prevents escape.

Pots are drawn in groups of ten tied among each other by a thick rope (line) and separated from each other by 20 m approximately. This potline is usually drawn in direction NE-SW so as to achieve the optimum procedure, and a beacon is fastened to both ends of the rope. All type of meat not used for human consumption (lamb, chicken, pig, etc.) is utilized as bait, which is placed in small nylon bags tied to the pot. The potlines are normally left two days in the water before being examined. The catch is withdrawn, the bait is changed, and if fishing was successful, the pots are drawn again in the same place, otherwise their position is modified. The caught specimens are stored on the deck until the return to the plant, where they are lodged in hatcheries until they are processed, which usually occurs the day after. The catch of "centollón" or false king crab (<u>Paralomis granulosa</u>) is often also utilized. The landing at Ushuaia Port during the period 1977-82 has varied between 160 and 300 annual tons, excepting years when fishing was interdicted.

Figure 1. Austral region of the Argentine Republic. The Isla Grande de la Tierra del Fuego with the Beagle Channel. Shaded, the surveyed area or SACB, between Lapataia Bay and the Frontón Gable.

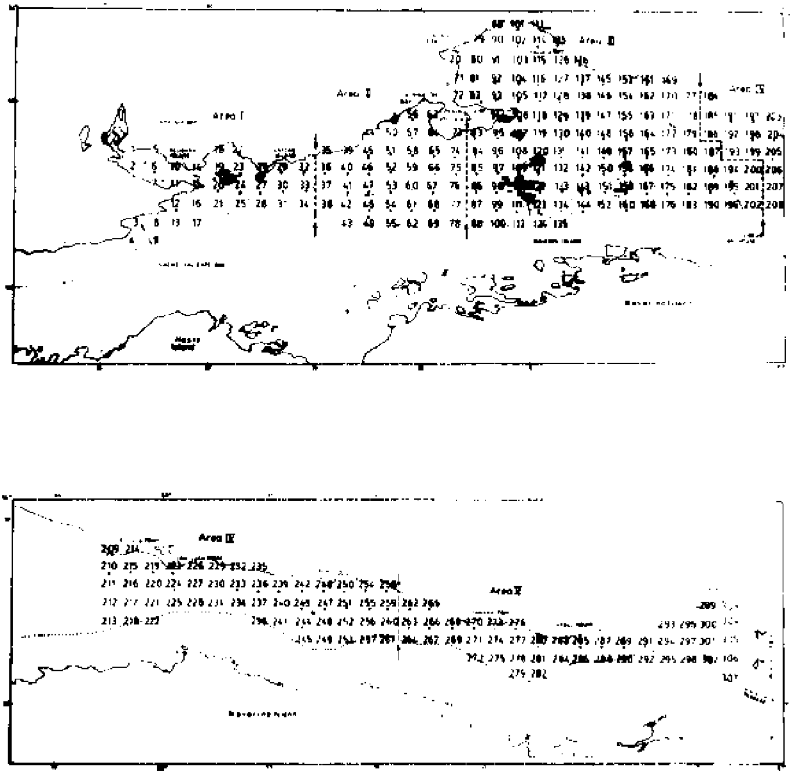


Material and Methods

Owing to the agreement signed with the fishery industries, a vessel was at our disposal with its fishing equipment and normal crew during ten days per month approximately. During that period, all trips meteorological conditions allowed were made, with two biologists of the INIDEP integrating the tripulation and supervising the task.

In order to localize the fishing operations, the surveyed region between Lapataia Bay and the Frontón Gable (SACB), was divided into squares of 30'' latitude per 1' longitude, equivalent approximately to 1,000 m per side. On the whole, 307 squares were delimited. Taking also into account the fishermen's experience, the region was subdivided into five areas (figure 2).

Figure 2. Surveyed area between Lapataia Bay and the Frontón Gable (SACB), indicating the boundary with Chile. The region was subdivided into 5 areas which include the 307 squares of approximately 1,000 m per side that were taken as reference to localize the pot-lines. Small circles indicate the surveyed squares and the broken lines, the isobaths of 5 and 50 m.



In each one of the periods during which a vessel could be used, the maximum number of fishing operations distributed at random in each one of the areas were tried to be fulfilled. The time the potlines remained in the water was usually two days and the bait utilized was lamb meat. The following data were registered from each operation, in specially designed forms: date, vessel, square number, depth, days the pot was left in the water, type of bait and number of king crab specimens caught by each pot. The following features were recorded for each specimen in the catch: sex, caparace length (LC), presence of eggs on the pleopods of females, eggs' stages and appearance of parasites and epibionts. In some cases also the caparace width (AC) and length and width of the right chela were registered. Measurements were made with an accuracy of 1.0 mm.

A modest program of tagging was also carried out in order to record some growth and displacement data. The tag was made of a yellow plastic spaghetti and nylon of 0.4 mm and tied up to the abdomen istmus so that it would not fall off, even during molting. 1,685 specimens were tagged of which less than 10% was retrieved.

The instantaneous estimate of the number of specimens which compose the fraction of the biomass vulnerable to the gear (FVAS) was realized according to the following method. It is assumed that the king crab's distribution in the SACB is of a contagious type. The area S of biomass is defined. This coincides with the area of the fishing effort distribution, between isobaths of 5 and 50 m. On the area S or some sub-area previously defined, n fishing operations were carried out (potlines drawn in direction NE-SW) distributed at random in the shortest lapse of time possible. This determines that n results are obtained consisting of a number of specimens caught per potline, whose probability distribution can be fitted to a negative binomial (Fisher, 1941; Haldane, 1941; Anscombe, 1949, 1950; Elliot, 1971; Ricker, 1973; Schaeffer, 1976). This distribution is determined by two parameters: the arithmetic mean m and the coefficient of contagion k. The latter was estimated by using the maximum likelihood method and the confidence interval taking into account Anscombe's transformation (Anscombe, op. cit.) according to Taft (1960).

The area of action of a potline (a) was determined by means of experiences with specimens tagged and freed by autonomous divers, and the catchability coefficient (q) was estimated. Then, solving $\sum_{t=0} t.p_t.q^{-1}.s/a$, an estimate of the number of specimens composing the FVAS was obtained, where p_t is the probability of each one of the mentioned results (t).

Results

Studies were made on 43,014 specimens, of which 20,453 were females and 22,561, males. These were caught by 563 potlines. In fact, a larger number was examined, but 27% was discarded since some potlines had not been drawn at random. From the whole, approximately 60% corresponds to area III, which fishermen frequent the most owing to the better relation yield/operative cost. The distributions of frequency of caparace length classes discriminated per sex and grouped bimonthly for all the SACB, are unimodal. On the righthand side of the modal class, the frequencies' decrease indicates the abundance of each size class. On the left side, the slope is a function of the gear's selectivity. Assuming these distributions are normal, the monthly mean LC for males and females caught in the SACB are those showed in Table 1. Standard deviation fluctuates between 10 and 20%.

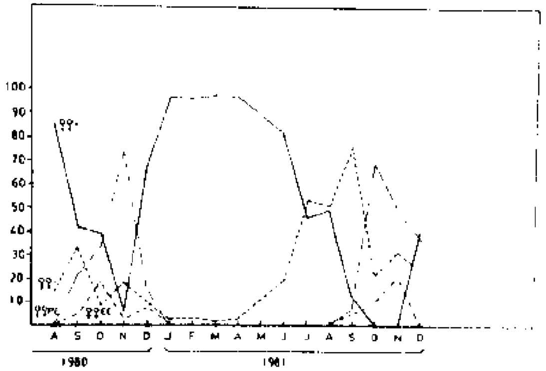
Table 1. Monthly mean caparace length (LC) for males and females caught in all of the region.

	MONTH/YEAR	MALES	FEMALES
1980	AUGUST	102.75	90.14
	SEPTEMBER	102.99	91.01
	OCTOBER	102.77	96.94
	NOVEMBER	99.18	91.51
	DECEMBER	102.27	94.47
1981	JANUARY	97.04	96.53
	FEBRUARY	101.77	93.14
	MARCH	103.32	94.14
	APRIL	95.74	95.39
	MAY	101.92	91.97
	JUNE	106.21	92.71
	JULY	105.51	86.54
	AUGUST	103.41	88.33
	SEPTEMBER	100.22	86.66
	OCTOBER	100.06	93.47
	NOVEMBER	97.43	95.53
	DECEMBER	97.65	89.25

Life cycle.

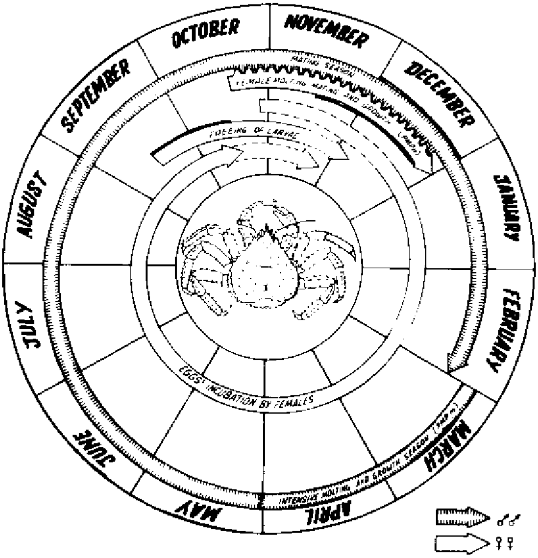
The variation of the structure of the population of females of the FVAS during the period of the research program for the SACB, is showed in Figure 3. This behaviour differs not very much from that observed in each of the defined subareas.

Figure 3. Percentage of females eith eggs (♀♀+), females without eggs (♀♀-), females freeing larvae (♀♀EC) and females after having freed larvae (♀♀PE), from the whole of females and for all of the region.



The hypothesis of the existence of a delay's gradient in the life cycle (figure 4) eastwards respect to the western end of the SACB, can only be handled in future investigations. From the month of April, the increase in the percentage of females without eggs attached to their pleopods in detriment to the percentage of females with eggs in the FVAS, is mainly considered owing to the recruitment to the area and/or to the gear of virginal females that join the reproductive fraction of the biomass (FRS), during the next Spring. The reason for the above as far as gear is concerned, is that molting and growth can occur outside the periods of maximum probability of molting of the females composing the FVAS. Virginal females have mainly clean pleopod setae with no filaments or rests of eggs, which make females that have liberated larvae appear to have at first sight a greater density of long and branched setae.

Figure 4. Life cycle of the king crab in the Beagle Channel. The thicker black lines mark the periods of greater intensity of each stage.



The decrease observed in the bimonthly estimates of the number of females composing the FVAS starting from the month of April (Tables 2 and 3), is consistent with the high instantaneous total mortality coefficients as a function of the size class (A), obtained for the females composing the fraction of the biomass totally recruited to the gear of the FVAS (FTRS), (table 4). This allows to assume that the effort applied in that moment caused a significant effect on the females of the FTRS (in spite of fishing being interdicted), or else there existed an important biomass flow between the SACB under survey and the adjacent areas. Results of the tagging program that was carried out seem to deny this second alternative; however, the information obtained up to the moment does not allow a quantitative and irrefutable demonstration of the first one. In this respect, the hypothesis of a different behaviour in relation to the gear in the different bimonthly periods considered, can be stated. With respect to males, a similar situation might apparently occur between two PMPm.

Table 2. Bimonthly estimates of the number of king crab males, females and commercial males, within the sizes vulnerable to the gear, with their confidence interval, for all of the SACB.

Year/Months	Number of males		Number of females		Number of commercial males	
	Instantaneous estimate	Confidence interval limits	Instantaneous estimate	Confidence interval limits	Instantaneous estimate	Confidence interval limits
Sept.-Oct. 1980	2,003,203	1,601,908 2,535,692	1,234,47	1,107,869 2,870,314	490,693	404,171 598,833
Nov.-Dec. 1980	2,288,106	1,964,049 2,680,306	659,870	493,17 901,454	536,232	448,88 644,126
Jan.-Feb. 1981	2,400,876	1,977,856 2,941,377	2,193,160	1,650,240 2,977,138	403,293	325,895 502,749
March-Apr. 1981	[illegible],353,683	969,935 1,382,526	2,539,204	2,068,796 3,151,707	262,993	209,541 333,685
May-June 1981	1,960,938	1,644,195 2,356,483	1,752,995	1,303,901 2,412,330	713,268	581,326 883,436
July-Aug. 1981	3,054,873	2,554,734 3,681,975	698,259	459,905 1,110,417	1,083,236	842,425 1,414,704

The number of eggs that a female carries per LC class is showed in table 5. Hatching takes place between September and October, but can also occur at the end of November (Figure 4). During the period this program lasted, no larval stages could be caught with conventional plankton nets.

Most of the females composing the FRS, molt, mate and attach the fertilized eggs to their pleopods between end of October and December (PMPh). Most of the males composing the FVAS molt in March and April (PMPm).

To estimate the male's first maturity, the growth of the right chela was studied, using methodology of Somerton (in press) for Lithodes aequispina in the Bering Sea. All the studied variables present two growth phases with a certain allometric degree (Harnoll,1972); a discontinuity between 91.0 and 99.0 mm of LC could be determined (table 6). Campodónico et al, 1974, determined a value of 90.0 mm for the same species in Punta Arenas - El Porvenir, Estrecho de Magallanes, Chile.

Table 3. Bimonthly estimates of the number of king crab males, females and commercial males, within the sizes vulnerable to the gear, with their confidence interval, for area III, (Bridges Is.).

	Number of males		Number of females		Number of commercial males	
Year/Months	Instantaneous estimate	Confidence interval limits	Instantaneous estimate	Confidence interval limits	Instantaneous estimate	Confidence interval limits
Sept.-Oct. 1980	1,288,040	971,836 1,569,879	320,243	179,322 621,622	274,155	223,111 336,901
Nov.-Dec. 1980	1,070,584	871,956 1,569,879	9 ,478	126,656 301,139	240,844	193,402 301,869
Jan.-Feb. 1981	954,879	7[illegible]8,272 1,272,669	1,158,770	847,863 1,620,527	146,910	102,298 714,464
March-April 1981	572,383	473,235 698,039	1,[illegible]10,336	881,501 1,417,784	114,95[illegible]	83,466 146,437
May-June 1981	1,051,738	874,507 1,275,506	797,338	581,138 1,123,459	380,033	307,659 474,237
July-Aug. 1981	1,566,760	1,252,416 1,983,443	517,368	265,729 1,145,811	572,940	384,422 888,376

Table 4. Instantaneous coefficient of total mortality for the female king crab of area III between two molt periods: from January to August 1981 and for the king crab male of area III between two molt periods: from September 1980 to February 1981, according to the caparace length.

LC mm	MALES	FEMALES
92.5	0.27	
97.5	0.60	0.13
102.5	0.99	0.09
107.5	1.21	0.46
112.5	1.32	0.43
117.5	0.86	0.59
122.5		0.88
127.5		0.66
132.5		0.90

Table 5. Fertility of 68 king crabs from the Beagle Channel, grouped by intervals of 1 cm of LC, with the corresponding typical deviation

LC mm	NUMBER OF EGGS	
	$\overline{X}$	s
60 - 70	5,430	
71 - 80	4,249	± 1,168.7
81 - 90	7,911	± 3,211.7
91 - 100	14,327	± 3,155,4
101 - 110	17,482	± 4,306.1
111 - 120	21,294	± 5,094.9
121 - 130	27,843	± 4.609.2

Table 6. Estimate of the first maturity size in king crab males from the Beagle Channel, according to morphometric variations of the chela.

INDEPENDANT VARIABLE	DEPENDANT VARIABLE	SLOPE CHANGE POINT
LC	chela length	91.00
LC	chela length	99.00
LC	$\frac{\text{chela width}}{\text{chela length}}$	90.20
LC	chela length	91.00
LC	$\frac{\text{chela width}}{\text{chela length}}$	94.20
LC	chela width	90.20

Some of these data were provided by Vinuesa.

Growth in the FVAS.

In order to study the growth of the FVAS in the SACB, the registered increase of the LC in tagged and re-caught specimens was considered to be representative. More precise methods for growth studying such as those applied with the Alaska king crab Paralithodes camtschatica (Mc. Caughran et al, 1977; Balsiger, 1974), could not be utilized on account of the scarce number of re-caught specimens and the briefness of our research program.

Since the number of re-caught females has been too low to be statistically treated, only the data corresponding to males have been analyzed. On the other hand, and considering that no significant differences have been observed between the results obtained for tagged and re-caught specimens of the FVAS and the population exploited in El Porvenir - Magallanes, Chile (Geagham, 1973), we worked on a pool of data for the same premolting LC class (pre-PMPm LC). We assume that:

1. No significant differences exist between the fraction caught by the pot and the rest of the males' population for sizes equal or larger than the minimum size of re-catching, at least with respect to molting probability.

2. The percentage of males of the FVAS that molt in a different season than PMP (March - April) is negligible.

Then, after a PMPm, for each pre-PMPm LC there is a fraction of specimens which have not molted and a fraction that has. Of the ones that have molted, for each pre-PMPm LC there is a group whose LC increase is not so large so as to consider the specimens in a class of larger LC, while the rest present a LC increase that allow their situation in a larger LC class. The fraction of specimens which do not molt in a PMPm increases as a function of the LC class (Mc. Caughran et al, op. cit.) and can be fitted to $P = 1/1 + A \exp\{-B (Li - C)\}$, where $A = 118.7224$, $B = -0.0965$ and $C = 100.0$, being Li = LC class.

If we immediately assign a probability to each one of the mentioned alternatives for each pre-PMPm LC, we can design a matrix (Mc. Caughran et al, op. cit.; Balsiger, op. cit.), as shown in table 7. With these values it is possible to estimate a curve of maximun growth probability of a male starting from the smaller size of the FVAS, simply considering that it moults every year only during the PMPm experiencing the most probable growth. The curves of minimum growth probability can also be designed, considering that a male molts only once every year during the PMPm, experiencing the least probable "jump" of LC class, for maximum growth as well as for minimum growth (figure 5).

Figure 5. Growth of a male king crab. It is assumed that it molts once during each molting period (March-April) every year. There is a maximum probability curve and two minimum probability curves, one of maximum and the other of minimum growth. The growth of a male king crab oscillates between these two points tending to get near the curve of maximum probability. The age of three years is assigned to the minimum size of re-catching.

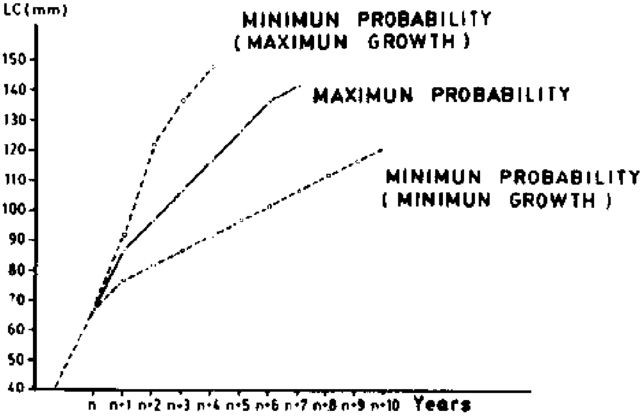


Table 7. Growth matrix of the king crab.

	Pre-molt mean LC (mm)																
	i	j	67	72	77	82	87	92	97	102	107	112	117	122	127	132	137
Post-molt mean LC (mm) m	A_{im}	A_{jm}															
n	A_{in}	A_{jn}															
67																	
72																	
77			.17	.15													
82			.13	.27	.08	.01											
87			.50	.15	.45	.09	.51										
92			.20	.27	.08	.41	.09	.01									
97				.16	.18	.19	.42	.05									
102					.18	.10	.30	.56	.07	.02							
107					.03	.09	.04	.28	.48	.10	.02						
112						.05	.10	.04	.40	.55	.07	[illegible]					
117						.03	.02	.04	.01	.29	.62	.17	.07				
122						.03	.02	.02	.03	.02	.29	.65	.12				
127									.01	.02		.13	.67	[illegible]	[illegible]		
132													.14	.18	[illegible]	.32	
137													.02	[illegible]	.51	.13	
142															.16	.42	
147																.13	

Note: A_{im} is the probability that an individual from the size i class when starting the molting period pass to a size m class when this period ends. Made out of our own data and of Geaghan's (1973).

Estimate of an instantaneous coefficient of total mortality in function of the LC class for the FVAS during the period inter-PMP.

The processed information only refers to the area III of the SACB. We assume the existence of a unique and annual PMPh and PMPm for the FTRS. It can be inferred, from what has been stated up to now, that in each PMPh o PMPm, individuals of different ages mix up efficiently, a fact that annually repeats itself determining a marked heterogeneity in the population structure, since each age group or cohort will present a great variability of sizes and, at the same time, a LC class will be composed of individuals of several ages. This process of mixing up for the groups that compose the FTRS, will only take place during the PMPh and PMPm, so that for the rest of the year one can accept that there are no changes or abrupt variations of LC class, and the decrease of the abundance for each LC class in absolute terms in the FTRS, will be determined by natural and fishing mortality.

The bimonthly estimate of the number of specimens for each LC class of the FTRS and for each sex, could be then fitted to an exponential. The periods considered were September 1980 to February 1981, for males, January to August 1981, for females. The exponent varies between 0.09 and 0.90 for males and between 0.27 and 1.32 for females (table 4). The exponents as a function of the LC class for both sexes could also be fitted to exponentials whose exponent take values of 0.0596 for males and 0.0775 for females. It can be then considered that the processes of the PMPh and PMPm to yearly produce the FTRS, are of great importance.

Instantaneous estimate of the FVAS.

Determination of the area of action of the potline (a) and the coefficient of catchability (q). In order to determine the area of action of the potline, the following experience was realized. Pots were drawn isolated and with bait in zones without turbulence (Golondrina Bay, area II), and groups of ten tagged specimens were freed in different positions with respect to the pot, in order to conform a sort of reticulate pattern. Specimens were of both sexes and were chosen at random from those of the LC classes included in the FVAS. In order to minimize stress effects and to avoid trophic disinterestedness when taken out from a pot with bait of which they could have fed, the specimens in this experience were picked up and freed by autonomous divers. Tagging was accomplished in a pneumatic craft. Fishing time was in every case 48 hours. The results allowed us to estimate the area of action of one pot, showed in figure 6. No consistent results were obtained in directions NW, SW and SE, therefore -also taking into account direct observations- the value of q in that direction was assumed to be null. In trying to explain the form this area of action adopts, we consider the predominance of the Pacific tides over the Atlantic ones in the SACB. A relation between q and the distance in direction NE from the pot (D) was obtained. It fits a linear function, $q = a + bD$, with $a = 0.4939$ and $b = -0.0066$. No significant differences were found perpendicular to D within the marked area.

Complementarily, lines of two pots were drawn during 48 hours at different distances within each other and placed parallel to an ideal axis NE-SW, over high density patches in areas of depictable turbulence (Golondrina Bay, area II). The patches are assumed to be circular, with a radio exceeding 70 meters and a uniform density in all of its points (figure 7). In spite of the great dispersion of the results, the average values of the percentage that pot N°1 caught related to the total catch of the potline (P), as a function of the distance between pots (D), could be fitted to $P = 50\ (1 - \exp K.D)$, with $K = 0.05$ becoming asymptotic to the values of D near 70-80 meters. This result is consistent with the one obtained in the previous experience.

The problem becomes very complex when considering the commercial line of ten pots (figure 8). However we can estimate the area of action of a potline by a simple geometric resolution and assuming it constant. Then CDE + ABCD = 6,450 sq.meters = 0.00188 sq. nautical miles. The surface S of the SACB (between Lapataía Bay and the Frontón Gable) is of 33.99 sq. nautical miles. Assuming the predominance of the Pacific tides and negligible turbulences, this surface would be covered by the action of 18,074 commercial potlines. The coefficient of catchability is also assumed to be constant (q = 0.4), because it is the value q takes when D = 20 meters (figure 6). This would be the lowest value of catchability next to a pot and up to 20 m from it, which is the distance between two pots in a commercial potline.

Instantaneous estimate of the FVAS for the SACB and area III. The results are shown in tables 2 and 3. Only the estimate of males, females and commercial males (LC larger than 110 mm) was realized for the SACB and area III.

Figure 6. Estimate of the area of action of one pot. Catchability coefficient (q) as a function of the distance in NE direction from the pot (D). The coefficient q is defined by the percentage of tagged specimens from each group of freed specimens in D, that enter the pot. The catchability of the pot is practically null at approximately 70 m.

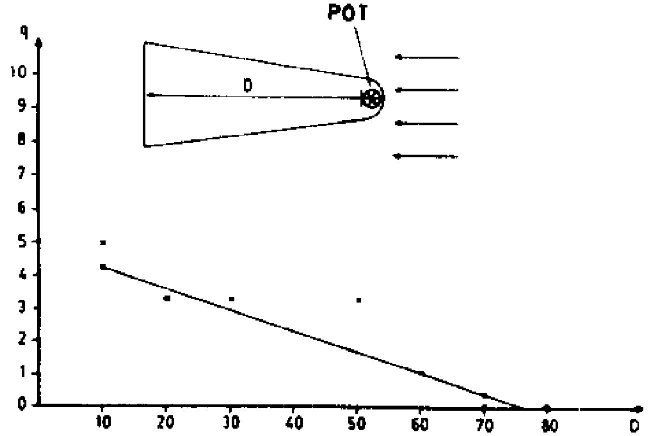


Figure 8. Area of action of a potline drawn parallel to the predominant tide current in areas without turbulence in the SACB.

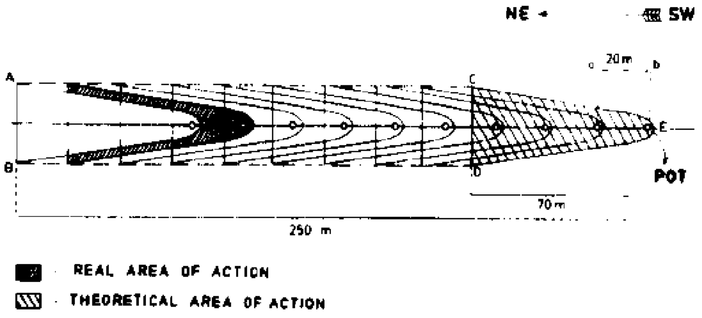
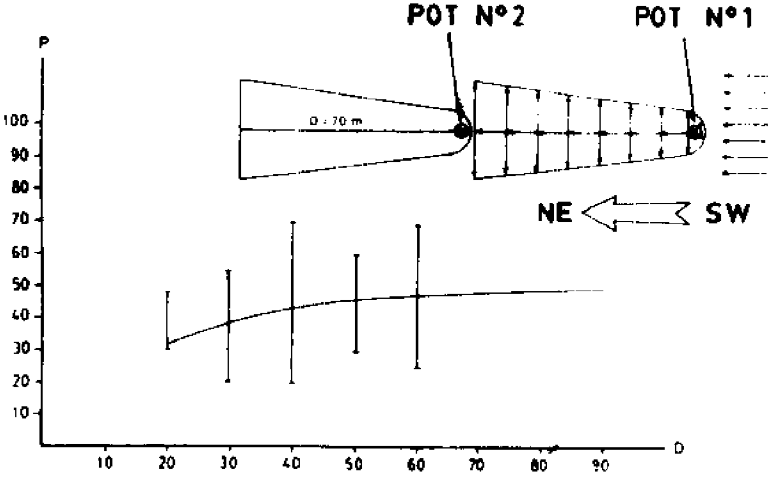


Figure 7. Experience realized drawing potlines parallel to the predominant tide current (SW → NE) in areas with no turbulence, and over king crab patches with high and uniform density, varying the distance between pots. Percentage of catch in pot N°1 (P) with respect to the total caught by the potline, as a function of the distance between pots (D).



Discussion and Management

Limitations in the resources prevented us to carry out an integral investigation of the king crab fishery in the SACB. Also the sudden interruption of our research program once the agreement with the fishery industries had ended, prevented the progressive improvement - in qualitative terms - of the information already achieved,as well as the periodic monitoring. However, according to the contents in this paper, it is possible to suggest some management guidelines. It is necessary to face future plans in order to set the structural changes in the FVAS during the life cycle. Studies on the fraction of the biomass which does not compose the FVAS are also essential. It is quite probable that the population distributed in the SACB might not constitute a stock, considering its orthodox definition, since this is only the population distributed in a few sq. nautical miles (strictly 33.99 if we consider as limits the isobaths of 5 and 50 meters). The predominance of the Pacific tides is also probably a determining factor in the dispersion of larvae. It is worth noting the idea that the groups localized in areas opposite to the SW Atlantic coasts have their origin in the groups of the Beagle Channel and adjacent areas, which are transported westwards from the Channel by the tide currents and northwards by the Malvinas Current. It would be very interesting to start research programs on these populations, almost unexploited and unknown.

The decrease in yields and average values of LC observed in the last years (Boschi et al, op. cit.; Bertuche, 1979; Campodónico et al, 1983), lead us to the idea of the overexploitation in the Beagle Channel, in the Argentine as well as in the Chilean zone. Legislation in force in the SACB before this investigation was realized, indicated:

1. The only gear allowed is the pot.

2. Fishing is completely forbidden between December 15 and May 31 of each year.

3. Fishing of females of every size is forbidden during the whole fishing season. Caught specimens must be immediately returned to the sea. In this way future recruitings are tried to be secured, since females carry the fertilized eggs on their pleopods for about 280 - 300 days.

4. The fishing of males with LC smaller than 110 mm (or AC smaller than 120 mm) is forbidden during the fishing season. Specimens caught must be immediately returned to the sea. This rule tends to ensure that males mate at least once before being caught.

According to these investigations, we suggest that the management must be different for the SACB respect to the areas East of Gable Island and even opposite to the SW Atlantic coasts.

It was advised to keep the force of 1, 3 and 4 for the SACB, considering it Fishing Preserved Region and establishing a unique and total interdiction of fishing during the PMPh which coincides with mating (October 1 up to December 31). Actually, formerly as well as now, clause 3 is partially observed but clause 4 is not observed at all by the fishermen, although continuous efforts are realized by state control institutions.

Therefore, until a certain population dynamics of the king crab in the SACB is achieved, and taking into account the difficulties for enforcing present legislation, the most advisable step is to determine an adequate mesh size so that the king crab specimens of LC smaller than 110 mm can escape, keeping the females' fishing interdiction and without restricting the number of pots or vessels authorized to fish. In this manner, the continuity in the generation of new cohorts every year, would be precariously ensured.

In relation to the areas East of the Beagle Channel and the SW Atlantic coasts, it is advisable to enforce clauses 1, 3 and 4, but favoring fishing intensifying and even radication of new industries. In this sense, a maximum number of 1,000 pots authorized for the whole SACB was advised , in order to urge the industries settled in Ushuaia to expand the fishery eastwards and even to diversify it with species of high commercial value in the zone: king klip (_Genypterus blacodes_), hake (_Merluccius hubbsi_), long tail hake (_Macruronus magellanicus_) and Tierra del Fuego sprat (_Sprattus fueguensis_). At the present time the fishery has only extended up to the Moat Channel and there, as well as in the SACB, only the "centollón" - false king crab - (_Paralomis granulosa_) and mussel (_Mytilus chilensis_) are commercially utilized.

Acknowledgement

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Differential aspects of the southern king crab *(Lithodes antarcticus)* in two latitudinally separated locations

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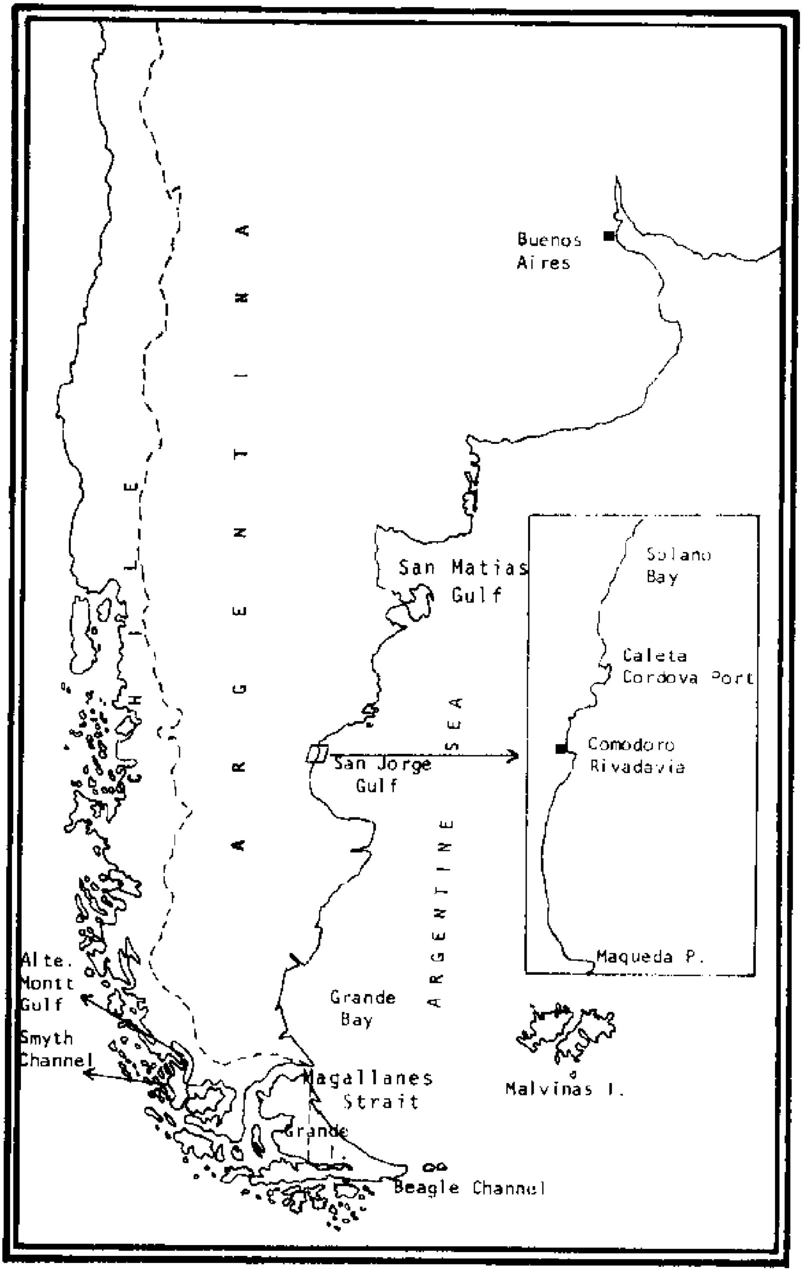
Introduction

Lithodes antarcticus is an important commercial harvest king crab from Chile and Argentina typically subantarctic cold-temperature waters. In the Pacific Ocean, from southern Chile to Cape Horn (Tierra del Fuego) and in the Atlantic Ocean, Malvinas and Georgias Islands and patagonian coasts to San Jorge Gulf. Then can be seen offshore in greater depths, following the Malvinas Current to Uruguay.

The southern king crab or "centolla" (common name) inhabit in water temperatures from 3° to 15°C and in depths from subtidal to more than 700m. In this largest distribution area, can be seen different population densities and concentrate the greatest fishery activity in Magallanes Strait and Beagle Channel. Other lesser important concentrations in Atlantic waters are located in Grande Bay and San Jorge Gulf (Figure 1). While in the first place exists a seasonally abundance due to reproductive migration, in San Jorge Gulf coasts is present during all the year. The catch here is made by coast trawlers with bottom nets, as part of a multiple fishery where important numbers of Argentinian hake (*Merluccius merluccius hubbsi*), codfish (*Genypterus blacodes*), elephant fish (*Callornchus callorhynchus*) and others like soles, sharks and trays are also obtained.

Up to 1979, the exploitation of the crab was based on catching both males and females. Only small specimens were discarded, since fleshing them is too difficult. The only legal regulation regarding this resource issued by Chubut province has been the prohibition to catch specimens with a carapace diameter less than 10 cm. This regulation was passed before any biological studies had been performed in the area. Studies of the crab in this area have been very limited, and the only data known correspond to an exploration campaign carried out in 1959 (Ange-


ARGENTINA
CHILE
Buenos Aires
San Matias Gulf
Solano Bay
Caleta Cordova Port
Comodoro Rivadavia
San Jorge Gulf
ARGENTINE SEA
Maqueda P.
Grande Bay
Alte. Montt Gulf
Smyth Channel
Magallanes Strait
Malvinas I.
Grande I.
Beagle Channel

lescu, 1960) and to another one performed by the "Cruz del Sur" vessel (Scelzo et al, 1974). No further data have been published on the species in this area.

The purpose of this paper is to contribute new biological data on the crab of the San Jorge Gulf, and to compare them with current knowledge of this same species in the Beagle Channel, the Strait of Magellan and in localities further North, in the Pacific Ocean.

This new contribution refers mainly to the morphology, reproduction, sexual maturity and molting of the species as well as to their duration.

Materials and Methods

All the crab specimens analysed come from the commercial coastal catches unloaded at Caleta Cordoba and caught between Bahia Solano and Punta Maqueda (Figure 1). These observations were made between 1979 and 1982. The samplings obtained as from March 1981 correspond to an Agreement entered into between the Instituto Nacional de Tecnología Industrial (National Institute of Industrial Technology) and the Ministerio de Economía, Servicios y Obras Públicas (Ministry of Economy, Public Works and Services) of the Province of Chubut. There are a total of approximately 30 samplings, and roughly 2,000 specimens were analyzed. The only measurement taken in all cases was the carapace length (C.L.); this measurement was taken from the concavity of the ocular peduncle to the posterior median line of the carapace. Other data colected were:

- Hardness of the carapace: according to a scale of relative appreciation, carapaces were brought under three categories: very soft, semi-hard and hard.
- Epibiosis: presence of organisms and approximate percentage of carapace covering.
- Embryos: presence or absence of embryos in the pleopods, and stage of development of the embryo, whether it is visible and whether it has acquired its ocular pigmentation.
- Remnants ofeclosion: presence or absence of remnants of embryonic capsules and funiculi.
- State of the ovary: the degree of maturity of the ovary was classified into three stages: initial vitellogenesis, advanced vitellogenesis and post-spawning.

Those specimens that were injured or dead, that had no appendages or that had parasites, oil, etc. were also recorded. As regards the analysis of the sexual maturity of females, the following characteristics were taken into consideration: size of the abdomen, presence or absence of embryos, presence or absence of remnants of eclosion and stage of development of the ovary.

Results

General aspect.

One outstanding characteristic of the crab of the San Jorge Gulf is its great phenotypical differences with that of the Beagle Channel. The crab of this area is similar to that found in the open sea, such as in Bahía Grande (Fig. 1): the colour of the carapace and of the dorsal part of the appendages goes from light pink to yellowish orange, and it becomes yellowish white in the edges of the carapace and the lateral areas of the appendages (Figure 2).

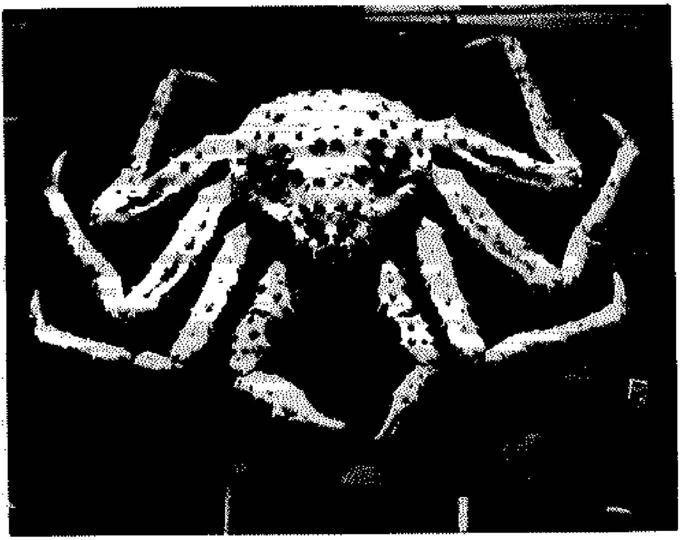


Figure 2. General aspect of a male crab from the San Jorge Gulf.

The gastric and cardiac regions in the carapace of large specimens are not too prominent and looks flatter.

The spines of both the carapace and the appendages are not very sharp-pointed.

Another characteristic is the large incidence of carapaces and legs with signs of necrosis, apparent wounds and perforations with black edges.

Crabs of the Gulf are also smaller in size than those of the Beagle Channel. Figure 3 shows the measurements of the studied population: the mean carapace length in males was 92.2 mm, and that of females was 69.1 mm -a remarkable difference between sexes.

The larger males caught measured between 126 and 128mm of C.L., and the largest one recorded in the area -a specimen caught in 1979- measured 136 mm. As regards females, the largest one obtained during our samplings measured 107 mm.

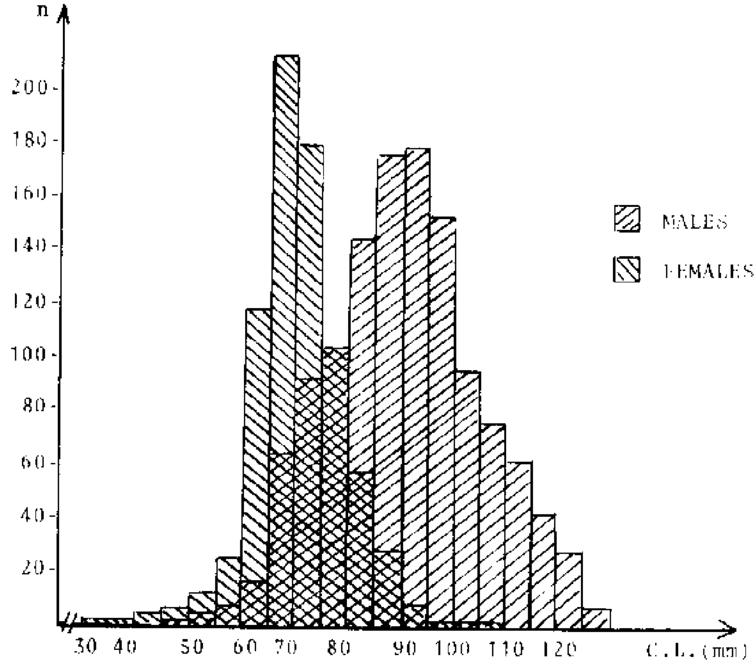


Figure 3. Size structure of the studied population.

Reproduction.

It is a well-known fact that the females of this specie, like other Lithodidae studied, molt before spawning. In the case of *L. antarcticus*, fertilization requires one oviposition and one deposition of spermatophores which should be roughly simultaneous, since the female has no seminal receptacle. We also observed an occlusion of the genital aperture before molting (Vinuesa and Lombardo, 1982), a fact that mechanically prevents fertilization, due to the impossibility of spawning.

For this reason, the initiation of the molting process in females also marks the beginning of the reproductive season. In the San Jorge Gulf, this season starts in late October and intensifies itself during November. Figure 4 shows the variation of the frequency of egg-carrying females during samplings.

There is a gradual decrease as from April up to October; this is followed by a large increase in November and another gradual decrease up to February. A large number of females with recently-spawned eggs found in January or February will indicate an extension of the reproductive season, probably until March. After spawning, a very quick reorganization is observed in the ovary and the beginning of secondary vitellogenesis can be seen several days later.

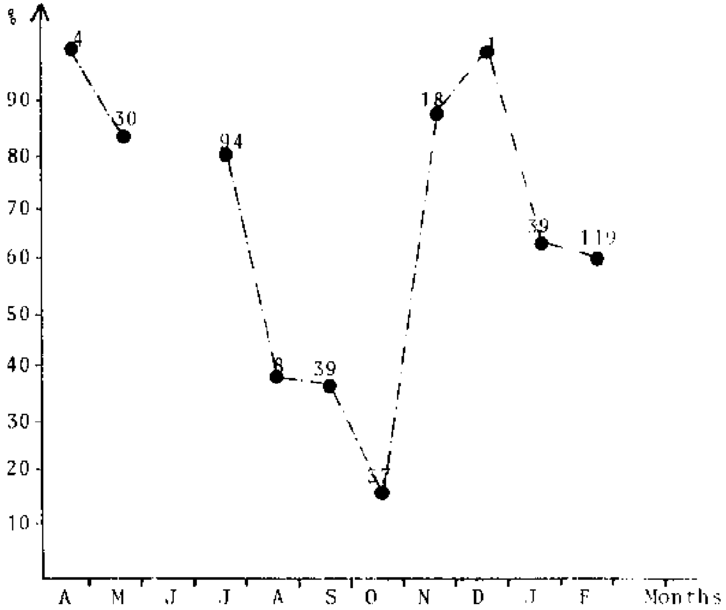


Figure 4. Incidence of egg-carrying females in monthly samplings (numbers indicate total analyzed females).

No reproductive migration has been observed in crabs of this area; it is well known that they remain in coastal waters throughout the year. However, statistics show that there is a decrease in the numbers caught between November and February.

The larvae birth occurs as from late July and lasts until October. The maximum peak in the birth takes place in August. During all the samplings, even though females with abdomens filled with eggs were found, a proportion that ranged from 8 to 64% were carrying a small number of embryos. Two females of 86 and 90 mm of C.L. had 3.863 and 2.945 eggs, respectively; females of this size usually carry more than 10.000 eggs. Likewise can be seen important percentages of non-ovigerous females during all the year, even after reproductive season. This fact corroborates a diminution of fertility in the San Jorge Gulf.

Molt.

The molt season differs in *L. antarcticus*, according to sex and size, as in *Paralithodes camtschatica* Juvenile crabs of both sexes may be undergo several molts during the year. Once attained the pubescent stage, females molt annually before spawning (Vinuesa, 1982).

Adult male crabs molt annually too, but molt frequency decreases to biennal in the greaters sizes (Geaghan, 1973). Molt season in males from San Jorge Gulf is observed between July and August, (winter in Southern

Hemisphere), but a small part of male population do it in November and December (Figure 5). Carapace hardening is very rapid; about 10-20 days after molt is already hard.

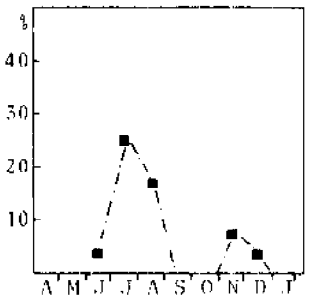


Figure 5. Frequency of soft shelled crabs in male samples.

Sexual maturity.

The study of sexual maturity was carried out by means of two samples taken in November of 1979 and 1980. Little difference was found in the sexual stage between females in both years. However, it was possible to differentiate females into seven types, according to individual characteristics:

a. Immature: females of small size and with a whitish firm; reduced,non-vitellogenic ovary; short and yellowish ovigerous setae, small abdomen not covering the coxae of legs.

b. Early spawned: ovigerous females with nearly hard carapace. Ovary in secondary vitellogenesis, nonflaccid. Eggs with no signs of development.

c. Recently spawned: ovigerous females with soft carapace. Ovary spent and faccid, surrounded by a thick layer of translucent connective tissue.

d. Molted and non-spawned: females without eggs, with a soft carapace and an apparently mature ovary.

e. Mature non-molted: females with a hard carapace, frequently with epibiosis. Abdomen covering the coxae of legs. Ovigerous setae with remnants of egg-cases and funiculi. Well developed ovary,orange or reddish brown, mature or near maturity.

f. Mature and not fecunded in the last reproductive season:non ovigerous females, without remnants of larvae birth. Ovary well developed and vitellogenic,nearly mature. Females of good size, with hard carapace and enlarged abdomen.

g. Pubescents: females of median or small size, abdomen non covering the coxae of legs. Non ovigerous and with a well developed ovary,mature or nearly mature. Very probably this includes some mature females of small size not fecunded in the last reproductive season.

Considering the different steps previous to spawning, it is possible to consider as mature females those included in points b to f. Using this classification, the sexual condition has been determined in 516 females: 41 immature, 314 mature and 161 pubescents (Figure 6).

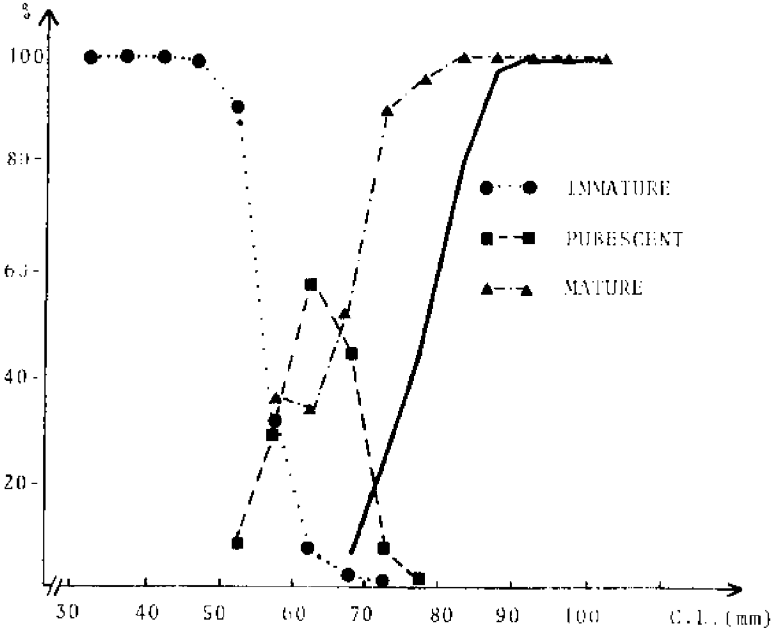


Figure 6. Frequency of females according to sexual condition (the thick line represents the mature females of Beagle Channel).

As can be seen, immature females have been obtained until the 70-75mm of C.L. interval. With regard to pubescents, they appeared in the samples starting from 53mm of C.L. and extending to 75mm of C.L. The smallest mature female captured measured 55mm of C.L.

A logistic curve was fit to the percentage of the data classified as mature by size, according to Somerton procedures (Somerton, 1979 and 1980) and the size of 50% maturity was estimated by evaluating the logistic curve at 50%. The calculated size was 67,5mm of C.L. for *Lithodes antarcticus* from San Jorge Gulf.

Discussion

Several differences have been observed between the southern king crab from San Jorge Gulf and from the Beagle Channel and other Chilean localities. The first one observed was their size, both in males and females: in the Gulf female's length reached 107mm of C.L., while in Beagle Channel and Magallanes Strait, lengths of 110 to 120mm of C.L. were commonly seen in captures, and have been registered lengths of more than 130mm.

The males were also of different size: In Beagle Channel, several crabs were captured with carapace lengths higher than 180mm, the greatest measured 198mm and 250mm of carapace width (Boschi et al, 1984). In Almirante Montt Gulf, Chile, the crabs are typically of lesser sizes than in neighbouring areas such as Smith Channel, Union Bay as well as in Magallanes Strait (González and Perugi, 1974; Sanhueza, 1976).

The exoskeletons color also show differences, since in San Jorge Gulf it is light orange-colored or rosaceus (see Figure 7).

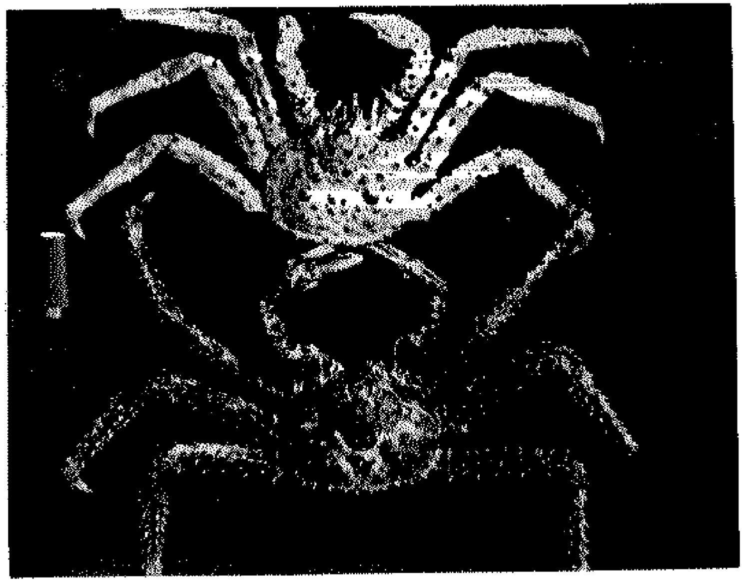


Figure 7. View of males from Beagle Channel and San Jorge Gulf of similar size.

Compared with Beagle Channel crabs, the Gulf crabs showed a more flattened carapace and less prominent spines. To all appearences, the walking legs are of a shorter length too.

In Almirante Montt Gulf, the crabs present a flat carapace, with few, soft spines and slender legs (González y Perugi, 1974). Great number of carapaces showed evident decomposition signs, like perforations with black edges, very similar to that observed in San Jorge Gulf crabs.

As for reproductive aspects, several differences have been noted. Reproductive migration is well known in *Lithodes antarcticus*; it is not very obvious in Beagle Channel, but was registered in Magallanes Strait (Geaghan, 1973; Campodónico, 1979), south patagonic waters (Grande Bay)(Angelescu, 1960; Scelzo et al, 1974) and Atlantic coasts of Grande Island (Tierra del Fuego). This annual population movement towards shallow waters was not observed in San Jorge Gulf crabs. In the latter, however there was a decrease in the catch between November and February, owing to the fact that fishermen prefer to catch shrimps (*Pleoticus muelleri*) and the hake during those months, for economical reasons.

With respect to the reproductive season, it begins one month earlier in San Jorge Gulf than in Beagle Channel and extends in time until February or March. Female samplings during January and February showed a 38% (n=15) and a 39% (n=15) of non ovigerous females who presented two main ovary types: post-spawning and nearly ripe.

In January, 11 females had nearly ripe ovaries and only 4 were in post-spawning stage and in February, 20 crabs were in post-spawning stage. According to the rapid ovary reorganization observed, those facts indicate the existence of spawned and non fertilized females and maybe non spawned females including oocyte reabsorption. The nearly ripe stages probably represent not yet fecunded females.

Even if both month samples suggest great reproductive activity, no crabs were observed with molt signs (a strange observation).

Reproductive season of San Jorge Gulf crabs differed from other localities. As observed in Figure 8, the spawning season is similar to that of Almirante Montt Gulf, more north than Magallanes Strait and Smyth Channel (see Figure 1).

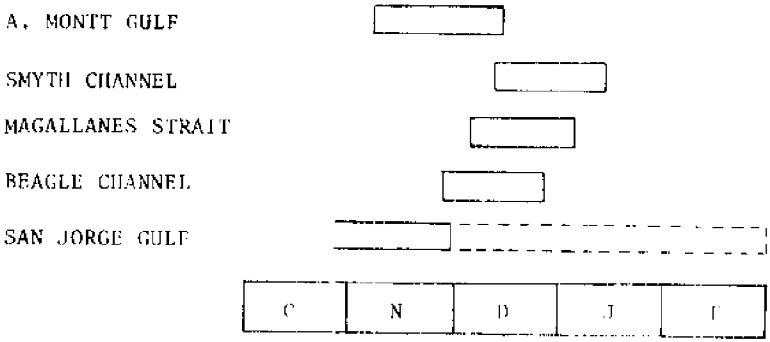


Figure 8. Reproductive season of *L. antarcticus* in different areas.

Length of carapace at sexual maturity varied among areas in *Lithodes antarcticus* (Campodónico et al, 1974; Sanhueza, 1976; Vinuesa, 1982 and 1984) as in *Paralithodes camtschatica* (Wallace et al, 1949; Powell and Nickerson, 1965).

In Magallanes Strait, the size of 50% maturity was estimated in 80mm of C.L. (Geaghan, 1973) and in the Beagle Channel in 82mm of C.L. (Vinuesa, 1982). Very different were the observations in Almirante Montt Gulf, where sexual maturity was attained at a minor size, starting from 61 mm of C.L. This is a normal fact, if the smaller size of this crab is taken into account (Sanhueza, 1976). The same thing was observed in female crabs from San Jorge Gulf, which presented a smaller average size and began to mature after nearly 55mm of C.L.

Molt season of San Jorge Gulf female crabs was observed exclusively between October and November (only one female was captured in December).No molt signs were seen in January and February, may be due to a swift carapace hardening helped with a lower occurrence of epibiosis, which does not make it possible to distinguish between new and old carapaces.

Male molt season also differed between localities (Figure 9).

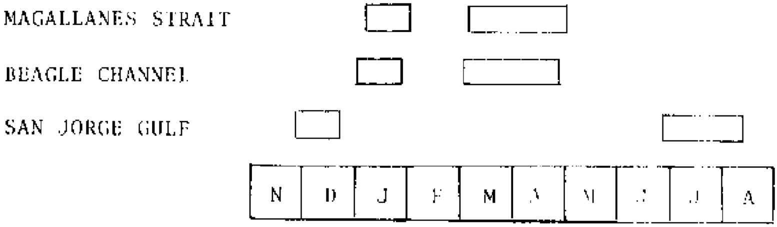


Figure 9. Male's molt season in different localities.

In the majority of the male population of San Jorge Gulf, molt occurred between July and August, but a small number of them molted in late November and December. Very similar observations have been made in Magallanes Strait (Geaghan, 1975) and Beagle Channel (Vinuesa, 1982) where the principal molt season is between March and April, with a reduced one in January. The recently molted crabs observed in Beagle Channel (in January) and in San Jorge Gulft (in late November and December) belonged to mature and may be immature crabs.

As was also observed in Almirante Montt Gulf, the crabs from San Jorge Gulf display a reduced vitality as compared with other localities.

The swift carapace hardening after molt and the ovary reorganization,included the early beginning of secondary vitellogenesis after spawning, indicated an increased metabolism in San Jorge Gulf crabs. The principal reason perhaps is the moderate water temperatures of the area.

A general comparison between *Lithodes antarcticus* from San Jorge Gulf and other localities permitted to observe great differences in their morphology and behavior, with the exception of Almirante Montt Gulf crabs. All features indicated that the crabs from San Jorge Gulf conform a separated population of the southern king crab.

Their resemblances with Almirante Montt Gulf crabs, surely another population, allowed to consider that both are examples of extremed life conditions of the species.

Acknowledgments.

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Growth of the golden king crab, *Lithodes aequispina*, in southeast Alaskan waters

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ABSTRACT

A spaghetti isthmus tag was utilized to tag 899 male golden king crab, Lithodes aequispina, from December 1970 through October 1972. Tagging was conducted from commercial fishing vessels on various commercial fishing grounds of Southeast Alaska. Recaptures collected during the 1970 through 1976 commercial fisheries totalled 112, of which 45 were returned with information necessary to determine growth increments for one molt. Premolt size distribution ranged from 126 to 170 mm in carapace length. Average growth per molt was 16.3 mm, within a range of 7 to 21 mm for recaptures indicating one molt. Average time at large was 17.5 months, within a range of 10 to 33 months for one molt. Multiple molt data indicates 7 recaptures accomplished two molts, 2 recaptures accomplished three molts, and 1 recapture accomplished four molts. The largest growth recorded was 60 mm in 51 months by a recapture with a premolt carapace length of 133 mm.

INTRODUCTION

Commercial exploitation of king crab from waters of Southeast Alaska was first documented in 1960. Although information of species composition during the early period of the fishery is not available, present knowledge suggests that red king crab, Paralithodes camtschatica, was the target species. Golden king crab, Lithodes aequispina, was probably harvested in significant quantities. Blue king crab, Paralithodes platypus, was probably harvested incidentally to red king crab in certain areas, and was taken in very small quantities.

During the 1969-70 season, species composition data were collected and reported through various informal documents. Since 1976, species composition data have been required on official records of landings--the Alaska Department of Fish and Game Shellfish Ticket. Golden king crab have been a significant proportion of the total king crab harvest, at least since the 1969-70 season (Fig. 1) when approximately 25 percent of the harvest was identified as golden king crab. The 1969-70 season was the third successive season when total king crab harvests exceeded 1.75 million pounds (Table 1), and the last season during which the minimum legal size was 6.5 inches in carapace width. Prior to the 1970-71 season, the minimum legal size was increased to 7.0 inches in carapace width. Since the 1970-71, season golden king crab have contributed an average of 340,819 pounds to the total king crab harvest which includes all species (Table 1). On the average, this figure is 45 percent of the total king crab harvest in Southeast Alaska waters. During the past five seasons (1980-81 through 1984-85) golden king crab have been the most significant species harvested (Fig. 1), averaging almost 65 percent of the total king crab harvest.

Biological information concerning golden king crab was not available to assist the biological staff in assessing the appropriateness of regulations utilized in the fishery, or the impacts of extensive commercial exploitation upon the population. In 1970, staff members from the Commercial Fisheries Division of the Alaska Department of Fish and Game in Petersburg, Alaska initiated a program which included sampling commercial landings to collect data on carapace length frequency distribution, making observations while on-board commercial king crab vessels, and tagging king crab while on-board commercial king crab vessels during the commercial fishery or through charter during the closed seasons.

During the period 1970 through 1978 effort and interest in the exploitation of golden king crab was declining. Tag and tag return data were collected and recorded, but analyses were not completed until recently. Impetus for analyzing the collected data was provided by the resurgence of effort and interest in the Southeast Alaska golden king crab fishery, and the development of other Alaskan golden king crab fisheries (McBride et al. 1982; Otto 1984). As interest in these fisheries grew, managers required the available biological information concerning this species to assist in the management process, especially in relation to the implementation of minimum legal sizes necessary to insure a potential for stock reproduction. Two pieces of information are essential in providing that potential. The first is size at maturity data, which has previously been determined for the golden king crab in other waters (Somerton and Otto in prep.) The second is growth per molt data. Growth per molt and a limited quantity of molt frequency data from Southeast Alaska will be the focus of this paper.

METHODS

Alaska Department of Fish and Game personnel tagged male golden king crab while on-board commercial fishing vessels during cooperative cruises in major fishing areas (Fig. 2) from 1970 through 1972. Capture gear utilized during the tagging cruises was normal commercial side-loading or top-loading king crab pots. Pots were individually suspended from buoys on the surface using nylon and polypropylene line, at depths ranging from 40 to 275 fathoms. Pots were baited with chopped herring and/or other fish species. Soak periods were not predetermined. Pot placement was not conducted in a specific manner, but rather according to the knowledge and perogatives of the vessel skippers that participated. Pots were pulled and brought on-board the vessel, where golden male king crab were collected, processed for necessary data, tagged, and

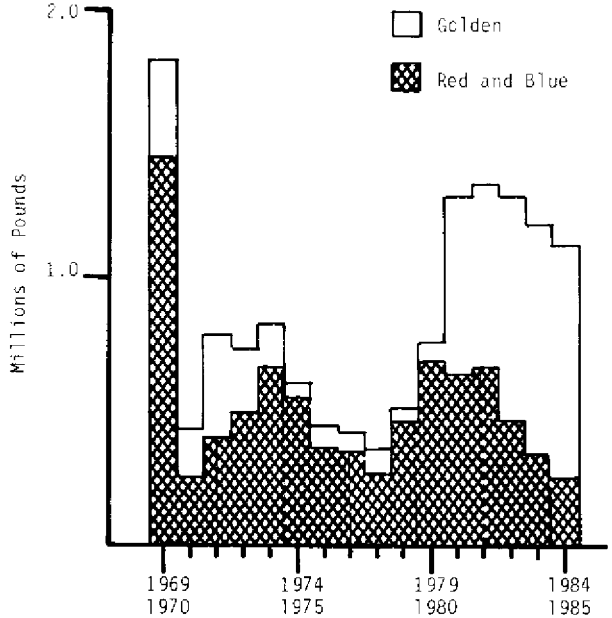

Figure 1. Historic commercial harvests of the different species of king crab from Southeast Alaska waters. Golden are *Lithodes aequispina*, red are *Paralithodes camtschatica*, and blue are *P. platypus*.

Table 1. Commercial harvests in pounds, of red and blue, *Paralithodes camtschatica* and *P. platypus*, and golden, *Lithodes aequispina*, king crab in Southeastern Alaska since 1960.

Season	Red & Blue	Golden	Total
1960			3,424
1961			429,600
1962			1,259,550
1963			1,112,200
1964			820,530
1965			579,300
1966			105,899
1967			2,199,772
1968			1,899,930
1969			
1969-70	1,438,226	359,567	1,797,833
1970-71	221,369	181,142	402,538
1971-72	391,623	372,933	764,556
1972-73	476,761	265,310	742,071
1973-74	640,369	179,520	819,889
1974-75 [a]	537,189	34,451	571,640
1975-76	346,341	68,429	414,770
1976-77	335,714	71,475	407,189
1977-78	241,220	81,746	322,966
1978-79	443,794	37,324	481,118
1979-80	672,734	46,551	719,285
1980-81	520,134	660,172	1,189,206
1981-82	530,461	625,244	1,155,685
1982-83 [b]	451,999	816,637	1,286,638
1983-84 [b]	303,916	996,357	1,300,273
1984-85	249,046	675,000	924,046
Total Poundage [c]	6,362,670	5,112,291	11,474,961
Average Poundage [c]	424,178	340,819	764,997
Average Percent [c]	55.45%	44.55%	

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[a] Data through 1975 from Annual Management Reports. Data beginning in 1976 from computer compilation of fish ticket landing data.

[b] Data preliminary for 1983-84 and 1984-85 seasons.

[c] Excludes 1969-70 season when minimum legal size was 6.5 inches (165.1 millimeters).

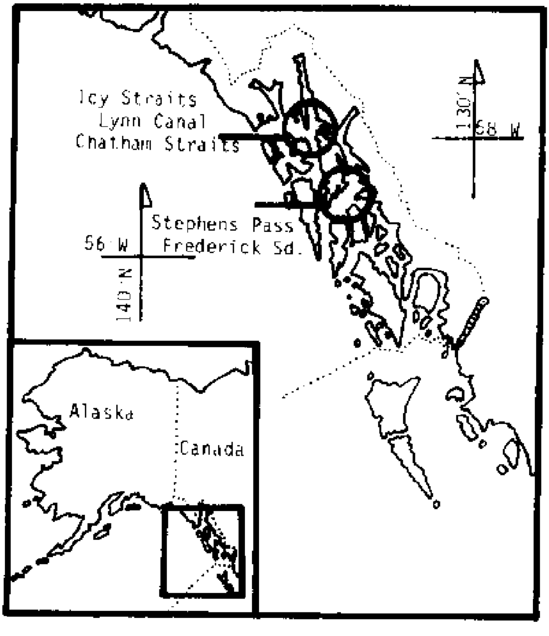

Figure 2. Location of golden king crab, *Lithodes aequispina*, tag and recovery areas in Southeast Alaska, 1970 through 1976.

released as soon as possible. Data recorded during processing included: date, depth, location, vessel, biologist or technician on-board, tag number, carapace length, and carapace age. Carapace length was determined to the nearest millimeter (mm) utilizing vernier calipers and was measured from the base of the right eye orbital to a midpoint of the posterior margin of the carapace. Carapace age was classified as either soft, new, old, or very old. Soft indicating a carapace condition where the carapace was the result of a very recent molt. New indicating a carapace resulting from a molt from the previous year. Old indicating a carapace that had skipmolted the previous year when a molting opportunity existed. And, very old indicating a carapace that had failed to molt during the previous two or more molting opportunities.

Tagging was accomplished utilizing either red or yellow plastic tube (spaghetti) tags. Tags were inserted through the muscular isthmus located between the posterior margin of the carapace and the anterior margin of the first abdominal segment. Tags were inserted through the isthmus utilizing a curved needle, and both tails of the tubing were hand-knotted together to secure the tag in place. This basic method has been previously described by other authors (Hulzer 1954 and Hayes 1963), and tags are retained through the molting process. One tail of each tag was printed with the legend "ADF&G" followed by a serially unique five digit identification number.

Recoveries were accomplished by the same method used in the initial collection process and occurred from one month after release in 1970 through March, 1976. Appropriated information was collected from the vessel skippers and crewmen at time of landing after recapture.

RESULTS AND DISCUSSION

From December, 1970 through October, 1972 the tagging program was successful in capturing, tagging, and releasing 899 male golden king crab on the commercial fishing grounds. Tagged crab were within a range of 93 to 195 mm of carapace length. Recaptures totalled 112 from the commercial fishery between February, 1971 and March, 1976. Data sufficient to determine whether growth occurred, growth per molt as an increase in mm of carapace length, and time at large, was obtained for 95 recaptured crab (Table 3). Carapace length distribution of the recaptured crab ranged from 143 to 191 mm of carapace length.

Due to the subjectivity associated with carapace age determination, this factor was not included in the analyses. Additionally, information suggesting that golden king crab molt asynchronously (McBride et al. 1982; Otto 1984; Sloan 1985) indicated that time of release or recovery would not be an appropriate factor to include in the analyses.

Recaptures were grouped into three categories of time at large to facilitate the analysis of growth per molt data. The three categories of time at large are: (A) recaptures at large for 12 months or less, (B) recaptures at large for 13 through 24 months, and (C) recaptures at large for 25 months or more. Based on data from category (A), recaptures in other categories were further categorized according to the number of molts accomplished.

Table 2. Summary of tag release and recapture data, and statistics for golden king crab, *Lithodes aequispina*, from 1970 through 1976 from Southeast Alaska waters.

Data or Statistic	One Molt ≥10 ≤ 12 mo.	One Molt ≥13 ≤24 mo.	One Molt ≥25 ≤33 mo.	One Molt ≥10 ≤ 33 mo.	Two Molts ≥28 ≤51 mo.
1. SAMPLE SIZE (N):	12	25	8	45	7
2. PREMOLT CARAPACE LENGTH RANGE (mm.):	145-159	132-170	133-170	132-170	126-152
3. POSTMOLT CARAPACE LENGTH RANGE (mm.):	163-175	150-184	152-187	150-187	167-183
4. CARAPACE LENGTH INCREASE (mm.)					
range:	12-19	7-20	8-21	7-21	26-34
mean ($\overline{x}$):	16.58	16.08	16.50	16.29	31.33
standard deviation (S_x):	2.02	3.11	4.14	3.01	2.80
standard error ($S_{\overline{x}}$):	0.58	0.62	1.46	0.45	1.17
5. TIME AT LARGE (mo.)					
range:	10-12	13-24	26-33	10-33	28-51
mean ($\overline{x}$):	11.17	17.00	28.37	17.47	38.50
standard deviation (S_x):	0.83	4.09	2.20	6.53	9.48
standard error ($S_{\overline{x}}$):	0.24	0.82	0.78	0.97	3.87
6. LEAST SQUARES LINEAR REGRESSION (PREMOLT =x, POSTMOLT=y)					
mean, x:	152.42	148.72	153.13	150.49	144.17
standard deviation, x:	4.27	8.50	11.19	8.24	6.97
standard error, x:	1.23	1.70	3.96	1.23	2.84
mean, y:	169.00	164.80	169.63	166.78	175.50
standard deviation, y:	3.86	8.32	11.90	8.31	5.43
standard error, y:	1.11	1.66	4.21	1.24	2.22
correlation coefficient:	0.88	0.93	0.93	0.93	0.92
coefficient of determination:	0.78	0.87	0.88	0.87	0.85
slope (m):	0.7964	0.9120	0.9971	0.9413	0.7186
intercept (b):	47.6230	29.8684	16.9366	25.1169	71.9018

Table 3. Summary of tag release and recapture data from golden king crab, *Lithodes aequispina*, from 1970 through 1976 from Southeast Alaska waters.

1. Number of tags released: 899

    In 1970: 3
    In 1971: 846
    In 1972: 50

2. Number of tags recaptures: 112

    In 1970: 0
    In 1971: 21
    In 1972: 48
    In 1973: 31
    In 1974: 8
    In 1975: 2
    In 1976: 2

3. Number of tags recaptured with adequate data: 95

4. Number of tags recaptured without adequate data: 17

5. Number of tags recaptured within 12 months of release: 31

    Number of crab with data indicating one molt: 12
    Proportion of crab indicating one molt: .39

6. Number of tags recaptured from 13 to 24 months of release: 46

    Number of crab with data indicating one molt: 25
    Proportion of crab indicating one molt: 54

7. Number of tags recaptured from 25 to 60 months of relase: 18

    Number of crab with data indicating one molt: 8
    Number of crab with data indicating two molts: 7
    Number of crab with data indicating thre or four molts: 3
    Proportion of crab that molted: 1.00

It was assumed that recaptures at large for 12 months or less, category (A), experienced only one molting opportunity. Information is available to support the stated assumption. Laboratory maintained male and female red king crab from Japanese waters, molted annually up to 124 mm of carapace length or molted annually up to size at maturity, and first skipmolted at 133 mm of carapace length (Matsuura and Takeshita 1976). A growth model for Kodiak male red king crab was developed based on data from tag and recapture, immature crab, and penned crab studies (McCaughran and Powell 1977). This growth model indicates that substantial skipmolting first occurs at approximately 120 mm of carapace length, and that the probability of molting decreases as carapace length increases beyond 120 mm of carapace length (McCaughran and Powell 1977).

Data estimating size at maturity for male golden king crab from Southeast Alaska is not available. Data for male and female golden king crab in the vacinity of the Eastern Bering Sea, and preliminary information for female golden king crab from the Lynn Canal-Icy Straits area of Southeast Alaska indicates that the largest mean size at maturity for males is 117.5 mm of carapace length, and for females is 107.2 mm of carapace length (Otto 1984; and Somerton and Otto in prep.).

Dockside samples of commercial landings of male golden king crab from Southeast Alaska during one season representing the developmental stage of the fishery (1970-71) and one season representing the fully developed stage of the fishery (1982-83) indicate that the maximum size is 215 mm of carapace length (Fig. 3). This is close to the previous information indicating a maximum size of 220 mm of carapace length for male golden king crab in the Bering Sea and Aleutian Islands areas (McBride et al. 1982). The minimum legal carapace width of 178 mm for Southeast Alaska, corresponds to a carapace length of 150.6 mm based on an unpublished linear regression equation of $Y = 44.3336 + 0.8875X$ for 345 observations of male golden king crab in Southeast Alaska, where X = carapace length in mm, and Y = carapace width in mm. Thus, the premolt carapace lengths of 126 to 170 mm and the postmolt carapace lengths of 150 to 200 mm utilized in this tag-recapture study, corresponds well to the range of 148 to 215 mm found through dockside samples of commercial landings.

Based on the information available, it does not appear as if extreme discrepencies exist between golden king crab stocks from Southeast Alaska and other areas. The majority of the tagged male golden king crab, and all of the recaptures from Southeast Alaska were larger than the expected mean size at maturity. The sample collected could be expected to molt only once in a 12 month period, if at all.

(A) Crab at large from 0 to 12 months.

Thirty-one crab were recaptured from 1 to 12 months of release. Recaptures ranged from 143 to 191 mm of carapace length. Of the 31 recaptures, 19 did not molt. Crab exhibiting no growth were at large from 1 to 9 months, while the 12 crab exhibiting one molt had been at large from 10 to 12 months. Recaptures that molted once had premolt carapace lengths ranging from 145 to 159 mm (Table 2). Mean growth per molt was 16.58 mm of carapace length, within a range of 12 to 19 mm. Mean time at large was 11.2 months for molting crab. No multiple molts were apparent within this group of recaptures.

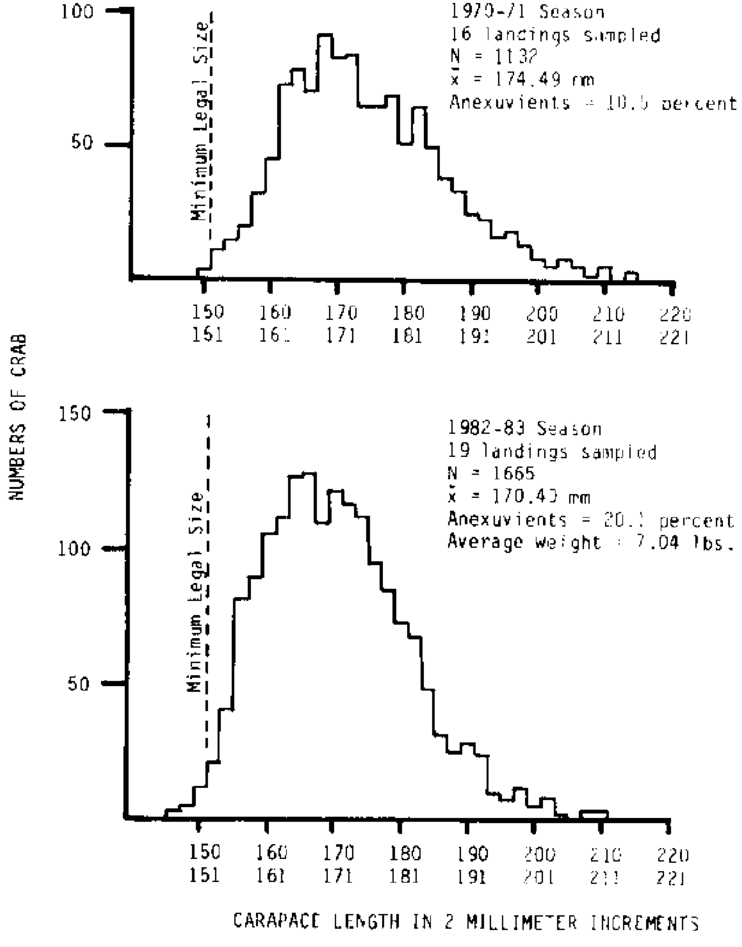

Figure 3. Size frequency distribution of golden king crab, *Lithodes aelquispina*, from dockside samples of commercial landings in Southeast Alaska.

(B) Crab at large from 13 to 24 months.

Forty-six recaptures occurred from 13 to 24 months of release. Recaptures ranged from 132 to 191 mm of carapace length. Of the 46 recaptures, 21 did not molt. Crab exhibiting no growth were at large from 13 to 23 months, while the 25 crab exhibiting one molt were at large from 13 to 24 months. Recaptures exhibiting one molt had premolt carapace lengths ranging from 132 to 170 mm of carapace length (Table 2). Mean growth per molt was 16.08 mm, with a range of 7 to 20 mm. Mean time at large for molting crab was 17.5 months. Once again, no multiple molts were evident within this group of recaptures.

(C) Crab at large from 25 to 60 months.

Eighteen crab were recaptured from 25 to 60 months after release. All crab in this category exhibited growth. The 8 recaptures exhibiting one molt had premolt carapace lengths ranging from 133 to 170 mm (Table 2) and were at large for a mean of 28.4 months. Mean growth per molt was 16.50 mm of carapace length within a range of 8 to 21 mm of carapace length.

The 7 crab exhibiting two molts had premolt carapace lengths ranging from 126 to 152 mm (Table 2), and were at large for a mean of 38.5 months. Mean growth for two molts was 31.33 mm of carapace length, or approximately 15.7 mm for each individual molt. The range of growth for two molts was 26 to 34 mm of carapace length, or 13 to 17 mm for each individual molt.

The remaining 3 crab with adequate data appeared to exhibit three molts (2 crab) and four molts (1 crab). Recaptured crab that exhibited three molts had premolt carapace lengths of 146 and 147 mm, and were at large for 18 and 56 months, respectively. Mean growth for three molts was 52.0 mm, or approximately 17.3 mm for each molt. One crab grew 50 mm and the other grew 54 mm. The recaptured crab exhibiting four molts had a premolt carapace length of 133 mm, was at large for 51 months and grew 60 mm, or approximately 15.0 mm during each molt. There is some uncertainty in determining how many molts these three crab actually accomplished, especially with respect to the limited sample. However, the determinations made appear to correspond well to the data available on crab accomplishing one molt.

Other data.

Basic statistics and a least squares linear regression was accomplished for recaptures from category (A) that exhibited growth. Premolt carapace length was set as the independent variable, and postmolt carapace length was set as the dependent variable. Results have been summarized and partially discussed above. Based upon the mean growth per molt (16.58 mm), standard error (0.58 mm), and the range of growth (12 to 19 mm), data from other recaptures at large for more than 12 months were categorized. Since statistics from categories (A), (B), and (C, only single molt) were very similar, all single molt data were combined and analyzed. Statistics for all combined single molt data are also summarized (Table 2). These statistics indicate a mean growth per molt of 16.29 mm, a standard error of 0.45, and a range of 7 to 21 mm. A least squares linear regression was performed for all single molt data and results are summarized in both tabular form (Table 2) and graphic form (Fig. 4).

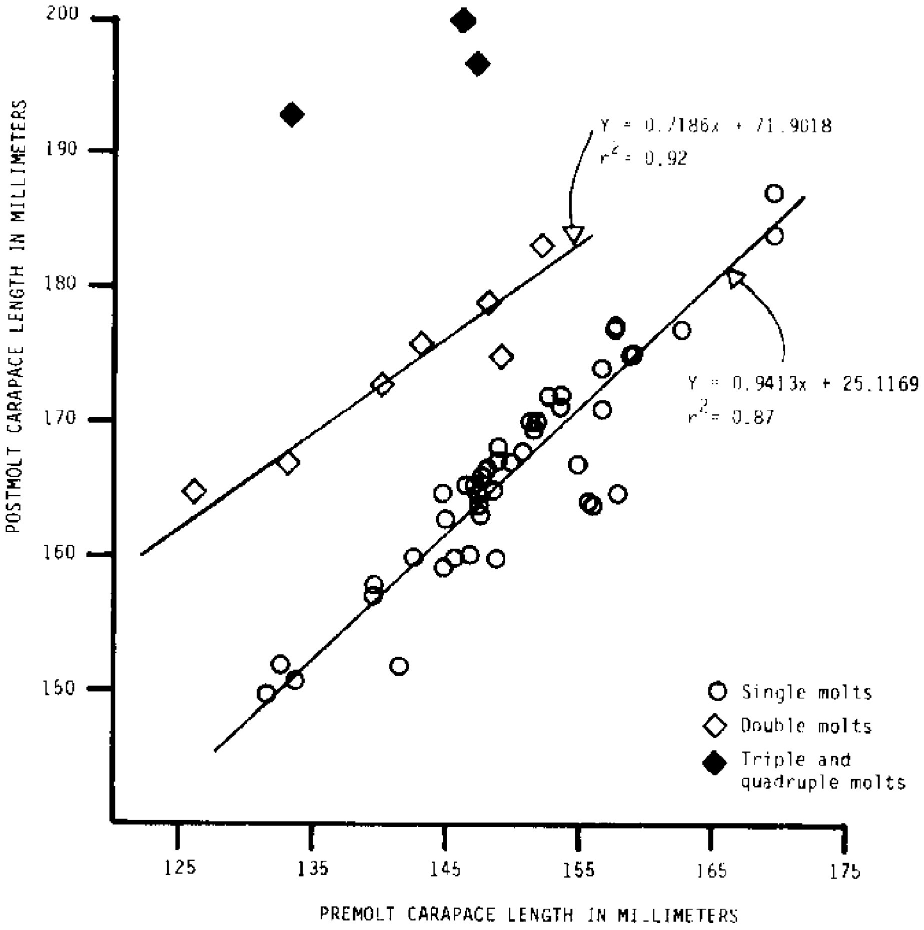

Figure 4. Scatter plot and least squares regression lines of premolt and postmolt carapace lengths from male golden king crab, *Lithodes aequispina*, that were at large for 10 to 60 months after tagging in Southeast Alaska waters.

Based on category (A) statistics, determinations were also made as to the appropriate number of multiple molts accomplished by the remaining recaptures in category (C). Basic statistics and a least squares linear regression was accomplished for the 7 recaptures which accomplished two molts, and the resulting data is summarized in both tabular form (Table 2) and graphic form (Fig. 4). Analyses were not accomplished on recaptures that accomplished three or four molts due to the limited sample, but these data points were plotted (Figs. 4, 5, 6).

Scatter plots of all data as premolt carapace length versus carapace length increase in mm (Fig. 5) and premolt carapace length versus percent increase in carapace length (Fig. 6) was accomplished to assist in categorizing the data.

One additional piece of information was available from the recapture data. Although, the probability of molting within a specific year may decrease, at least for red king crab (McCaughran and Powell 1977), it does not appear as if crab cease to molt entirely. For male golden king crab recaptured within 12 months of release 39 percent molted, from 13 through 24 months 54 percent molted, and from 25 through 60 months 100 percent molted (Table 3). It appears that the probability of molting increases with each additional year after an initial skip-molting occurs. However, the sample size considered is limited and the specific year in which skipmolting first occurred is not known.

SUMMARY

Information presented indicates that male golden king crab can be successfully tagged and recaptured after accomplishing as many as four molts, and after being at large for up to fifty-one months. Growth data resulting has assisted in providing additional understanding of some aspects of golden king crab biology. More information is needed to insure that our perceptions of the life history and population dynamics of this species approach completeness. Especially, if such perceptions are utilized to develop an appopriate management and regulatory system. In Southeast Alaska, necessary information includes, but is not limited to: definative size at maturity estimates for male and females; growth and survival information for all life history stages; habitat requirements, especially as they relate to the younger life history stages; predators and diseases; migration of all life history stages; indices of abundance or estimates of abundances; and effects of the commercial fisheries associated with this species. Many of these informational voids require significant time series to understand the variabilities associated with the parameters. To date, the fishery for golden king crab in Southeast Alaska has been significant for approximately eighteen years, and definative programs have not been implemented to provide the necessary information which will insure continued, and viable fisheries. Occurrances in other king crab fisheries should provide impetus to seek the necessary information.

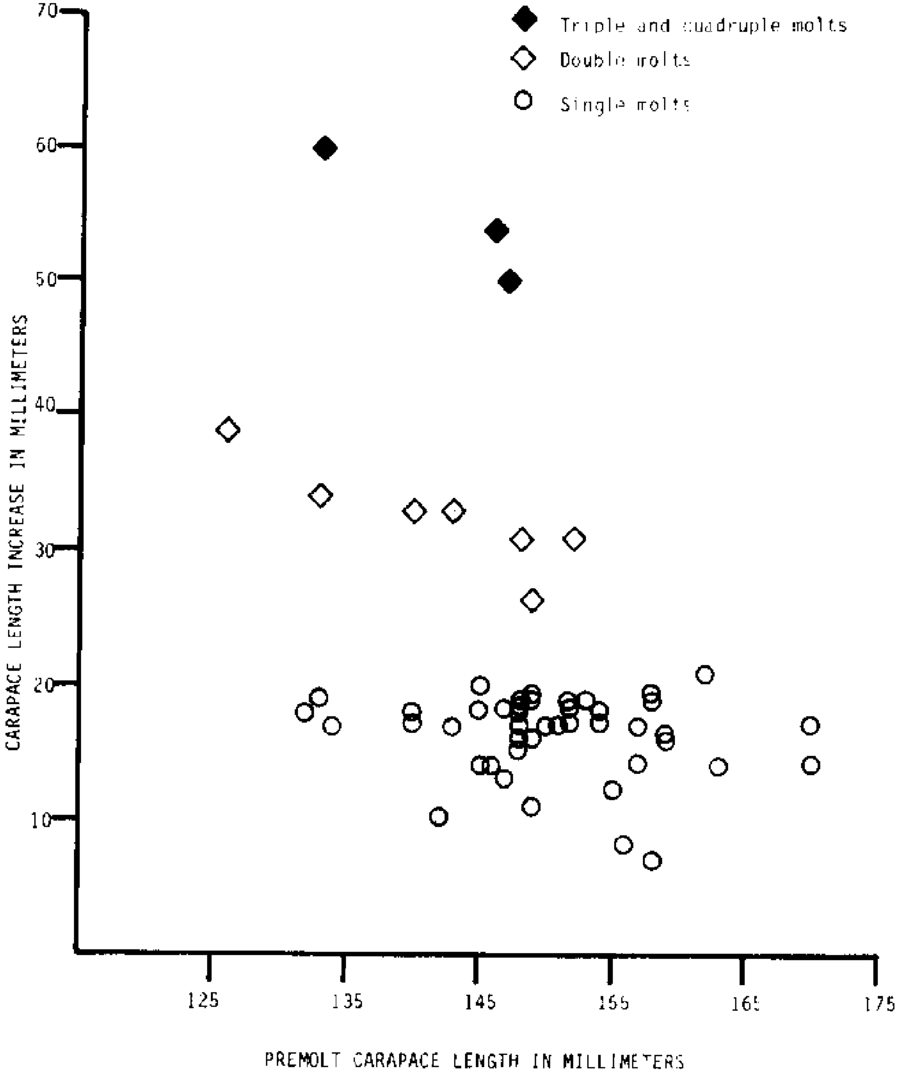

Figure 5. Scatter plot of premolt carapace length at time of tagging and millimeters of increase in carapace length at time of recapture of male golden king crab, Lithodes aequispina, that were at large from 10 to 60 months in Southeast Alaska waters.

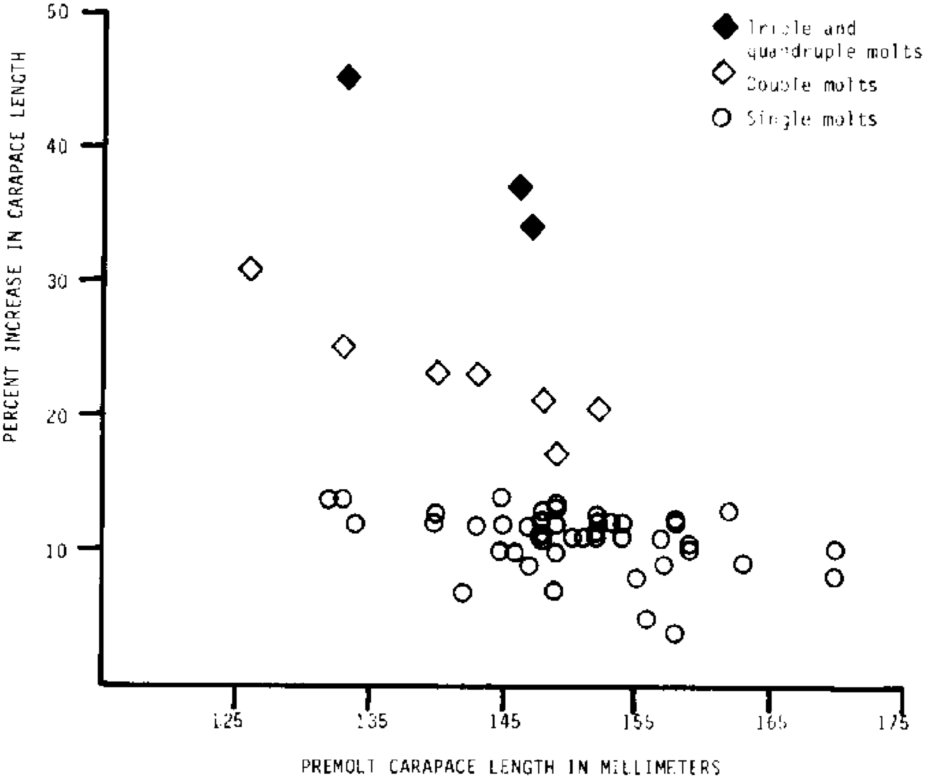

Figure 6. Scatter plot of premolt carapace length at time of tagging and percent increase in carapace length at time of recapture of male golden king crab, Lithodes aequispina, that were at large from 10 to 60 months in Southeast Alaska waters.

ACKNOWLEDGEMENTS

Sincere gratitude is expressed to skippers and crewmen of the king crab fishing vessels of Southeast Alaska, especially Lloyd Pederson and Eldor Lee of the F/V Middleton, Andrew Greinier of the F/V Charles T., and Tom Maloney of the F/V Nova. Thanks are due to many Alaska Department of Fish and Game biologists and technicians that participated, especially to Paul Tate and Barry Bracken for data collection, and to George Curtiss for diligently transcribing the original data to a computerized format. The efforts of Rich Peterson and Mary Ellen Harris are also greatly apreciated, for without their efforts to computerize and summarize the data, the project would not have been completed.

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Overview of the golden king crab, *Lithodes aequispina,* fishery and its fisheries biology in the Pacific waters of Central Japan

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Introduction

Fifteen species of Lithodid crabs in seven genera have been documented from the Pacific coast of Japan (Table 1). Two commercially important species belong to the genera Lithodes and Paralomis. These are Lithodes aequispina and Paralomis multispina. Among them, the golden king crab, Lithodes aequispina, occurs from 450-850 m depth on the continental slope, and has been exploited as a deep-sea fishery resource.

The geographic distribution of L. aequispina extends from the Okhotsk coast of Hokkaido Island to Hyuganada, Kyushu Island (Figure 1). However, commercial concentrations exist from the northern to central Pacific coast of Honshu Island.

The golden king crab fishery began in 1963 in the Tohoku region, off the northern part of Honshu Island. Later in 1968-1969, the commercial fishery started in the Tokai region covering the area off Boso Peninsula, Uraga Straits, Sagami Bay and Suruga Bay. A substantial fishery existed between 1977 and 1980 with the highest landing of 126 mt in 1977-1978, but thereafter the landing drastically declined. The resource appears to have been heavily exploited within a few years. At present, a substantial fishery continues in the Tohoku region.

Although the golden king crab fishery is small compared with the king crab and Tanner crab fisheries in the North Pacific, this fishery holds an important position for local fishermen because of high market values of the golden king crab.

This paper summarizes the status of the golden king crab fishery and biological information in the Tokai region. Although available

Table 1. List of Lithodid crabs from the Pacific coastal waters of central Japan.

Family Lithodidae
Subfamily Hapalogastrinae Ortmann
Genus *Hapalogaster* Brandt
H. dentata (De Haan)
Genus *Oedignathus* Benedict
O. inermis (Stimpson)

Subfamily Lithodinae Ortmann
Genus *Lithodes* Latreille
L. turritus Ortmann
L. aequispina Benedict*
L. longispina Sakai
Genus *Paralomis* White
P. hystrix (De Haan)
P. multispina (Benedict)*
P. verrilli (Benedict)
P. dofleini Balss
P. japonica Balss
P. cristata Takeda et Ohta
P. hystrixoides Sakai
Genus *Neolithodes* A. Milne Edwards et Bouvier
N. nipponensis Sakai
Genus *Cryptolithodes* Brandt
C. expansus Miers
Genus *Lopholithodes* Brandt
L. odawarai Sakai

* The species for the edible resources.

data are sporadic, the obtained information elucidates some biological aspects of the golden king crabs in the southern limit.

Data Source

The catch data have been compiled by the prefectural governments of the Tokai region: Shizuoka, Kanagawa and Chiba Prefectures. Catch statistics and biological data were obtained off the east coast of Boso Peninsula in 1968-1971, and in Suruga Bay in 1976-1977, and Uraga Straits and Sagami Bay in 1977-1980. The catch per unit of effort (CPUE) in this report is expressed as catch per boat and catch per crab pot.

To investigate the population size and migratory pattern, tagging experiments were conducted in 1978 and 1979, using Petersen's disc and anchor tag. A total of 665 golden king crabs were tagged and released in Uraga Straits; 151 individuals in 1978 and 515 in 1979. Based on Petersen's method, the inception was estimated.

Size distribution, width-length and width-weight relationships, and sex ratios were analyzed on the sample off Boso Peninsula and in Suruga Bay. Carapace width and length measurements exclude lateral spines and rostrum. The development stages of eggs were identified and seasonal changes in stage compositions were compared. The egg

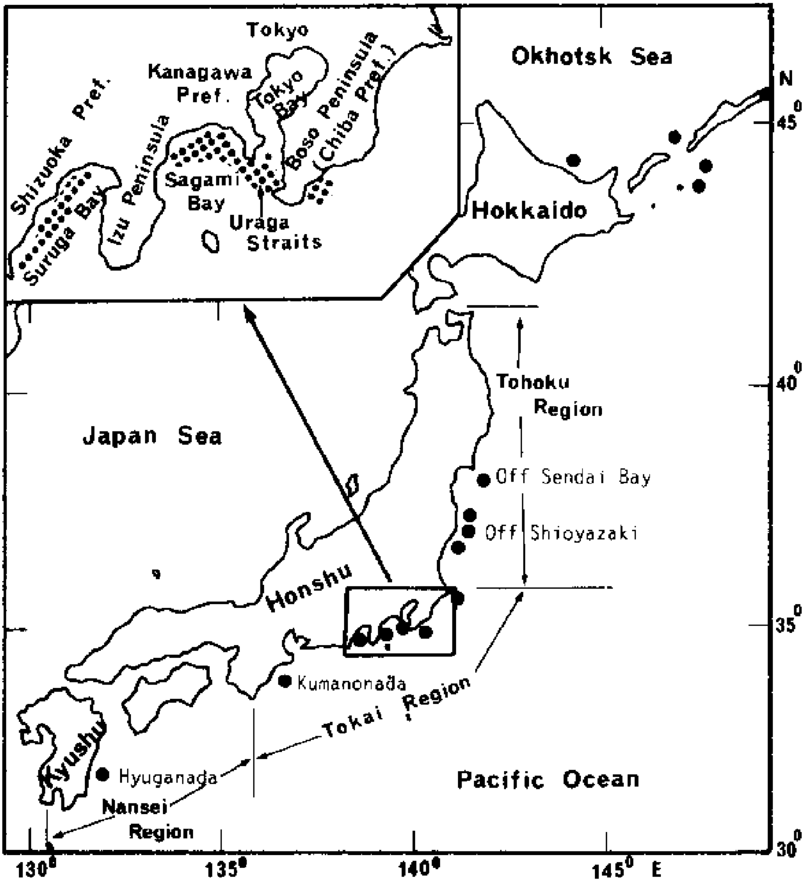

Figure 1. Distribution (lower; dot) and fishing area (upper; shade) of the golden king crabs in the Japanese waters.

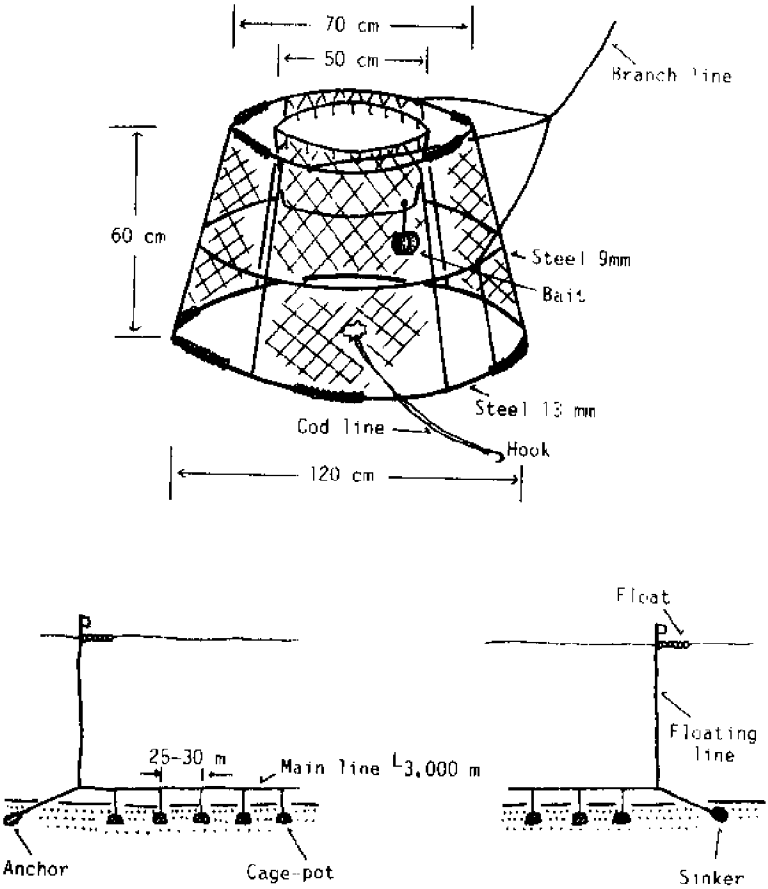

Figure 2. Cage-pot for the golden king crab (upper) and schematic diagram of its fishing gear (lower).

stages were classified into the five categories: (1) spent stage - no external eggs, but remnants of eggs, especially the funiculi, attached to the pleopod bristles, (2) new egg stage - orange external eggs with no evidence of embryonic eyes, (3) early zoeal stage - orange external eggs with thin dark embryonic eyes, (4) late zoeal stage - tan external eggs with obvious dark embryonic eyes, and (5) hatching stage - partial clutch of well-developed eggs, with remnants of hatched eggs attached to pleopod bristles and occasionally with prezoea on the egg mass.

Results

Fishery and fishing gears

Golden king crabs in the Tokai region are exclusively captured by crab pots operated by small boats ranging between 3 and 14 gross tons . The crab pots are similar to those which had been used in the Japanese king crab fisheries in the Bering and Okhotsk seas, with minor modifications in size and structure. The pot is conical in shape and measures 0.6 m high x 1.2 m bottom diameter x 0.7 m top diameter. A pot mouth opens in the upper cover with 0.5 m diameter. Typically, a total of 30-100 pots with attractive baits are attached to a ground line with 25-30 m intervals (Figure 2). A set of line and pots are placed on the sea bottom at 500-800 m depth. The number of set varies depending upon the size of the fishing boat and sea conditions. The pots are usually retrieved after one day.

The registered number of fishing boats for this fishery is few, varying by year and by management area. In Chiba Prefecture, one potter was registered in 1978 and two in 1979. In Kanagawa Prefecture, 4-8 potters were operating in 1977-1980. Only one potter was engaged in the fishery in Shizuoka Prefecture in 1976 and 1977 (Table 2).

Submarine topography and hydrography of fishing grounds in the Tokai region

The Pacific area between southern Boso Peninsula and Suruga Bay, which is the fishing grounds of the golden king crab, is situated on the east coast of central Honshu Island and is a distinctive type of embayment in which a deep-sea system penetrates deep into the land. The area is characterized by deep troughs: the Sagami Trough and the Suruga Trough. The Sagami Trough extends southward at the mouth of the bay, and its deepest depth is about 1,500 m (Figure 3). The Suruga Trough also extends southward at the mouth of the bay to a depth of about 2,500 m.

Example of vertical profiles of the temperature in the area off Cape Nozimasaki, southern Boso Peninsula, and Suruga Bay are shown in Figures 4 a and b. A steep temperature gradient is recognized at depths shallower than 200 m, and then gradually it decreases with depth. The salinity profile in Suruga Bay shows a steep decrease beginning at a depth of about 200 m, ending in the salinity minimum layer (< 34.3‰) at a depth between 400 and 700 m, and then increases again with depth (Figure 4 b)(Ohta 1983). The intermediate water is characterized by low salinity (34.2-34.4‰), and a temperature range of 3-11°C is found between depths of 300-800 m in the observed

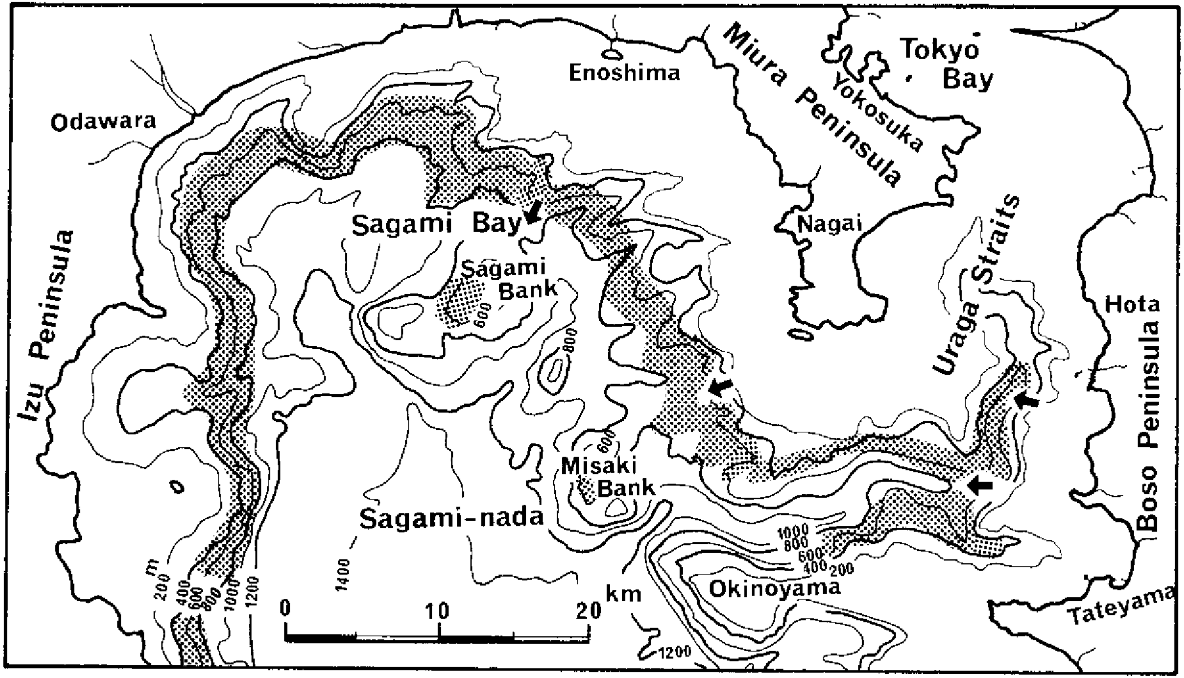

Figure 3. Submarine topography of the Uraga Straits and Sagami Bay. The bathymetrical contour interval is 200 m. Shaded area denotes the fishing grounds of golden king crab, and arrows show the major concentrations.

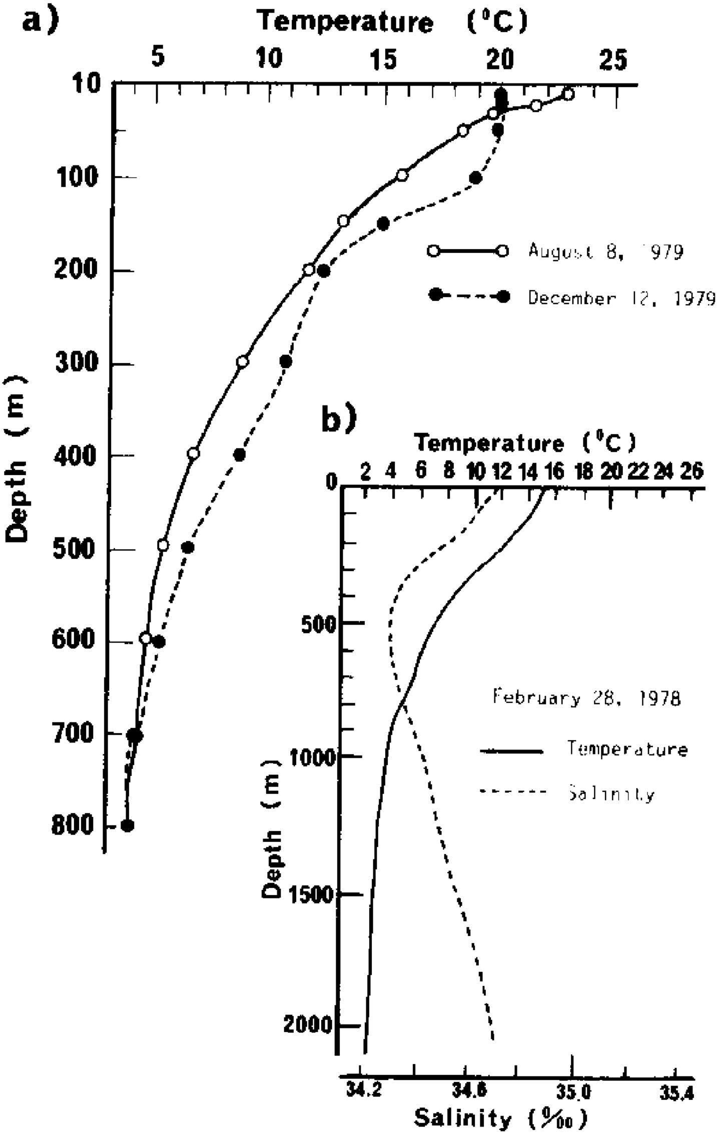

Figure 4. Vertical profiles of (a) water temperature off Cape Nozimasaki of South Boso Peninsula (after Ishino et al. 1981) and of (b) water temperature and salinity in the central part of Suruga Bay (after Ohta 1983).

Table 2. Number of cage-pot fishing boats on the golden king crabs in the Tokai region, 1976-1980.

Prefecture	Fishing ground	Year				
		1976	1977	1978	1979	1980
Chiba	Uraga Straits	–	–	1	2	–
Kanagawa	Uraga Straits and Sagami Bay	–	8	7	5	4
Shizuoka	Suruga Bay	1	1	–	–	–

area of the Tokai region (Ishino et al. 1981; Ohta 1983).

The fishing grounds of the golden king crab in Uraga Straits and Sagami Bay are distributed widely on the continental slopes from 500-800 m depth shown in Figure 3.

Catch and stock size

The landings were recorded for major fishing ports or particular fishing grounds. No reliable data exist on the stock identification and intermingling of populations in the Tokai region.

The catch in Kanagawa Prefecture, represented by the landings from Uraga Straits and Sagami Bay, reached 126 mt in 1977-1978, but rapidly declined to 37 mt in 1978-1979 and 17 mt in 1979-1980 (Figure 5). The fishery almost closed in 1980-1981 season and thereafter. Correspondingly, the mean catch per boat decreased from 275 kg in 1977-1978, to 222 kg in 1978-1979, and to 98 kg in 1979-1980 (Kanagawa Pref. Fish. Expr. Stn., unpubl.). The CPUE in 1977-1978 increased from November to February, and declined in March and April. In 1978-1979, the CPUE declined from October to December, and then increased toward February. A similar trend can be traced in 1979-1980. The stock assessment, based on the tag-recovery experiments, indicates the inception of each fishing year to be 792 mt in 1977, 258 mt in 1978, and 153 mt in 1979 (Table 3). The values are probably overestimated due to the insufficient data to fulfill the assumptions in Petersen's method.

In Chiba Prefecture, the monthly mean catch per pot by 3.5 tonnage boat at Hota Port showed relatively similar values (0.8-1.8 kg/pot) between November 1978 and June 1979. But, it showed the only low value (0.1 kg/pot) in July 1979 (Table 4).

In summary, the stock size of the golden king crab in the Tokai region appears to be marginal, and the recruitment and emigration do not seem intensive. This is exemplified by an abrupt decline in 1978, followed by the exploitation of the virgin stock in 1977 in Kanagawa Prefecture, which resulted in the closure of the fishery in 1981.

Size composition

The carapace width (CW-excluding lateral spines) of the golden king crabs off Boso Peninsula measured between 8.3 and 19.2 cm in

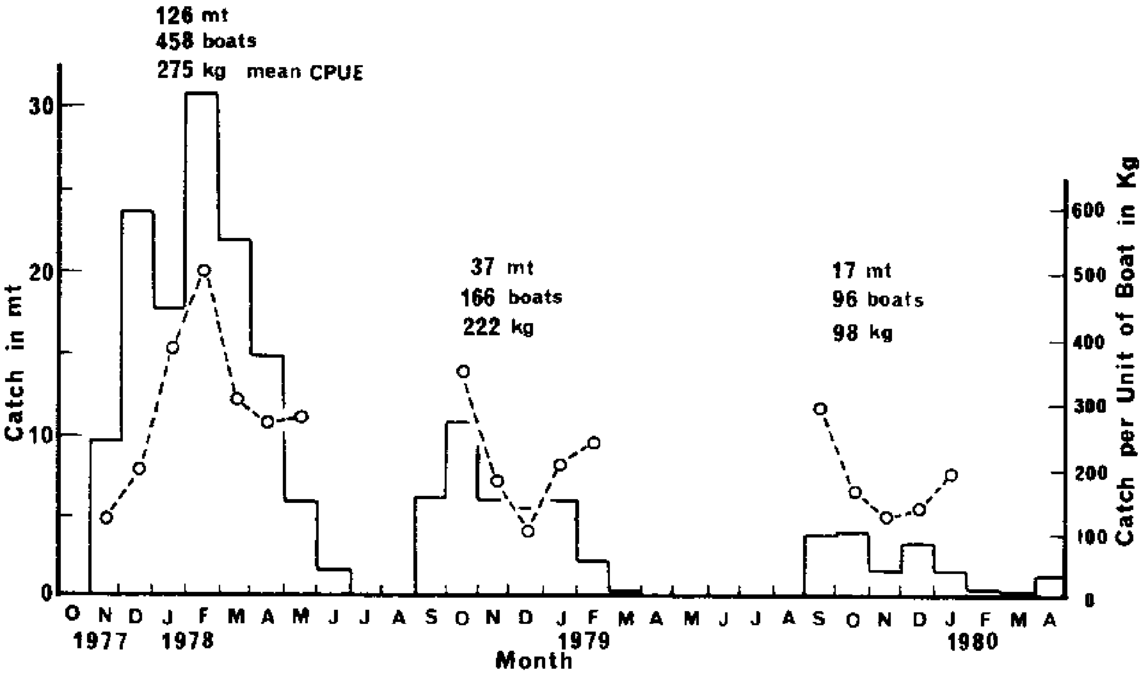

Figure 5. Seasonal and yearly changes of landings (histogram) and catch per boat (circle and dotted line) of the golden king crab at Nagai in Yokosuka, Kanagawa Prefecture, from 1977-1978 through 1979-1980, which were caught in Uraga Straits and Sagami Bay. (Kanagawa Pref. Fish. Expr. Stn., unpubl.)

Table 3. Estimated stock of the golden king crab by Petersen's method in Uraga Straits and Sagami Bay at the inception of each fishing year. (Kanagawa Pref. Fish. Expr. Stn., unpubl.)

Year	Catch (mt)	Rate of recaptured (%)	Estimated stock at the inception of each year (mt)
1977-1978	126	–	792
1978-1979	41	15.9	258
1979-1980	17	11.1	153

Table 4. Monthly catch of the golden king crab in Uraga Straits at Hota in Chiba Prefecture, 1978-1979.

Month	Days fished	Total number of pots	Catch (kg)	CPUE (kg/pot)
1978 Nov.	1	25	30	1.2
Dec.	13	297	311.2	1.0
1979 Jan.	10	284	215.3	0.8
Feb.	18	639	1,121.0	1.8
Mar.	10	301	527.9	1.8
Apr.	11	406	623.6	1.5
May	13	367	559.8	1.5
June	8	254	302.9	1.2
July	4	128	12.2	0.1
Total	88	2,701	3,703.9	

females and between 8.0 and 22.0 cm in males. Figure 6 shows the frequency distribution of carapace width for both sexes. The data combined for the years 1968-1970, as there was no remarkable annual difference. It is apparent that the distributions assume polymodality, suggesting several ages in both sexes, though attempts failed to delineate modes. A difference in size distribution between females and males is quite obvious. While females exhibit a mode around 14-15 cm, no particular mode can be detected in males. The proportion of crab with size >16 cm CW is high in males and low in females. The reasons of such differences are not explained at present.

A comparison of size range showed no difference between Uraga Straits and Sagami Bay.

Carapace length-width relationships

Carapace width and length (CL) of females and males combined from off Boso Peninsula were regressed with a simple linear equation (size range: 6.6-20.4 cm CW; N=485; r=0.98):

$$CW = -0.48 + 1.06\ CL \qquad (1)$$

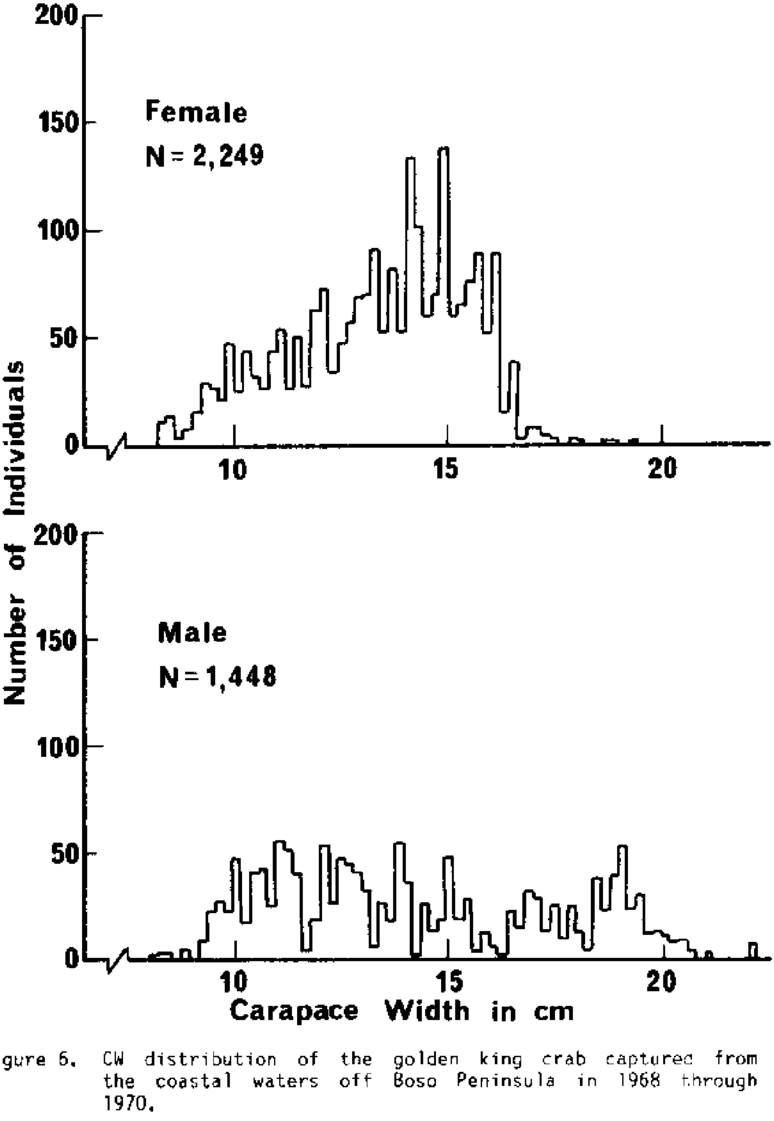

Figure 6. CW distribution of the golden king crab captured from the coastal waters off Boso Peninsula in 1968 through 1970.

A similar linear equation was obtained for the Suruga Bay samples (Suzuki and Sawada 1978) (size range 7.3-20.5 cm CW; N=192; r=0.99):

$$CW = -0.85 + 1.11\ CL \qquad (2)$$

The regression equation for females (6.6-18.1 cm CW) is shown as (N=303; r=0.97):

$$CW = -0.69 + 0.96\ CL \qquad (3)$$

and for males (7.7-20.4 cm CW) as (N=182; r=0.99):

$$CW = -0.68 + 1.09\ CL \qquad (4)$$

Thus, male is slightly wider than female in shape, and statistical difference is significant ($t=4.703 > t(481,\ 0.05)=1.960$).

Carapace width and body weight relationships

The body weight (BW, kg) of the crab is expressed as a power function of carapace width (CW, cm):

$$\text{Female: } BW = 8.03 \times 10^{-4}\ CW^{2.83} \qquad (N=90) \qquad (5)$$

$$\text{Male: } BW = 5.62 \times 10^{-4}\ CW^{2.98} \qquad (N=102) \qquad (6)$$

The increase rate of body weight relative to carapace width is slightly greater in males than in females, though statistical difference is insignificant ($t=1.752 < t(188,\ 0.05)=1.960$).

Biological minimum size

Hiramoto and Sato (1970) found that 15 % of the females at 12.6 cm CW and 60 % of the females at 13.6 cm CW were mature (spent or ovigerous). Thus, the 50 % maturity can be assigned to 12-13 cm CW.

The smallest female was 10.5 cm CW off Boso Peninsula which carried eggs on pleopods (Hiramoto and Sato 1970). Similarly, Suzuki and Sawada (1978) reported the smallest egg-bearing female in Suruga Bay was 10.9 cm CW (calculated from a CW-BW regression). Thus, it is conclusive that the minimum biological size of the golden king crab in the Tokai region is about 11 cm CW.

Egg development and spawning cycle

Based on the monthly observations of egg stage, Hiramoto and Sato (1970) depicted the spawning cycle of the golden king crab population for the waters off Boso Peninsula.

Figure 7 illustrates the monthly percent occurrence of females with different egg stages. Spent females were found throughout the year, showing 2 to 39 % occurrence with a peak in September. Females with new eggs appeared mostly from November through February, with 48 % occurrence in November and 36 % by the end of February. Females with hatching eggs occurred throughout a year with 11-57 %, but peaked in May and June. Similarly, the early and late zoeal stages also

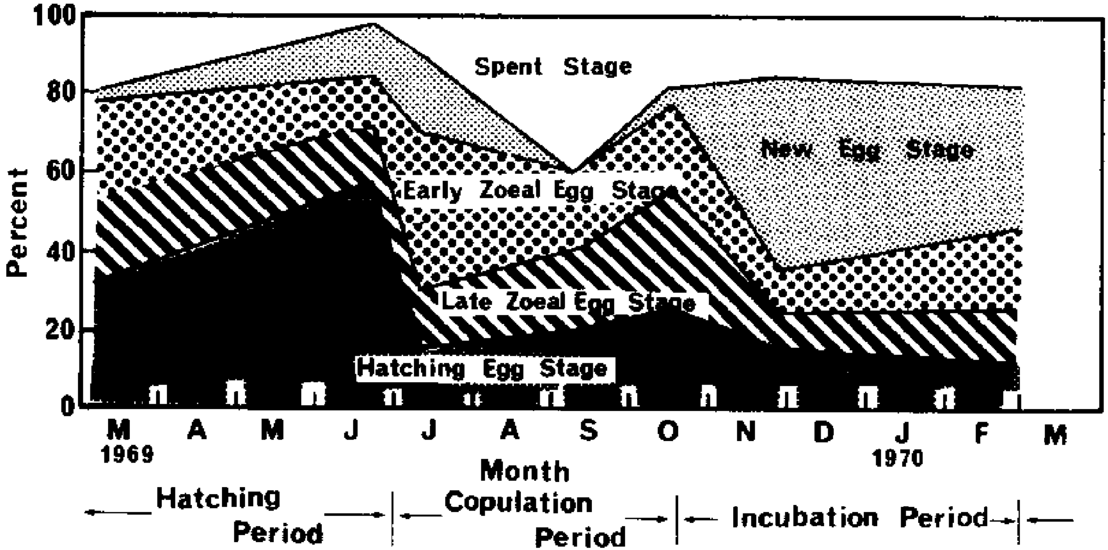

Figure 7. Seasonal frequency of mature females of the golden king crab in each of the five categories of reproductive condition off Boso Peninsula from March 1969 through March 1970.

took place at every month. The peak occurrence of the early zoeal stage was July, and that of late zoeal stage was March and October. The finding of various egg stages throughout a year indicates that the golden king crab undergoes asynchronous spawning.

Although a seasonal cycle is indistinct, prominent periods were evident, i.e., copulation from July through October, incubation from October through February, and hatching from March through June.

Female ratio

In the years 1976-1977, females accounted for 62.5 % of the population off Boso Peninsula and 53.1 % in Suruga Bay.

The proportion of females off Boso Peninsula varies seasonally. Female prevailed in October- December and January-July period, ranging between 40-90 %, whereas during July-October, the female proportion slightly declined by 15-80 % (Hiramoto and Sato 1970).

The proportion of adult crabs changed with season and with depth. The adult:immature crab ratio was about 3:4 during June-September, but reversed by 7:3 during October-December. Adults outnumbered the immatures at 450-600 m depth, but decreased in number at depth >600 m (Hiramoto and Sato 1970).

The results suggest that the maturing females aggregate with males for mating during copulation period, and tend to segregate from males during incubation and hatching periods. It is also presumable that the maturing crabs move to shallower water from deeper water, separating from immatures.

Egg size and number of eggs

The egg of the golden king crab is ovoidal in shape, and the mean long axis measures 2.38 mm at new egg stage, 2.40 mm at early zoeal stage, 2.41 mm at late zoeal stage, and 2.50 mm at hatching stage (Hiramoto and Sato 1970). The short axis measures between 1.9 and 2.3 mm. The egg size increased slightly with development.

The number of eggs per female tended to increase with crab size from 9,500 on a female 12.9 cm CW to 30,100 on a 15.7 cm CW female. The egg count at spawning (E) is empirically regressed to carapace width (CW, cm) by a linear equation, though the correlation coefficient is relatively low (N=12; r=0.65), shown in Figure 8:

$$E = 3,998\ CW - 35,200 \qquad (7)$$

Similarly, Suzuki and Sawada (1978) established a linear relationship of the egg count with body weight (BW, kg) for the crab with size range 1.2-2.5 kg BW, though the sample size was only 6. The equation is given by (r=0.97):

$$E = 17,200\ BW - 3,900 \qquad (8)$$

Migration

The monthly changes in the CPUE suggest dispersion and aggrega-

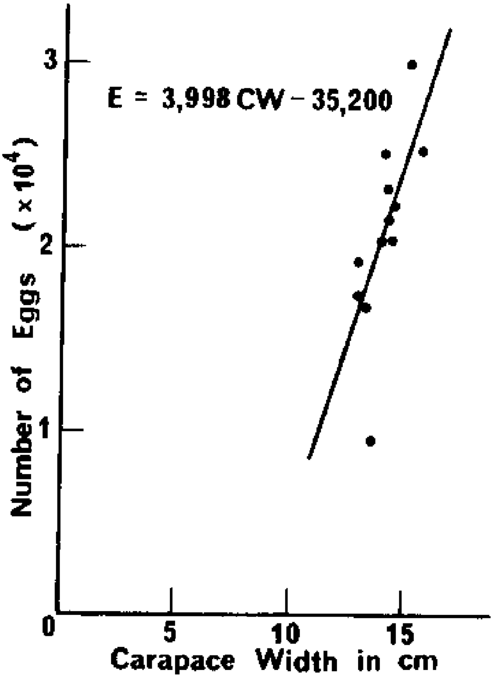

Figure 8. Relationship between number of external eggs and carapace width of the golden king crab off Boso Peninsula, 1969-1970.

tion of the golden king crab to some extent. As shown in Figure 5, the CPUE in Uraga Straits and Sagami Bay increased from November to February, and declined in March and April in the 1977-1978 fishing season. In the subsequent fishing years of 1978-1979 and 1979-1980, the CPUE declined earlier from September or October to November or December, and then increased January or February. Thus, it is assumed that during November and December crabs are widespread from the fishing ground, and then aggregate in January and February. It is also indicative that the aggregation will take place in September. Table 4 suppliments the above trend in 1978-1979 in Uraga Straits. The low CPUE values suggest the spreading in December, whereas the high CPUE values suggest the aggregation in February and March.

The results of the tag-recovery experiments give some insight into the migration of golden king crabs in Uraga Straits and Sagami Bay. In 1978, a total of 151 crabs with mean size 10.6-12.8 cm CW were released, of which 24 crabs were recaptured. The time required to recapture varied from 29 days to 379 days, with an average 220 days. Despite a relatively long duration at liberty, the crabs were recovered only 10 km southest of the release area. In 1979, 515 crabs (4.5-18.1 cm CW, mean 9.95 cm) were released, and 11.1 % of them were recaptured after 6 to 268 days (average 56 days). Nearly 90 % of the crabs moved southwestward within 5 km of the northest

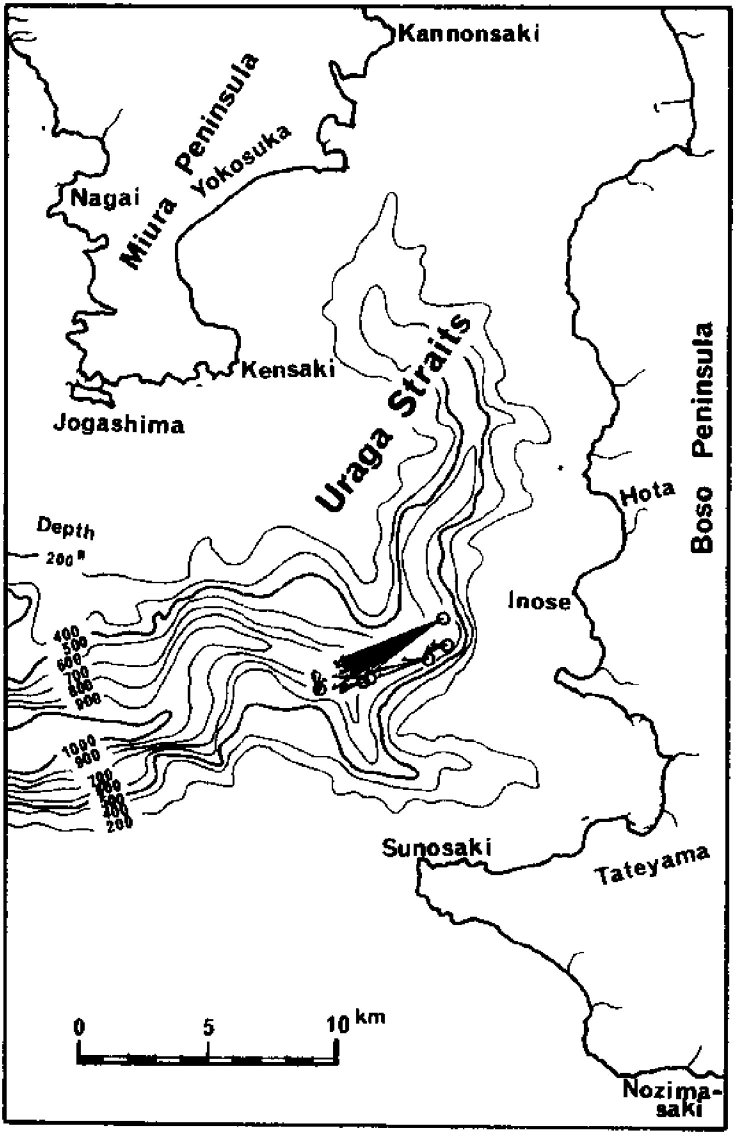

Figure 9. Movement of the immature golden king crab in Uraga Straits, 1979. Open circles denote the releasing stations from February to May, and arrows show inferred migration route of the recaptured crabs.

release site, off Inose. The remaining crabs were found in the vicinity of the released location (Figure 9).

Data were insufficient to examine the seasonal and spawning migration relating to size, sex and maturity of the crabs. However, the results indicate that both young and adult golden king crabs do not reveal an extensive migration in the Tokai region. However, the change in the CPUE, sex ratio and maturity ratio indicate the spawning aggregation occurs with season and depth.

Discussion

The results indicate that there is a seasonal reproductive cycle in the golden king crab, despite its indistinctness. Further, the data demonstrate that the spawning takes place throughout a year, revealing a type of asynchronous spawning. Based on a two-month survey in the West Kamchatka in Okhotsk Sea, Rodin (1970) concluded that the molting, copulation and spawning of L. aequispina occur from late August through mid September. This short spawning period contrasts the longer period found in the Tokai region. The discrepancy in spawning duration between these two areas cannot be explained. Rodin did not mention the reproductive conditions in other months. Somerton (1981) suggests an asynchronous spawning of L. couesi, a rlative of L. aequispina, in the Gulf of Alaska.

Rodin (1970) presented data on carapace width, carapace length and fecundity for the golden king crabs of size range 10.6-14.8 cm CW in the West Kamchatka. From Rodin's data, we can derive empirically the CW-CL relationship: $CW = 0.76 + 0.97\ CL$ $(r=0.97)$. Similarly, based on Rodin's data, we obtain a fecundity-carapace width relationship, with an equation $E = 2,065\ CW - 14,236$ $(r=0.53)$. The comparison of the CW-CL equation between Rodin's and ours (Hiramoto and Sato 1970; Suzuki and Sawada 1978) reveals insignificant difference in morphometry between the West Kamchatka and the Tokai region. Unlikely, an apparent difference is seen in the fecundity equation. However, it is inappropriate to draw any conclusion from the comparison because of a wide variability in egg count data in the two studies.

Rodin (1970) claimed that in the West Kamchatka the habitat range is definitely separated between the adult crabs (females, 12.5-13.0 cm CW; males, 17.0-17.5 cm CW) and young crabs (females, 6.0-6.5 cm CW; males, 7.5-8.0 cm CW): adults are concentrated in the southern area around 53-55°N (250-800 m), whereas young crabs predominated in the northern area around 55-57°N (400-450 m). This means that in the West Kamchatka the young crab must recruit periodically to the fishing ground from a distant area. On the relation between spatial segregation and reproduction, he presumes that the pelagic larvae of the golden king crabs released from the spawning ground in the southern area are transported to the northern area by a northward current along the Kamchatka Peninsula. The larvae settle there and when metamorphosis advances, the youngs commence a southward migration. Adults do not reveal the seasonal migration. Unlike the West Kamchatka, in the Tokai region both mature and immature crabs (5-22 cm CW) concomitantly occurred in a same area and the extent of migration was very limited. This suggests that both young and adult golden king crabs do not reveal an extensive migration. The deep water of the habitat of the golden king crabs in the Tokai region is strongly influenced by the intermediate water of the North Pacific as defined by temperature, salinity and oxygen (Ishino et al. 1981; Ohta 1983), which stems from the Subarctic water. This water is sharply distinguished from the upper water which is associated with the warm Kuroshio current. It is inconceivable that the larvae of the golden king crabs rise to the upper layer where the northeastward current prevailed and temperature is inevitably high. Thus, the dispersion of the larvae in the study area is unlikely. At present, the selectivity of the crab pot limits the obtainable minimum crab size and there is no incidental catch record of the small crabs by deep-sea trawl. Although the migration pattern of the entire life span is not known because of inadequate information on larvae and juvenile forms , it is thought that the golden king crabs in the Tokai region complete their life cycle in a relatively confined area.

The temperature of the habitat for the golden king crabs in the study area is between 3-5°C(Ishino et al. 1981; Ohta 1983), which is 1-5°C higher than the reported temperature (0.2-2°C) in the West Kamchatka (Rodin 1970). Since the temperature affects the growth and reproduction processes, it is presumable that such a difference of temperature will cause the changes in egg development, spawning and hatching periods between the two areas. It is likely that the higher temperature in the Tokai region derives faster development and facilitated growth of the golden king crab than those in the West Kamchatka. However, available data are not sufficient to prove this assumption.

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I wish to express my gratitude to Dr. T. Nishiyama, Institute of Marine Science, University of Alaska and Dr. S. C. Jewett, North Pacific Research, Alaska, for their kind reading of the manuscript.

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ABSTRACT

The geographic distribution of the golden king crab, Lithodes aequispina, extends from the Okhotsk coast of Hokkaido Island to Hyuganada of Kyushu Island in Japan. However, commercial concentrations exist on the ocean floor at depths of 450-850 m from the northern to central Pacific coast of Honshu Island.

In 1968-1969, the commercial fishery started in the Tokai region covering the area off Boso Peninsula, Uraga Straits, Sagami Bay and Suruga Bay. A substantial fishery existed between 1977 and 1980 with the highest landing of 126 mt in 1977-1978, but thereafter the the landing drastically declined. The resource appears to have been heavily exploited within a few years. The stock size of the crabs in the Tokai region appears to be marginal, and the recruitment and emigration do not seem intensive.

The carapace width ranged from 8.3 to 19.2 cm in females and from 8.0 to 22.0 cm in males. Carapace width (CW, cm) and length (CL, cm) of females and males combined from off Boso Peninsula were regressed with a linear equation (size range 6.6-20.4 cm CW; N=485; r=0.98):

$$CW = -0.48 + 1.06\ CL \qquad (1)$$

A similar linear equation was obtained for the Suruga Bay samples (size range 7.3-20.5 cm CW; N=192; r=0.99):

$$CW = -0.85 + 1.11\ CL \qquad (2)$$

The regression equation for females(6.6-18.1 cm CW) off the Boso Peninsula samples is shown as (N=303; r=0.97):

$$CW = -0.69 + 0.96\ CL \qquad (3)$$

and for males (7.7-20.4 cm CW) as (N=182; r=0.99):

$$CW = -0.68 + 1.09\ CL \qquad (4)$$

Thus, male is slightly wider than female in shape, and statistical difference is significant.

The body weight (BW, kg) of the crab is expressed as a power function of carapace width (CW, cm):

$$\text{Female:}\ BW = 8.03 \times 10^{-4}\ CW^{2.83} \qquad (N=90) \qquad (5)$$

$$\text{Male:}\ BW = 5.62 \times 10^{-4}\ CW^{2.98} \qquad (N=102) \qquad (6)$$

The minimum size of females carrying in eggs was 10.5 cm CW. Fifteen percent of the females at 12.6 cm CW and 60 percent of the females at 13.6 cm CW were mature. Thus, the 50 percent maturity can be assigned to 12-13 cm CW.

The golden king crab shows a type of asynchronous spawning. Although a seasonal cycle is indistinct, prominent periods were evident, i.e., copulation from July through October, incubation from

October through February, and hatching from March through June. The results suggest that the maturing females aggregate with males for mating during copulation period, and tend to segregate from males during incubation and hatching periods. It is also presumable that the maturing crabs move to shallower water from deeper water, separating from immatures.

The number of eggs per female tended to increase with crab size from 9,500 on a female 12.9 cm CW to 30,100 on a 15.7 cm CW female. The egg count at the new egg stage (E) is regressed to carapace width (CW, cm) by a linear equation (N=12; r=0.65):

$$E = 3{,}998\ CW - 35{,}200 \qquad (7)$$

In 1978 and 1979, 665 golden king crabs were tagged and released in Uraga Straits. In 1978, a total of 151 crabs with mean size 10.6-12.8 cm CW were released, of which 24 crabs were recaptured (15.9 %), and in 1979, 515 crabs (4.5-18.1 cm CW, mean 9.95 cm) were released, and of which 57 crabs being recaptured (11.1 %). Some of recaptured crabs were found within 5-10 km southwestward of release area, and of which others were found in the vicinity of the released location. The results indicate that both young and adult golden king crabs do not reveal an extensive migration in the Tokai region.

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On food composition of the deep-water crab species *Lithodes aequispina* Benedict and *Chionoecetes tanneri* Rathbun in the Bering and Okhotsk seas

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Lithodes aequispina occurs from the central part of the Bering Sea to the Okhotsk coast of Sakhalin and to the north part of the Pacific coast of Honshu at depths between 185m and 730m. *Chionoecetes tanneri* occurs off Bering Island and from Washington to southern California at depths between 50m (usually 450m) and 1910m (Vinogradov, 1950).

In the Bering Sea, we found both species inhabiting the slope. the first one occurred at 300-700m and the second at 500-700m depths. There are few grounds propitious for trawling (Kotenev, 1965, 1970), so the possibility of finding commercial concentrations of these species is not great. Catch per trawl seldom exceeds 10-20 specimens. Perhaps the narrowness of the slope prevents formation of considerable concentrations of these crabs in the Bering Sea (Slizkin, 1974). Both species are found in the western part of the sea, but their feeding areas are generally separated: *C. tanneri* is present along all the Koryak coast, but *L. aequispina* mainly appears to the south of Cape Navarin. A rather numerous population of *L. aequispina* exists in the Sea of Okhotsk where the slope is less steep and more expanded (Rodin, 1970; Hiramoto and Sato, 1970).

Data on feeding of deep-sea crabs are not available in the literature. The material used in this paper was collected by the authors in the west and central parts of the Bering Sea in October of 1972 (R/V *Pelamida*) and in the central part of the Sea of Okhotsk in 1975, 1976, and 1977 (R/Vs *Pelamida*, *Adler* and *Gerakl*). Seventy-seven specimens of *L. aequispina* (27 from the Bering Sea, 39 from the Sea of Okhotsk and 11 from a region off the Kuril Islands) and 57 specimens of *C. tanneri* from the Bering Sea were studied. We looked at stomach and intestine contents of the crabs and calculated frequency indices of food items (by occurrence and domination), taking into account non-empty stomachs. The contents were weighed and total indices of fullness (content of stomach per body weight) in ^{0}/ooo were also calculated.

The food of both species consisted largely of bottom animals (Table I): echinoderms (mostly Ophiuroidea), bottom crustaceans (Amphipoda and Decapoda), polychaetes and, off the North Kurils, also hydroids; molluscs and fish and plant remains were of less importance.

In the Bering Sea, stomachs of crabs studied contained *Ophiura leptoctenia* (Ophiuroidea); *Strongylocentrotus droebachiensis* (Echinoides); remains of Paguridae and Macrura Natantia; bivalves: *Crenella* sp., *Dacrydium* sp. (family Mytilidae), *Venericardia* sp. (Carditidae), animals of family Ungulinidae; classes Solenogastres and Scaphopoda; foraminifers *Rhabdommina* sp.; and diatoms (mostly *Coscinodiscus* sp.).

The food composition of *L. aequispina* in the Sea of Okhotsk has been studied in the most detail. The stomachs there contained bivalves of family Nuculidae (maybe *Nucula tenuis*), gastropods of families Trochidae and Naticidae and Buccinidae (young *Buccinum* sp.). We found tentacular hooks of Teuthoidea (squid); hooks and a beak of *Gonatopsis* sp. were found in the stomachs of *Paralithodes camtschatica*. Teuthoidea had not previously been registered in the food of crabs.

Among the crustaceans were amphipods of families Photidae, Ischyroceridae, Aoridae (*Lembos arcticus*), Lysianassidae, Calliopiidae, Hyperiidae and of suborder Caprellidea; isopods of family Authuridae; *Scalpellum* sp. (Cirripedia); and majid and lithodid crabs (fragments of carapace and mouth parts).

Worms were represented by carnivorous polychaetes of families Glyceridae, Eunicidae, Oweniidae and Aphroditidae.

The presence of Pogonophora and deep-sea fishes (fragments of skeletons) in the stomachs of *L. aequispina* is an interesting peculiarity of the feeding habits of this crab.

Food spectra of the two crab species are different in the same region (Table I). In the Bering Sea, *L. aequispina* feeds largely on ophiuroids, sponges and plant remains, but the food of *C. tanneri* consists of polychaetes, bottom crustaceans and ophiuroids. Both crabs were found together at the only trawl station to the south of Cape Navarin at 700m depth. The crabs were mainly adult; their carapaces were of less than 120mm and 100mm wide, respectively. The principal food objects of the two species also appeared to be different here (Fig. 1). *L. aequispina* fed largely on sponges and fish and plant remains but stomachs of *C. tanneri* contained polychaetes, fragments of crustaceans (mainly decapods), and remains of fishes, molluscs and echinoderms (mainly Ophiuroidea).

Data on feeding of *L. aequispina* are available from a region to the south of Cape Navarin in the Bering Sea at depths between 300m and 700m. More data were obtained on feeding habits of juveniles (nine males and 10 females); not many adults were studied. Fig. 2 represents the food composition of *L. aequispina* of different sizes.

Juveniles and adults kept away from each other. At the depth of 510m, the juveniles (carapaces of 9-33mm wide) fed mainly on ophiuroids and less on sponges. Other food objects were unimportant, although some of them (hydroids, plant remains, foraminifers, polychaetes, bivalves, amphipods) occurred rather frequently. Stomachs often (frequency index of 95 percent) contained sand and silt. The instantaneous fullness of stomachs was very high: the mean index was 25 $^{o}/_{ooo}$ (the

Table I. Food composition of *Lithodes aequispina* and *Chionoecetes tanneri* in the Bering Sea and the Sea of Okhotsk.

Components of Food	Bering Sea 300-700m depth *L. aequispina* 9-164mm CW		 500-720m depth *C. tanneri* 18-144mm CW		Sea of Okhotsk 240-760m depth *L. aequispina* 36-162mm CW		North Kuril 190-395m depth *L. aequispina* 62-225mm CW	
	FI	DI	FI	DI	FI	DI	FI	DI
Foraminifera	14.8	--	10.2	--	--	--	--	--
Spongia	63.0	11.1	--	--	25.0	--	27.3	--
Hydroidea	33.3	--	1.7	--	15.6	2.5	63.6	33.3
Actiniaria	--	--	--	--	3.1	2.5	--	--
Mollusca, total	22.2	1.8	13.6	4.9	40.6	5.0	54.5	--
Solenogastres	--	--	1.7	1.7	--	--	--	--
Gastropoda	--	--	3.4	1.7	6.3	--	18.2	--
Scaphopoda	--	--	3.4	1.0	--	--	--	--
Bivalvia	18.5	1.8	5.1	0.5	31.3	5.0	54.5	--
Teuthoidea	--	--	--	--	9.4	--	--	--
Unidentified	3.7	--	6.8	--	3.1	--	--	--
Vermes, total	25.9	--	76.3	36.3	25.0	--	54.5	--
Polychaeta	25.9	--	74.6	36.3	25.0	--	54.5	--
Others	--	--	1.7	--	--	--	--	--
Crustacea, total	22.2	3.7	50.8	23.2	62.6	32.5	63.6	--
Cirripedia	--	--	3.4	--	21.8	2.5	9.1	--
Amphipoda	14.8	--	27.1	12.4	15.6	7.5	45.4	--
Isopoda	--	--	--	--	12.5	5.0	--	--
Decapoda	7.4	--	13.6	5.9	21.8	17.5	--	--
Unidentified	11.1	3.7	15.2	4.9	3.1	--	18.2	--
Echinodermata, total	77.9	40.7	71.2	17.8	37.5	25.0	72.7	44.4
Ophiuroidea	77.9	40.7	40.7	16.9	34.4	25.0	72.7	44.4
Crinoidea	--	--	--	--	3.1	--	--	--
Echinoidea	3.7	--	5.1	--	--	--	--	--
Unidentified	--	--	32.2	0.9	--	--	--	--
Pogonophora	--	--	--	--	15.6	5.0	--	--
Eggs (laying)	--	--	13.6	3.4	--	--	18.2	--
Fish, bones/scales	14.8	9.3	15.2	5.1	12.5	--	18.2	--
Plant remains	40.7	7.4	--	--	--	--	--	--
Bird feather	3.7	--	--	--	--	--	--	--
Digested masses	63.0	25.9	30.5	7.6	53.1	27.5	45.4	22.2
Sand, silt	70.5	--	18.6	1.7	25.0	--	45.4	--
General Index of Stomach fullness, °/ooo	18.0		5.6		4.0		--	
Non-empty Stomachs, ex.	27		59		32		11	
Empty Stomachs (%)	0		0		17.9		0	

CW = carapace width

FI = frequency index (%)

DI = dominance index (%)

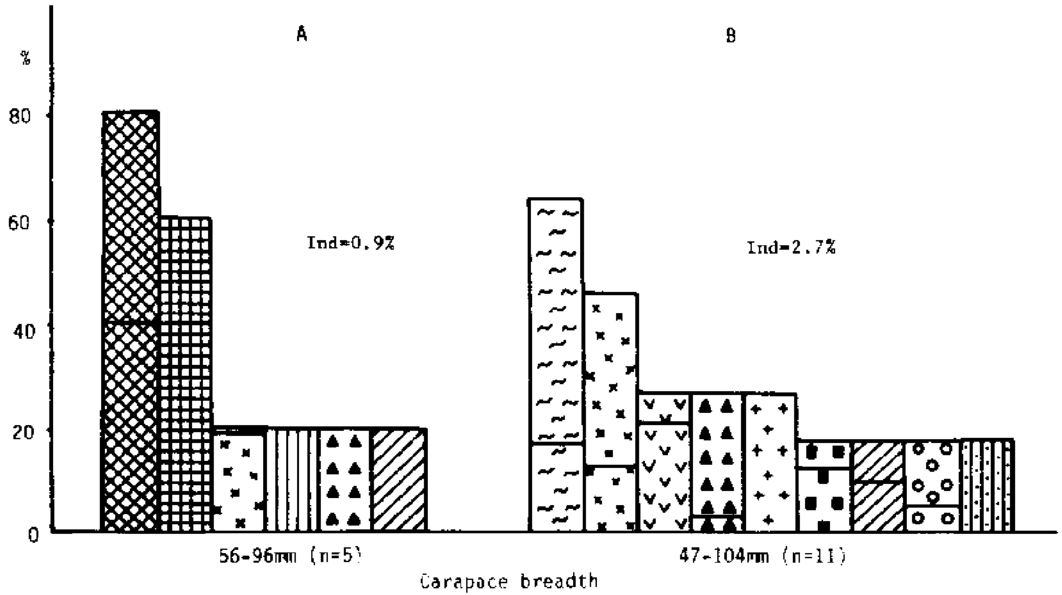

Figure 1 The food composition of *Lithodes aequispina* (A) and *Chionoecetes tanneri* (B) at the south of Cape Navarin at 700m depth. Height of columns indicate the frequency of occurrence (in %); lower parts represent the frequency of dominance (in %). See also Figure 1A.

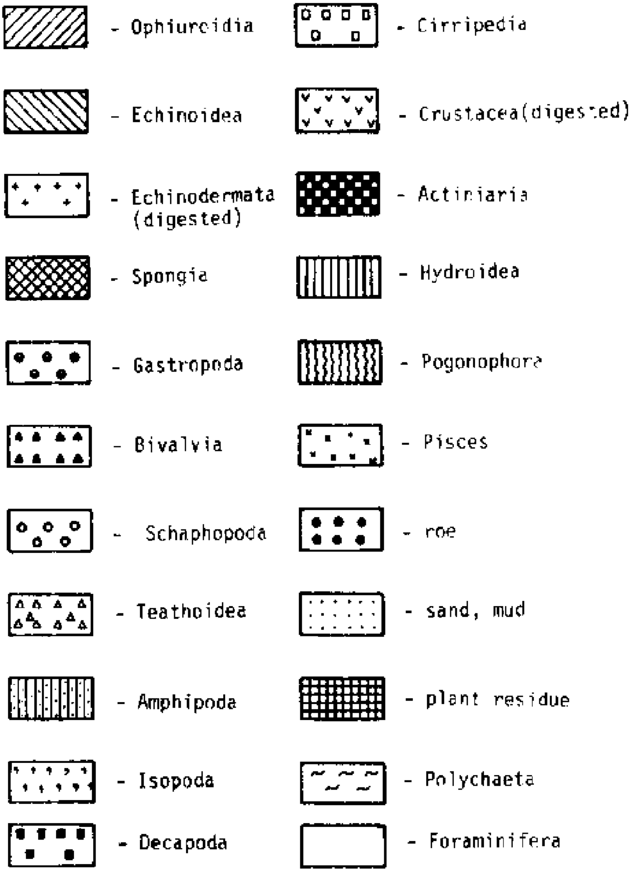

Figure 1A The food composition of different size groups of crabs (key to Figures 1-4).

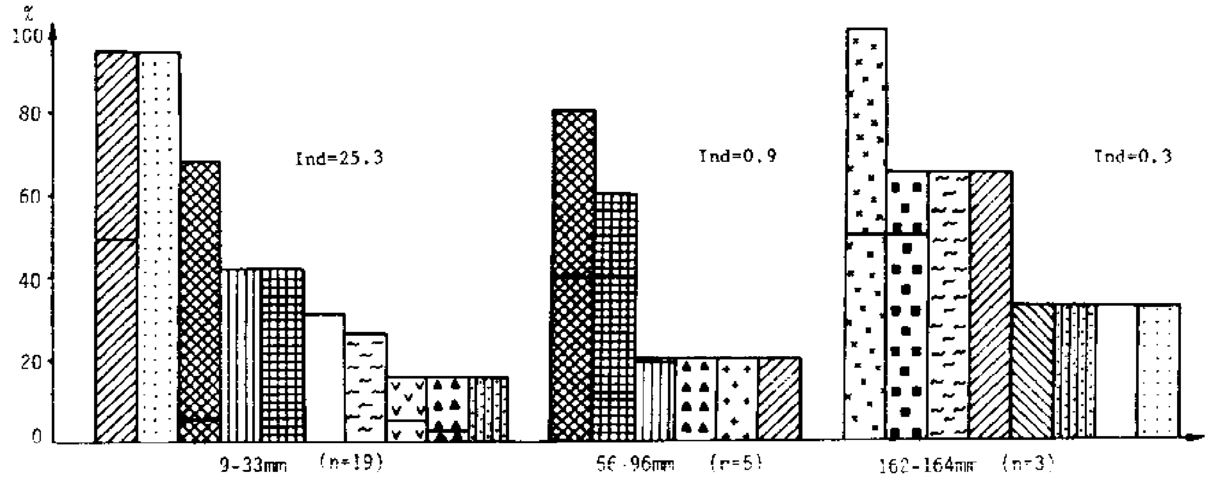

Figure 2 The food composition of *Lithodes aequispina* of different size groups in the Bering Sea to the south of Cape Navarin. For key, see Figures 1 and 1A.

maximum value was ^{0}/ooo). Five crabs (three males and two females) taken from the depth of 700m had carapaces wider (56-96mm) and food spectra narrower: stomachs contained primarily sponges and plant remains, followed by remains of fishes. The crabs were very underfed; the average index of stomach fullness was 0.9 ^{0}/ooo. The main forage items found in the stomachs of three large males (carapace width 162-164mm) taken from 300m depth were fish remains and ophiuroids. These crabs (as well as juveniles) fed on a wide variety of organisms (Fig. 2), but the intensity of feeding was the lowest; the index was 0.3 ^{0}/ooo.

Thus, the different size groups of *L. aequispina* in the Bering Sea inhabit different depths, and the most important sources of their food differ. Stomachs of juveniles, adults (carapace width 56-96mm) and large males chiefly contained ophiuroids, sponges and fish remains, respectively. Irrespective of crab size, the food spectrum of *L. aequispina* is wider, the lesser the depth it inhabits.

We have data on feeding of *C. tanneri* in the Bering Sea from the Olyutorskiy Zaliv, off the Koryak coast and from the central part of the sea to the south of Cape Navarin. Figure 3 represents the food composition of some size groups of this species in different regions. Off the Olyutorskiy Zaliv, juveniles were found at 500m depth where they exhibited intensive feeding, mainly on polychaetes, followed by amphipods and ophiuroids (the mean index of stomach fullness was 15 ^{0}/ooo and the maximum, 51 ^{0}/ooo). At the same station, adult *C. tanneri* (carapace width 78-97mm) fed chiefly on ophiuroids and to a lesser extent on amphipods; polychaetes occurred in the stomachs frequently but in small amounts. Adult crabs (carapace width 102-144mm) fed on ophiuroids, decapods and polychaetes. Indices of stomach fullness were low: 1.7 and 3.3 ^{0}/ooo, respectively.

We examined the food of adult *C. tanneri* (carapace width 48-94mm) taken from 720m depth off the Koryak coast; the chief constituents in the diet were polychaetes and to a lesser degree echinoderms, roe and molluscs. The stomachs were poorly filled, too (the index was 2.4 ^{0}/ooo).

Adult crabs (carapace width 47-87mm) taken to the south of Cape Navarin from 700m depth fed on polychaetes, decapods and also on fish remains and molluscs; the mean index was low: 3.3 ^{0}/ooo. Remains of crustaceans, polychaetes, ophiuroids and fishes were found in the stomachs of two large crabs; the indices were even lower, 1.2 ^{0}/ooo.

Juvenile *C. tanneri* were found only on the slope off the Olyutorskiy Zaliv, and adult crabs occurred all along the Koryak coast. Food spectra of adults (especially of large crabs) were wider than those of the young.

In the central part of the Sea of Okhotsk, *L. aequispina* fed on bottom crustaceans (decapods, amphipods, cirripedians and isopods), echinoderms (mainly ophiuroids) and molluscs (mainly bivalves) (Table I). Juveniles (carapace width 36-61mm) were found at 340-370m depth, where they fed largely on cirripedians and decapods (Fig. 4). Food spectra of adult crabs (73-171mm) taken from 240-760m depth were much wider: they fed on crustaceans, ophiuroids and molluscs. Indices of stomach fullness for crabs with carapaces 73-118mm and 127-171mm wide were medium (4.5 ^{0}/ooo and 7.5 ^{0}/ooo, respectively) and exceeded those for crabs of similar sizes from the Bering Sea.

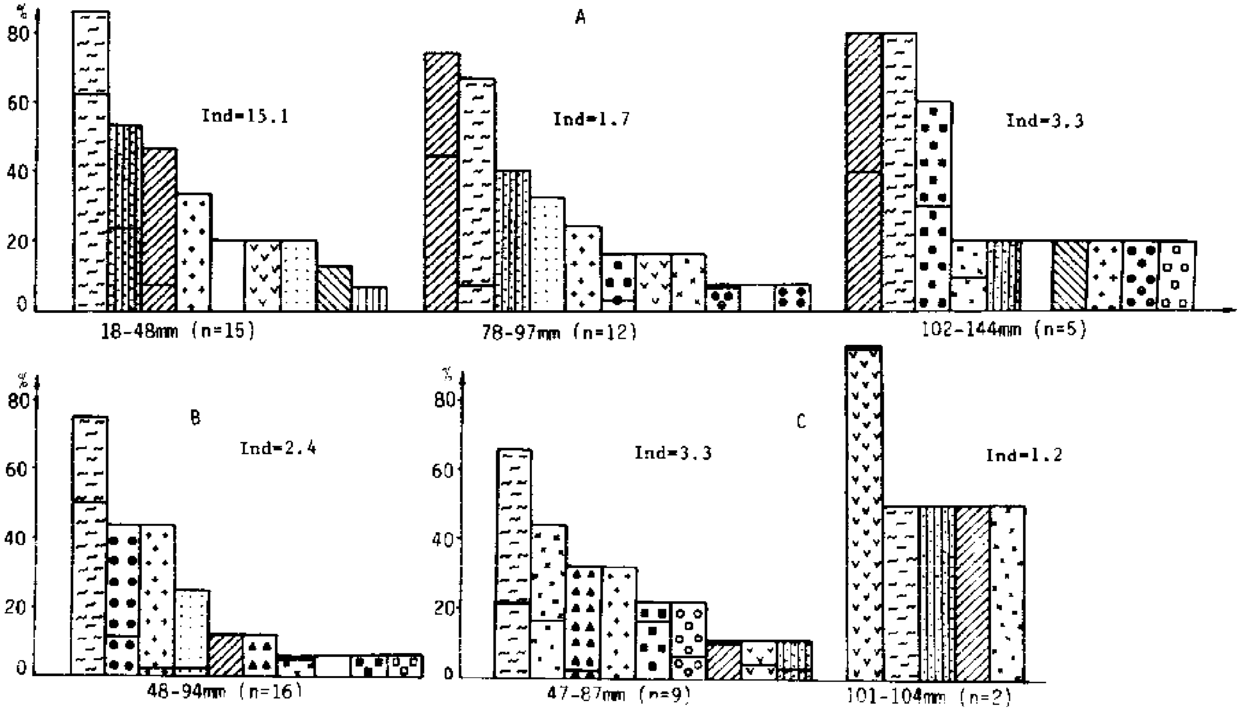

Figure 3 The food composition of Chionoecetes tanneri in different size groups from different areas of the Bering Sea: (a) Olyutorskiy Zaliv; (b) off the Koryak coast; (c) to the south of Cape Navarin. For key, see Figures 1 and 1A.

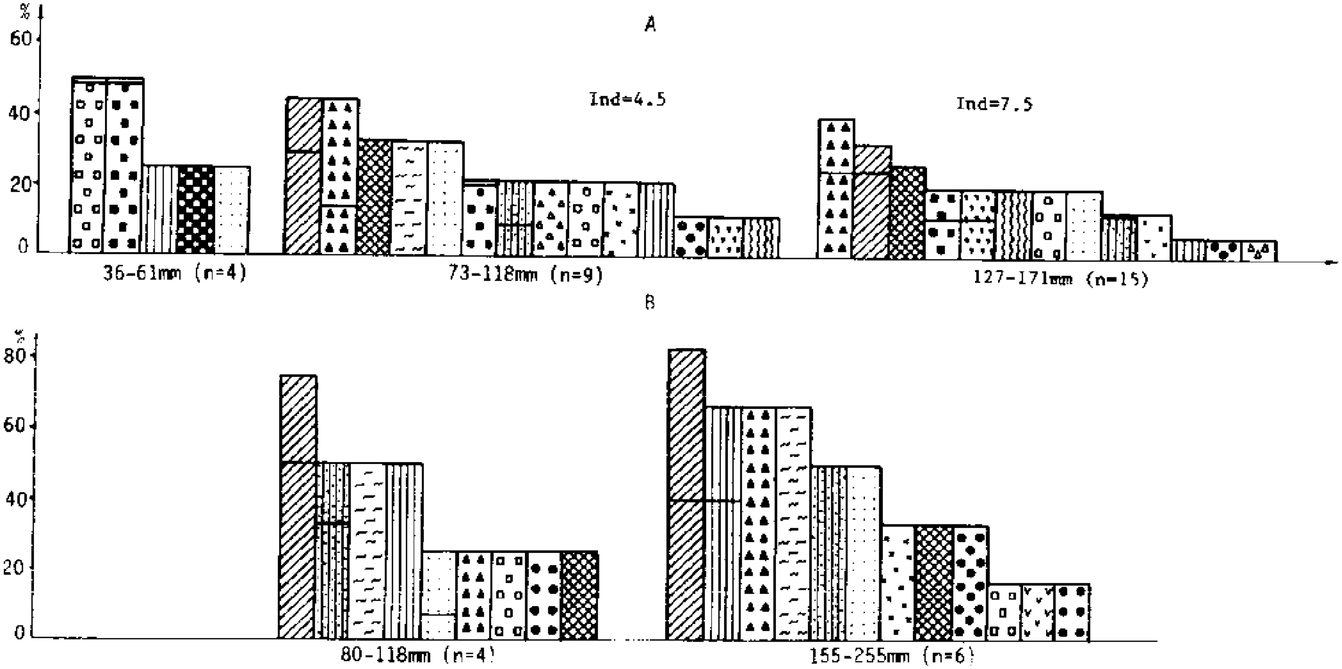

Figure 4 The food composition of Lithodes aequispina of different size groups in the Sea of Okhotsk. For key, see Figures 1 and 1A.

Off the North Kurils, *L. aequispina* fed chiefly on ophiuroids and hydroids (Table I). Figure 4 represents the food composition of different size groups of crabs. Hydroids, sponges and ophiuroids were found in a stomach of a small crab (62mm). Adult crabs with carapace 80-118mm wide fed mainly on ophiuroids and amphipods, whereas crabs with carapace 155-225mm wide fed on ophiuroids, hydroids and also on bivalves and polychaetes.

Conclusions

1. The food composition of *L. aequispina* in the regions studied was rather similar; ophiuroids were the important constituent of the diet everywhere. Moreover, sponges and plant remains ranked high as forage in the Bering Sea, bottom crustaceans in the Sea of Okhotsk, and hydroids off the North Kurils.

2. The main food organisms of adult *C. tanneri* were different in different regions: ophiuroids in the Olyutorskiy Zaliv, polychaetes off the Koryak coast, polychaetes and decapods in the region to the south of Cape Navarin.

3. Juveniles of the crab species studied were restricted to a narrower range of depths, as compared with adults. Young occurred at the depth of about 500m in the Bering Sea and between 350m and 400m in the Sea of Okhotsk.

4. It was noted that in both the Bering Sea and the Sea of Okhotsk, the food spectra of the two species became, as a rule, wider as crabs grew.

5. Neither species showed competition for food because they were separated either spatially or on the basis of the main forage items they fed on. They do not compete either with *Paralithodes platypus*, *Chionoecetes opilio* or *C. bairdi*, which also inhabit the western part of the Bering Sea but form main concentrations on the shelf and don't penetrate deeper than 300m.

6. In the Sea of Okhotsk, *Chionocetes angulatus* occurs at the same depth as *L. aequispina*. Data on feeding of the former are not available in literature, but it is safe to say that the two species don't compete for food, as they are separated in space.

7. In the Bering Sea, juveniles of studied crabs are characterized by high indices of stomach fullness: 25 ^{0}/ooo (*L. aequispina*) and 15 ^{0}/ooo (*C. tanneri*); adult crabs of all sizes feed poorly: main indices of stomach fullness vary from 0.3 to 0.9 ^{0}/ooo (*L. aequispina*) and from 1.2 to 3.3 ^{0}/ooo (*C. tanneri*) in different regions.

Data on stomach fullness of adult crabs only are available from the central part of the Sea of Okhotsk; the indices are medium (4.5-7.5 ^{0}/ooo) and exceed those for crabs of about the same size from the Bering Sea.

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SESSION III

MORTALITY FACTORS AND POPULATION

Proc. Int. King Crab Symp.
Jan. 1985, Anchorage, Ak.

A preliminary report on the diseases of Alaska king crabs

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Introduction

In June, 1978, 10 red king crabs, *Paralithodes camtschatica*, collected in Kalsin Bay, Kodiak Island, Alaska, were examined in a search for infectious diseases or pathological conditions. Except for a parasitic dinoflagellate on the gills of one crab, the major organ systems of all crabs were relatively normal and no infectious disease agents were observed.

When it became obvious in 1982 that substantial mortalities were occurring in some king crab populations, we initiated a substantial effort to examine as many lithodid crabs from as many areas as possible within the constraints of collection, processing, and microscopic examination limitations.

Materials and Methods

Crabs were obtained from a variety of sources and locations. Most were collected during the annual crab-groundfish surveys of the NMFS Kodiak Laboratory, some during tagging cruises, others were obtained from commercial fishermen, ADF&G personnel (Kodiak and Homer), and some were collected by Kodiak Laboratory personnel in crab pots in the Kodiak area. The majority of crabs were necropsied aboard ship, where observations on gross pathology were recorded and small random samples of all major organ systems were excised and fixed in Helly's fixative, then transported to our laboratory in Washington for processing and microscopic study. Several collections were sent live from Kodiak and Homer, and necropsied and processed in Washington. Tissues from a number of crabs were also fixed in fixative suitable for electron microscopy (Hawkes and Stehr 1982). Tissues were processed and examined by transmission electron microscopy.

Between early 1982 and the summer of 1984, a total of 376 lithodid crabs have been necropsied, processed and examined (Table 1) (115 *P. platypus*, 199 *P. camtschatica*, 62 *Lithodes aequispina*). Approximately 70 *L. aequispina* collected in the summer of 1984 have not been processed. It quickly became obvious that all three species harbor infectious disease organisms that are probably lethal. Furthermore, diseased crabs were collected in all areas sampled from Cook Inlet and Bristol Bay to the Pribilofs and the western Aleutians.

Results

Virus diseases

Red king crab. One of 5 red king crabs (RKC) from Kodiak necropsied in March, 1982, had a few, lightly to moderately hypertrophied nuclei and chromatin margination in the antennal gland and was diagnosed as a possible early or light viral infection. One of 44 crabs collected in the fall of 1982 was also diagnosed as having a possible light viral infection of the antennal gland.

Prevalence of the putative virus disease of the antennal gland of RKC's rose rather dramatically in early 1983 with 14 of 72 (19.3%) of the crabs with antennal gland nuclear hypertrophy. Additionally, infections were typically heavier, with extensive areas of the antennal gland and bladder destroyed. Prevalences were 3 of 36 in Bristol Bay, 8/29 in Cook Inlet and 3/7 from the eastern Aleutians (Egg Island). A significant number (5) was also evident in crabs collected from Bristol Bay in the spring of 1984. No suspected viral infections were present in Kodiak crabs collected in the summer (6) of 1983, winter (5) of 1984 and spring (3) of 1984 or eastern Aleutian crabs of fall (3), 1983. Single infections were diagnosed in Bering Sea crabs of fall (44) 1982 and summer (7) 1983 and Kodiak crabs of winter (5) 1982. Overall, the prevalence was 4.1% (2/49) in 1982, 17% (15/88) in 1983, and 8.1% (5/62) in 1984.

We have designated the disease of the antennal gland and bladder of the RKC as a putative viral disease because we have not yet confirmed its viral nature by transmission electron microscopy. We are confident that it is caused by a virus because of the characteristic nuclear hypertrophy, coarsely dispersed or, in advanced infections, emarginated chromatin.

Blue king crab. In early 1983, 21 blue king crabs (BKC) were collected in the Pribilofs, 7 of which (33%) had massive destruction of the bladder and antennal gland epithelium. There was marked hypertrophy of the nuclei, chromatin emargination and occasional nuclear inclusion bodies. Fortuitously, tissues from one of the affected crabs was fixed in electron microscopy fixative, thus we were able to confirm that the disease was caused by a Herpes-type virus. The few BKC's collected near St. Matthew Island in the spring (6) and summer (2) of 1983 did not harbor the virus, but 7 of 44 (15.9%) collected in the summer of 1984 were infected. Only 2 of 39 (5.1%) crabs from the Bering Sea in the summer of 1983 had recognizable virus infections of the bladder and antennal gland.

Golden king crab. The golden king crab (GKC) also harbors a putative viral infection of the bladder and antennal gland that, at the light

Table 1 - Disease prevalences by location and quarter.

		BLUE	KING			RED	KING			GOLD	KING		
LOCATION	QUAR	R	M	V	T	R	M	V	T	R	M	V	T
Bristol Bay	F82					2	3	1	44				
	W83						2	3	36				
	Su83							1	7				
	Sp84						1	5	54				
	total					2	6	10	141				
Cook Inlet	W83							8	29				
E. Aleutians	F83								3				
	W83							3	7				
	total							3	10				
Kodiak	W82							1	5				
	Su83								6				
	W84								5				
	total							1	16				
Olga Bay	Sp84				3				3				
Pribilof Is.	W83		1	7	21								
	Su83			2	39								
	total		1	9	60								
St. Matthew	Sp83		3		6								
	Su83		1		2								
	Su84			7	44								
	total		4	7	52								
Pribilof Cany.	W83									2		4	10
	F83											1	2
	total									2		5	12
Zemchug Cany.	Sp83									4			18
	Su83									4	1	2	10
	total									8	1	2	28
W. Aleutians	W83									4		1	8
	Su84									2	1		14
	total									6	1		22

R = Rhizocephalan Diseases
M = Microsporidan Diseases
V = Viral or Putative Viral Diseases
T = Total
W = Jan., Feb. and Mar.
Sp = Apr., May and Jun.
Su = Jul., Aug. and Sep.
F = Oct., Nov. and Dec.

microscope level, appears identical to that of the blue king crab. Four of 10 crabs from the shelf collected in early 1983 were infected, 1 of 2 from Pribilof Canyon in the fall of 1983, none of 18 from Zemchug Canyon were infected in the spring of 1983, but 2 of 10 collected in the summer of 1983 contained the putative virus. One of 8 collected in the western Aleutians in early 1983 was infected, but none of 14 examined from the same area collected in summer 1984 contained the characteristic hypertrophied nuclei, nuclear inclusions and emarginated chromatin. However, an additional 70 crabs from that collection have not yet been processed and examined.

Microsporidan diseases

Alaskan crab biologists have long been aware of a grossly recognizable abnormal condition in lithodid crabs which they call "cottage cheese disease" because of the white, cheesey appearance of much of the viscera. Though most obvious when the carapace is removed, live, heavily infected crabs can be recognized by the whitish discoloration of the abdominal tissues seen through the thin cuticle of the underside of the abdomen.

Red king crab. Three of 44 RKC's collected in Bristol Bay in the fall of 1982 had massive accumulations of the cheesey material in the viscera. Microscopical examination revealed that the material consisted of huge masses of developing spores and spores of a microsporidan. Eight spores developed in a pansporoblast, characteristic of the family Thelohanidae. Electron microscopy confirmed this and also enabled us to identify it as an undescribed species of the genus Thelohania. In the winter of 1983, 2 of 36 (5.6%) and 1 of 54 (1.9%) in the spring of 1984 were heavily infected with the same parasite. Virtually all organ systems were invaded, with much of the cellular constituents of the hepatopancreas, ovary, tegmental glands and wall of the digestive system replaced by the proliferating parasites.

Blue king crab. An apparently different, undescribed species of Thelohania has been found and studied at the light and electron microscopical level in the blue king crab from the Pribilof Islands and St. Matthew Island. One of 21 BKC's collected in early 1983 from the Pribilofs was infected but none were detected in the summer. Three of 6 and 1 of 2 BKC's collected from St. Matthew in the spring and summer of 1983 were infected, but none of the 44 collected in the summer of 1983 harbored the parasite.

The gross, light microscopical and ultrastructural appearance and progression of the disease is identical to that of the Thelohania sp. in RKC's. As in the RKC, heavily infected crabs could be recognized grossly to have the disease. Strangely, we have never found a light infection in either species of Paralithodes.

Golden king crab. One of 10 Lithodes aequispina collected in Zemchug Canyon in the summer of 1983 was diagnosed grossly as having "cottage cheese disease". Light microscopical examination revealed a heavy infection of muscle, both skeletal and cardiac, tissue throughout the crab by a microsporidan belonging to the family Nosematidae. Lack of material suitable for electron microscopy has prevented us from establishing the genus to which it belongs, but it is also almost certainly an undescribed species. Subsequently, 1 of 14 crabs examined to date had a widespread but earlier infection of the same microsporidan. It was the only infected crab studied that was not diagnosed grossly, probably because the infection, though widespread, had not reached mature sporulation stages in most infected muscle.

Although confined largely to muscle, this disease is probably also fatal because cardiac muscle of the heart is heavily invaded and destroyed.

Rhizocephalan diseases

Red king crab. Infection of RKC's by the rhizocephalan Briarosaccus callosum has been observed in only two crabs, both sent to us from Homer, Alaska, in the fall of 1982. The pathological effects and progression of the disease appears identical to that in golden king crabs. We have never observed Briarosaccus infections in blue king crabs, though they occur at high prevalences in BKC's in certain areas of Alaska (T. Myers and C. Hawkes, personal communication).

Golden king crab. The GKC is apparently much more susceptible to infection than the BKC or RKC in the areas we have studied. Prevalences have ranged from 17% to 29% in our limited random samples, and have occurred in all areas except Pribilof Canyon where only 2 crabs were collected. Although most infections can be recognized grossly by the conspicuous externa of the parasite, we've had several, probably early, infections in which neither an externa nor a scar from a previous externa was present.

Virtually all organs of the crab are invaded by the proliferating rootlets of the rhizocephalan interna. The brain, thoracic ganglion and major nerves are typically invaded, the ovary is usually invaded but is undeveloped or the developing ova are degenerate even without invasion, the hepatopancreas is heavily involved and large areas of the wall of the digestive tract contain numerous rootlets.

Discussion

Although several other infectious agents, trematode metacercariae, larval acanthocephalans, parasitic dinoflagellates on the gills, and a variety of idiopathic lesions occurred at low prevalences in the lithodid crabs examined, only the viral, microsporidan and rhizocephalan infections occurred at significant levels. Sufficient histopathological effects were caused to be considered possible contributors to extensive mortalities of the crabs. Virus diseases are a major cause of mortality in insects and are becoming recognized as casual agents in devastating epizootics in marine crustaceans, especially under the crowded conditions of intensive aquaculture (Lightner et al 1983a; Lightner et al 1983b; Sano et al 1981). Virus diseases are also common in portunid crabs. Johnson (1983) discussed 17 different virus diseases, many of which are highly pathogenic, in European and American crabs. Microsporidan Protozoa are among the most pathogenic and frequently encountered infectious agents known to occur in Crustacea, even though little is known of their impact on natural populations (Couch, 1983). The major effect of rhizocephalan infections is parasitic castration, thus potentially affecting recruitment. However, evidence is accumulating that they cause some mortality, especially during molting (T. Myers and C. Hawkes, personal communication).

The virtual complete destruction of the bladder and antennal gland, the major excretory organ, in heavy infections is highly suggestive that the viral diseases are lethal to all three species of crab However, we do not know whether all infections are fatal or if infected crabs may recover from lighter infections. We also do not know if the disease is caused by the Herpes-type virus in the red and golden king crab.

Thelohanid microsporidan disease in red and blue king crabs is almost certainly fatal, probably in all crabs that become infected. Fewer tissues are infected with the Nosematid parasite of the golden king crab, but heavy involvement of cardiac muscle is suggestive of a fatal disease.

The rhizocephalan may contribute to mortalities in the golden king crab, but appears to be of little importance in red and blue king crabs in the areas we have sampled.

Assessment of the role of the virus and microsporidan diseases in the population structure is impossible at the present time for two reasons. First, we do not know the time span between initial infection and death. Obviously, a five percent prevalence in a sample of a disease with a mean time to death of a month, for example, is much more serious than if progression from initial infection to fatal termination requires a year. Second, we do not know the prevalences prior to and during any mortalities before the fall of 1982 in Kodiak or early 1983 in Bristol Bay in red king crabs, spring of 1982 in blue king crabs and early 1983 in golden king crabs. However, cursory examination of our limited data suggests the prevalence of both types of diseases in all three species declined during 1984. This is the situation one would expect of density-dependent diseases causing mortalities, with high prevalences during an epizootic and lower prevalences subsequently when many susceptible animals had been removed from the population and population density was lowered.

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Hemolymph studies of blue (*Paralithodes platypus*) and golden (*Lithodes aequispina*) king crab parasitized by the rhizocephalan barnacle, *Briarosaccus callosus*

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The precipitous decline in the red king crab fishery since 1980 has focused research efforts on factors that may have contributed to the decline or are potential threats to the king crab populations of Alaska. *Briarosaccus callosus* (Crustacea:Cirripedia), a rhizocephalan parasite of lithodid crabs, has recently been investigated because of its high infection rates in commercially important Alaska king crab species.

The first published report of *B. callosus* in Alaskan waters was on the golden king crab, *Lithodes aequispina*, from the Bering Sea in 1962 (Boschma 1962). The parasite was discovered on red king crab, *Paralithodes camtschatica*, in the northeast Pacific Ocean in 1969 (Boschma and Haynes, 1969). The blue king crab, *Paralithodes platypus*, has just recently been reported to have infection rates of over 70% in Glacier Bay in southeastern Alaska (Hawkes *et al.* in press).

The known effects of parasitism by *B. callosus*, and rhizocephalans in general, on host crabs are reduction in growth rate, sterilization of both male and female crabs and the appearance of female secondary sex characteristics in parasitized male crabs (Reinhard 1950, 1956; Hartnoll 1967; C. R. Hawkes, personal communication).

The literature is lacking reports of physiological responses of the host to parasitism by *B. callosus*, and only a few studies of host crabs parasitized by rhizocephalans have been documented, most dealing not with *B. callosus* but with other rhizocephalans (Robson 1911; Smith 1913;

Zambovileanu 1932; Drilhon 1936; Reinhard and von Brand 1944; Frentz and Veillet 1953; Andrieux *et al*. 1976).

An unusual feature of *B. callosus* is the presence of a red-colored hemolymph visible in the external brood sac. Few invertebrates, and even fewer crustaceans, are known to possess the iron-containing respiratory pigment hemoglobin. Hemoglobin therefore serves as an excellent marker to test the integrity of the host crab's circulatory system and the degree of host-parasite interaction. Hemoglobin has a higher oxygen affinity than hemocyanin, the respiratory pigment of crabs. Possible alterations in the oxygen carrying capacity of crab hemolymph could result if hemoglobin from the parasite were present in the host hemolymph. Rhizocephalans also have been reported to absorb nutrients directly from the host hemolymph, but no definitive studies have been published (Baer 1951). Our study investigated the effects of parasitism by *Briarosaccus callosus* on the composition of the host crab hemolymph and examined the relationships between the circulation of the host and its parasite.

Materials and Methods

Blue king crab, *Paralithodes platypus*, were collected in March, 1984, in Glacier Bay, Alaska, with modified commercial pots at depths of 10 to 240 m. Golden king crab, *Lithodes aequispina*, were collected in May, 1984, in Lynn Canal near Haines, Alaska, at depths of 180 to 480 m. Crabs were maintained in holding tanks with a flowing sea water system. Parasitized crabs were identified by the presence of a sausage-shaped externa on the abdomen of the crab or by the presence of a scar where an externa had been previously attached.

Crabs were removed from holding tanks and allowed to drain for five minutes before wet weights and carapace measurements were taken. Nine (1 female + 8 males) control or non-parasitized and 10 (2 females + 8 males) parasitized blue king crab were sampled. Six (6 females) control and 12 (8 females + 4 males) parasitized golden king crab were sampled. Five to ten ml of crab hemolymph was collected with a syringe from the coxal podites of the 3rd and 4th walking legs. Hemolymph was collected from the externa of the parasites near its attachment to the host abdomen. Hemolymph smears for cell counts were made and stained (Mix and Sparks 1980). The hemolymph was transferred to glass tubes in an ice bath and centrifuged at 2,900 x *g* for 10 min at 4^0C to minimize clotting. Hemolymph osmolality and pH of the supernatants were measured immediately after centrifugation. Osmolality was measured with a vapor pressure osmometer and the hemolymph was then frozen.

Hemolymph ion concentrations were measured on undiluted hemolymph. Chloride ion concentrations were determined with an Aminco electrometric titrator. Sodium and potassium were measured with an Orion Na-K Analyzer.

Total hemolymph protein was determined by the Lowry method (Lowry et al. 1951). Hemocyanin concentrations were assayed spectrophotometrically (Mason et al. 1983). Hemolymph was diluted 1:19 with 50 mM Tris buffer containing 10 mM EDTA, pH 8.9. Hemocyanin concentration of the hemolymphs and a *Limulus polyphemus* hemocyanin standard were read at 338 nm. Hemoglobin concentrations were determined with a colorimetric hemoglobin assay kit (Sigma No. 525) with a human hemoglobin standard.

Electrophoresis of the hemolymphs was performed using a 10% starch gel with a Tris/citric acid gel buffer, pH 8.5, and a lithium hydroxide/boric acid electrode buffer, pH 8.1 (Ridgway et al. 1970). Gels were run for 5.5 hr at 55 mAmp. A 0.25% Coomassie blue general protein stain and a dianisidine-oxidase stain, specific for hemocyanin and hemoglobin, were used to identify hemolymph proteins (Manwell and Baker 1963).

Hemolymph glucose concentrations were measured by the hexokinase reaction with a colorimetric assay kit (Sigma No. 115-A).

Parasitized and control crabs were x-rayed to determine the extent of parasite invasiveness. The pericardial region of a control crab and the parasite externa of a parasitized crab were injected with 3 ml of Renografin-60, a radiographically dense dye, to determine if hemolymph was circulating from the externa into the internal rootlet network of the parasite. Radiography was conducted 2 hr after injection of the dye.

Comparison of data from control vs. parasitized crabs was analyzed using Student's t-tests. All data are presented as mean ± standard error.

Results

Parasitized blue king crabs had an average wet weight of 1328 ± 73 g, with a mean carapace length of 123 ± 2 mm. Control blue king crabs had a mean wet weight of 1944 ± 107 g and a mean carapace length of 132 ± 3 mm. The wet weight of parasitized golden king crabs was 1451 ± 41 g compared to 1009 ± 76 g for the control golden crabs. Carapace length was 137 ± 14 mm for control and 135 ± 2 mm for parasitized golden king crabs.

In both blue and golden king crabs, no significant difference in pH existed between control and parasitized crabs. The pH of golden king crab hemolymph was slightly lower than that of blue king crabs (Table 1). The hemolymph pH of the parasite was lower than that of its host crab's hemolymph in both cases.

Hemolymph osmolality was significantly lower in parasitized blue crabs than in controls. The decrease in osmolality is attributable to a significant reduction in hemolymph sodium concentration. No alterations in either chloride or potassium ion concentrations were noted in parasitized blue king crabs (Table 1). Parasite hemolymph osmolality was significantly higher than its host crab's hemolymph. In parasitized golden king crabs no significant change in total osmolality was found, but a highly significant reduction in hemolymph chloride concentration was present. Unlike the parasites on blue king crabs, *Briarosaccus callosus* parasitizing golden king crabs had a significantly lower hemolymph osmolality than control golden king crabs. The osmolality of the sea water in the holding tanks was 859 mosm/l.

			mmol/l		
	pH	mosm/l	Na	K	Cl
Paralithodes platypus:					
Control	7.4±.02	869± 4	449±2	9±.1	499±14
Parasitized	7.4±.02	851± 5*	439±4*	9±.1	473± 8
B. callosus	7.2±.04	907±26*	-----	----	-----
Lithodes aequispina:					
Control	7.1±.01	891± 7	434±8	9±.4	459±8
Parasitized	7.1±.01	907±10	444±9	9±.4	422±7**
B. callosus	6.9±.01	821±15**	401±10*	9±.3	421±11

*P<0.05, **P<0.01

Table 1. Hemolymph ion concentrations and pH values for blue (*Paralithodes platypus*) and golden (*Lithodes aequispina*) king crabs parastized by *Briarosaccus callosus*. Asterisks indicate values significantly different from controls. Data presented as mean ± SEM.

After electrophoresis of control and parasitized blue king crab hemolymph, six protein bands stained with Coomassie blue (Figure 1A). The electromorphs were identical in control and parasitized hemolymph. Hemolymph from *Briarosaccus callosus* appeared to have no proteins in common with the king crab hemolymph. The two broad bands in the crab hemolyph stained with dianisidine-peroxide as hemocyanin. The top band represented a protein with a molecular weight of approximately 80,000 daltons which is characteristic of crustacean hemocyanin monomers (Mangum 1983). Most of the bands in the parasite hemolymph appeared to be hemoglobin, as the dianisidine-peroxide also stains hemoglobin. The crab hemolymph had no hemoglobin present, and the parasite hemolymph had no hemocyanin present (Figure 1B).

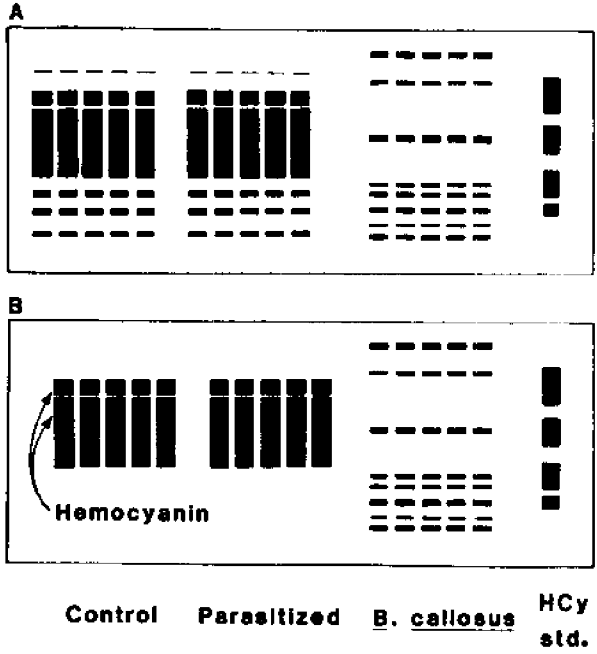

Figure 1. Electrophoresis of hemolymph from control and parasitized blue king crabs, and *Briarosaccus callosus*. A. Gel stained with Coomassie blue, a general protein stain. B. Gel stained with dianisidine-peroxide.

Total hemolymph protein was not significantly different in parasitized blue king crabs, 8.67 ± 0.74 g/100 ml, compared to controls 9.53 ± 0.78 g/100 ml (Figure 2). Also, no difference was found in hemocyanin concentrations between control and parasitized blue crabs, 1.83 ± 0.14 vs. 2.05 ± 0.21 g/100 ml. Hemocyanin in blue king crabs comprised approximately 21% of the total protein pool. Parasitzed golden king crabs had a significant elevation in total hemolymph protein, 8.53 ± 1.30 g/100 ml, compared to 5.26 ± 1.06 g/100 ml in controls. Hemocyanin levels were also significantly higher in parasitized golden king crabs, 2.93 ± 0.40 vs. 1.34 ± 0.36 g/100 ml in controls. Hemocyanin comprised 25% of the protein pool in control golden king crabs and 34% in parasitized golden crabs.

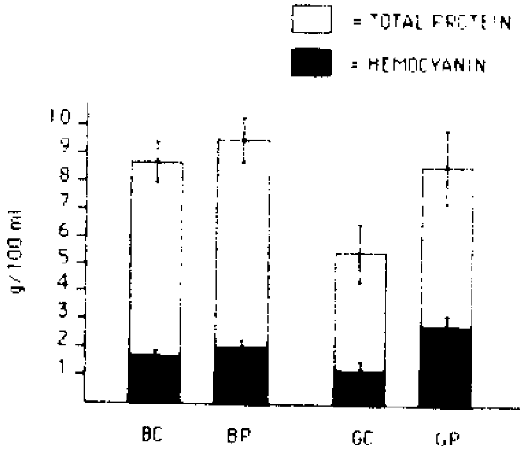

Figure 2. Hemocyanin and total hemolymph protein concentrations (mean ± SEM) of control and parasitized blue (BC, BP) and golden (GC, GP) king crabs.

A spectrophotometric scan of hemolymph from B. callosus had absorbtion maxima at wavelengths of 586, 550 and 422 nm corresponding to the absorption maxima for the alpha, beta and gamma, respectively, components of hemoglobin (Figure 3). Hemoglobin concentrations of 6.28 ± 0.74 and 5.88 ± 0.55 mg/ml were measured in the hemolymph of Briarosaccus callosus from blue and golden king crabs (Table 2). Hemoglobin concentrations of parasites from different host species were not significantly different. No hemoglobin was present in the hemolymph of parasitized blue or golden king crabs.

Total hemolymph cell count was not significantly different between control and parasitized blue king crabs (Table 2). Large variations in total cell number were observed among the crabs in each group. Differential cell counts were not obtained due to difficulty in achieving proper differential staining of the hemocytes.

Hemolymph glucose concentrations were not significantly different between control (3.14 ± 0.45 mg/100 ml) and parasitized (4.45 ± 0.44 mg/100 ml) blue king crabs (Table 2). The glucose concentration of 7.38 ± 0.63 mg/100 ml of B. callosus was significantly higher (P<0.01) than the glucose concentration of the host crab hemolymph. Control golden king crabs had a hemolymph glucose concentration much lower than that of control blue king crabs. A significant

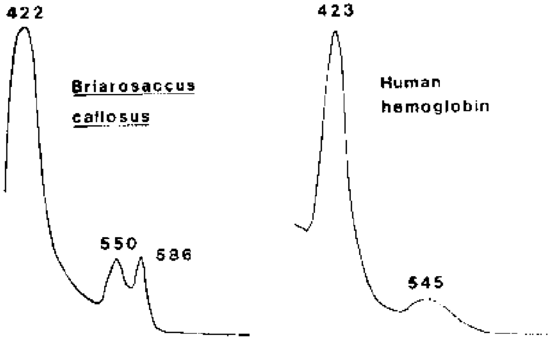

Figure 3. Spectrophotometric scan of *Briarosaccus callosus* hemolymph compared to a scan of human hemoglobin. Wavelengths (nm) of absorption maxima are indicated.

($P<0.05$) elevation of glucose occurred in parasitized golden crabs, from 0.89 ± 0.39 mg/100 ml in controls to 3.11 ± 0.53 mg/100 ml in parasitized crabs. Although the parasite hemolymph glucose concentration was lower in parasites infecting golden king crabs than that of parasites infecting blue king crabs, the concentration was still significantly higher ($P<0.01$) than the glucose concentration of the control crab hemolymph.

Injection of the radiographically dense dye into the externa *B. callosus* demonstrated that most of the hemolymph of the parasite remains within the externa and does not circulate freely into the hemocoel of the host crab.

Discussion

A brief summarization of the results of this study would consist of the following points: 1) Blue king crabs parasitized by *Briarosaccus callosus* had a reduced hemolymph osmolality caused by a decrease in sodium ion concentration; 2) Parasitized golden king crabs had a reduced hemolymph chloride concentration; 3) Parasitized golden king crabs exhibited increased total hemolymph protein and hemocyanin concentrations; 4) Hemolymph glucose concentration was significantly higher in parasitized golden king crabs; 5) No exchange or mixing of respiratory pigments occurred between parasite and blue king crab hosts; 6) The host response to parasitism by *B. callosus* was different between host crab species.

The parasitism in both blue and golden king crabs caused some disruption of hemolymph ion regulation. Other than that, the different host species responded differently to

	Hemoglobin mg/ml	Total Cell Count/mm^3	Glucose mg/100 ml
Paralithodes platypus:			
Control	0	9060±2764	3.1±0.5
Parasitized	0	9597±2344	4.5±0.4
B. callosus	6.3±0.7	-----	7.4±0.6**
Lithodes aequispina:			
Control	0	-----	0.9±0.4
Parasitized	0	-----	3.1±0.5*
B. callosus	5.9±0.6	-----	3.5±0.6**

*P<0.05, **P<0.01

Table 2. Hemocyte counts and glucose concentrations of hemolymph from control and parasitized blue (*Paralithodes platypus*) and golden (*Lithodes aequispina*) king crabs. Hemoglobin and hemolymph glucose concentrations are given for the parasite, *Briarosaccus callosus*, from the two crab hosts. Data presented as mean ± SEM. Asterisks indicate statistical differences from control values.

the parasite. Golden king crabs had a definite physiological response to the parasite, whereas the blue crabs had very little response.

The hemolymph protein values for control blue and golden king crabs were within the upper part of the range of hemolymph protein values reported by Florkin for 15 species of crustaceans (Florkin 1960). Hemocyanin concentrations in some crustaceans comprise 85-90% of the total protein pool (Claybrook 1983). The hemocyanin values obtained for the blue and golden king crabs were quite low compared to other crustaceans, but were in accord with low hemocyanin concentrations previously measured in red king crab (C. P. Mangum, personal communication).

The 60% increase in hemolymph protein concentration in the parasitized golden king crabs is significant. Half of the increase is due to elevated hemocyanin levels, but the additional protein could be attributed to the presence of lectins, specific carbohydrate-binding proteins suspected of playing a role in crustacean immunity (Bang 1983). Lectins bind specifically to certain sialic acids. Sialic acids are not produced by crustaceans and their presence in hemolymph has been linked to bacterial infections and possibly parasitisms (Ravindranath et al. 1984). The golden king crabs may have an immune response to the parasitism that blue king crabs do not.

Other observations made in our laboratory corroborate this hypothesis. Golden king crabs rarely have more than one B. callosus externa present per crab. Blue king crabs commonly have multiple parasitisms with as many as four externae on a single crab. Reduction in growth rates is less severe in golden king crabs than in blue king crabs. Histological examination of parasitized blue king crab tissues also indicates little host response to the parasite. Parasitized blue king crabs are generally more lethargic than are parasitized golden king crabs.

Increases in hemocyanin and another protein, dianisidine-oxidase, have been reported in the Atlantic blue crab, Callinectes sapidus, parasitized by another rhizocephalan, Loxothylacus texanus (Manwell and Baker 1963). Blue king crab hemolymph electrophoresed on starch gels had very little or no dianisidine-oxidase activity. Hemolymph of parasitized golden king crabs has not been examined for the presence of dianisidine-oxidase, which may explain part of the increase in total protein. Increases in hemocyanin may be a stress response to changes in host metabolic demand that may be induced by the parasite.

The hemolymph glucose concentrations of blue and golden king crabs were low, but within the range of hemolymph glucose concentrations reported by Florkin for 11 species of crustaceans (Florkin 1960). The high levels of hemolymph glucose in Briarosaccus callosus from parasitized blue and golden king crabs is a possible indicator of nutrient demand on the host. If the parasite is maintaining its high hemolymph glucose levels at the expense of the host crab's energy stores, it might explain the reduction in growth seen in all species of king crab parasitized by B. callosus. This would support the theory that rhizocephalans absorb nutrients directly from the host's hemolymph. Another explanation of the elevated glucose levels in parasitized golden king crabs could be a disruption of the normal glycogen storage function of the hepatopancreas. The hepatopancreas is one of the major target organs for the internal rootlet network of B. callosus. Smith (1913) reported progressive depletion of glycogen from the hepatopancreas in Carcinus parasitized by Sacculina.

This study indicated that the parasite and the host crab maintain discrete circulatory systems. No mixing of respiratory pigments between host and parasite hemolymphs was found. The circulation of B. callosus is mostly restricted to the externa with possibly minimal circulation through the internal rootlets for transport of nutrients from the host to the externa where the parasite larvae are brooded.

The red coloration of the parasite hemolymph was confirmed to be due to the presence of hemoglobin. The hemoglobin in _B. callosus_ is thought to be functional in larval development (Bloch-Raphael 1948a,b).

The physiological impact of _Briarosaccus callosus_ on king crabs varies with host species. Work is presently underway to examine the effects of _B. callosus_ on the red king crab, _Paralithodes camtschatica_. The potential impact of _B. callosus_ on the population as a whole is devastating considering the sterilizing effect of the parasite and the high levels of infection present in some king crab populations. Clearly, further work is necessary to determine the extent of physiological interactions of _B. callosus_ parasitism with Alaskan king crab species.

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The prevalence of the rhizocephalan *Briarosaccus callosus* Boschma, a parasite in blue king crabs, *Paralithodes platypus* (Brandt), of southeastern Alaska

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Abstract

The prevalence of the rhizocephalan barnacle, Briarosaccus callosus Boschma, in commercially harvested male blue king crabs (Paralithodes platypus Brandt) from Lynn Canal and Glacier Bay, Alaska, was 6.3% and 11.6%, respectively. However, when crabs of both sexes and smaller sizes were collected from Glacier Bay, the prevalence of the barnacle increased significantly to 76%. Female crabs also had a significantly higher prevalence (90.3%) of barnacle externae than males (64.5%), but no correlation of parasite prevalence with depth was evident. Consequently, prevalence assessment of the barnacle in commercial catches of P. platypus was biased. Parasitism was greater in the smaller size classes of crabs and in females, both of which are not retained in the commercial harvest. Catch data supported by laboratory studies indicate that B. callosus causes reduced growth in parasitized blue king crab hosts. Growth inhibition and castration caused by barnacle parasitism could severely limit recruitment in isolated blue king crab populations having high prevalences of the rhizocephalan. Thus, a potential management strategy for control of parasitism would be to allow commercial harvest of parasitized crabs regardless of sex and size.

Introduction

The fishery for blue king crab, Paralithodes platypus (Brandt), has become the leading crab fishery in Alaskan waters with the recent decline in stocks of red king crab, Paralithodes camtschatica (Tilesius). However, the catch of blue king crabs has also declined in recent years (Armstrong et al. 1983). Reasons for the general decline of king crab stocks are unknown but may include overfishing, predation of juveniles, or changes in environmental conditions. Parasitism is another factor which could contribute in the decline of king crab stocks. Rhizocephalans are parasitic barnacles that only resemble Cirripedia during their larval stages. Adult Rhizocephala consist of an external sac-like structure, the externa, that contains the sexual organs and an internal root system, the interna, which absorbs nourishment from the host's tissues and body fluids (Baer 1952). Rhizocephalans invade many species of decapods and cause a degeneration of the gonads (Reinhard 1956). King crabs parasitized by *Briarosaccus callosus* Boschma have greatly reduced or no apparent gonads (Boschma and Haynes 1969; McMullen and Yoshihara 1970; Hawkes et al., in press). Parasitized crabs may also grow slower, as indicated by their reduced body weights when compared with equal-sized nonparasitized animals (Hawkes et al, unpublished manuscript).

The rhizocephalan *B. callosus* was initially described from specimens parasitizing the lithodid crab *Lithodes agassizii* Smith collected in the Atlantic off Florida and North Carolina (Boschma 1930). The parasite is cosmopolitan in distribution, having been reported on *L. antarcticus* and *Paralomis granulosa* (Hombron and Jacquinot) from Antarctic and sub-Antarctic waters (Boschma 1962), *P. camtschatica* from southeastern Alaska (Boschma and Haynes 1969), *L. aequispina* Benedict from the Bering Sea (McMullen and Yoshihara 1970), *L. murrayi* Henderson from the southwestern Indian Ocean (Arnaud and Do-Chi 1977), and *L. couesi* from the Gulf of Alaska (Somerton 1979). No attempt has been previously made to measure the prevalence of *B. callosus* in various populations of Alaska king crabs. Recently, Sloan (1984) reported high prevalences in *L. aequispina* from British Columbia. McMullen and Yoshihara (1970) also reported a high incidence in golden king crabs near Kodiak. No comprehensive reports have been made on prevalence; therefore, it has been assumed to be low in other areas of Alaska. This report documents the incidence of parasitism in *P. platypus* by *B. callosus* in commercial catches sampled at dockside and in field samples collected from Glacier Bay.

Materials and Methods

Parasitism by *Briarosaccus callosus* is easily determined from the presence of one or more large visible externa (Figure 1) or scar on the underside of the abdomen. A scar is a short chitinous brown pedicel from which an externa was attached. Necropsy is the only method for detection of *B. callosus* in parasitized crabs in which no externa has yet erupted and secondary sexual changes caused by the parasite have not yet occurred. Such changes are most obvious in male crabs and include widening of the abdomen and thick growths of coxal setae. Because internal examinations of crabs for barnacle interna were not performed in the field, prevalence figures are conservative. Detailed descriptions of the externae of *B. callosus* have been previously reported by Boschma (1930, 1962), Boschma and Haynes (1969), and Hawkes et al. (in press). Field data for each crab included determination of sex, wet weight to the nearest 25 g, width and length of carapace (Wallace et al. 1949) to the nearest 1 mm, and prevalence and intensity of barnacle externae. Shell condition, an index of postmolt age based on exoskeleton wear and

Figure 1.--Paralithodes platypus with externae (arrows) of Briarosaccus callosus.

accumulation of epifauna, was classified according to a four-point scale (Somerton and MacIntosh 1983b). A subsample of live crabs composed of parasitized and nonparasitized individuals was returned to the laboratory for long-term rearing studies, gross necropsy, and histopathological examination of the tissues. Wet weights of these crabs were measured to the nearest 1 g, and the size and color of externae were also recorded. Severed externae were measured to the nearest 1 mm and weighed to the nearest 0.1 g. Tissues for histology were preserved in Helly's fixative for later processing.

Lynn Canal (Figure 2) blue king crabs were examined in November 1983, during the unloading process at a crab processing plant in Douglas, Alaska, and also in December, while they were being sold to the public in Juneau. Glacier Bay crabs were sampled at a crab processing plant in Pelican, Alaska, and while being sold to the public in Juneau. Boat skippers were interviewed to determine the depth and location of harvests. Blue king crabs were also sampled by the authors from Muir and Adams Inlets in Glacier Bay from March 2 to March 5, 1984. Standard pots were modified to prevent the escape of sublegal-sized animals. Some blue king crabs were taken incidental to Tanner crab fishing in the same area. A small number of juvenile blue king crabs (n = 10) were later collected from an intertidal beach in Queen Inlet, Glacier Bay, Alaska.

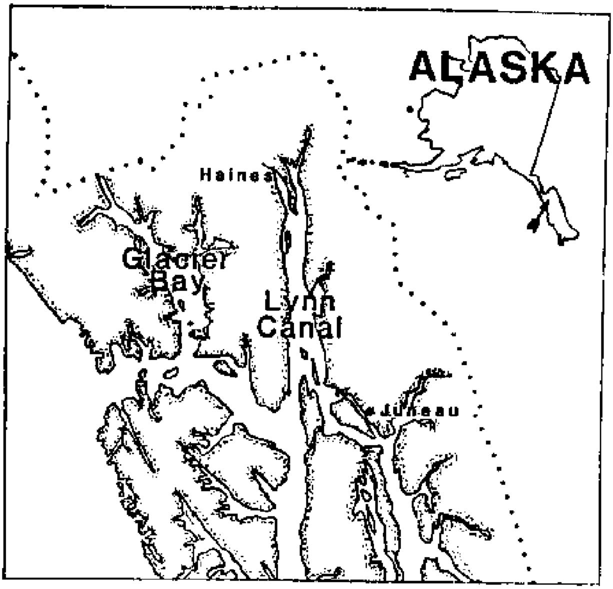

Figure 2.--Collection areas for Paralithodes platypus parasitized by Briarosaccus callosus in southeastern Alaska.

Results

Male blue king crabs in the commercial catches from Lynn Canal (n = 175) and Glacier Bay (n = 225) had barnacle prevalences of 6.3% and 11.6%, respectively (Figures 3 and 4). Among the 114 Glacier Bay crabs of both sexes and various sizes collected by the authors, 87 (76%) were parasitized (Hawkes et al., in press). No correlation of parasite prevalence with depth was evident since parasitized crabs were found in depths from 10 m to 240 m. However, female crabs (47 parasitized of 52 sampled) (Figure 5) had a significantly higher ($P < 0.001$, Z test) prevalence of parasite externae than male crabs (40 parasitized of 62 sampled) (Figure 6). Among the parasitized crabs, seven had two externae, six had three externae, and one had four externae. Additionally, nine crabs, including one with two externae and one with one externa, each had a scar where an externa had been present. During necropsy, two crabs previously thought to be nonparasitized each contained a barnacle interna(e). One of these crabs was an ovigerous female which contained no ovaries for the succeeding brood. Most of the crabs had a carapace condition of two, however a few were condition three. None of the 10 blue king crab juveniles examined from the intertidal zone of Queen Inlet were parasitized.

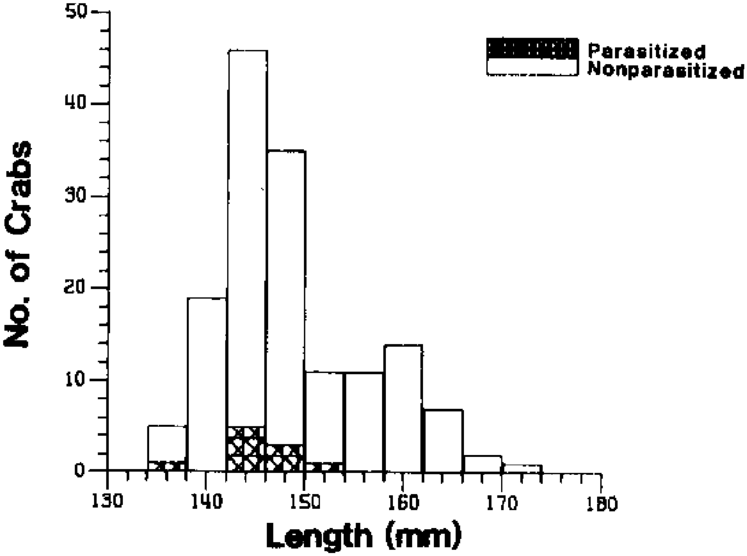

Figure 3.--Length frequency distribution of parasitized and nonparasitized *Paralithodes platypus* in the commercial catch from Lynn Canal during November-December 1983.

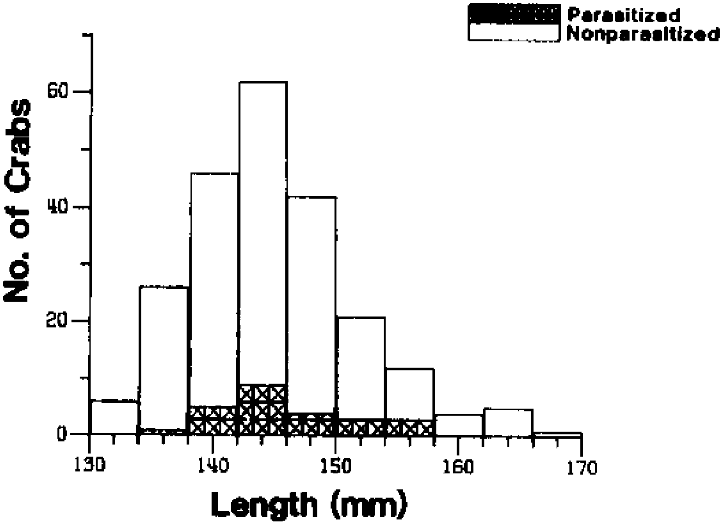

Figure 4.--Length frequency distribution of parasitized and nonparasitized *Paralithodes platypus* in the commercial catch from Glacier Bay during December 1983-January 1984.

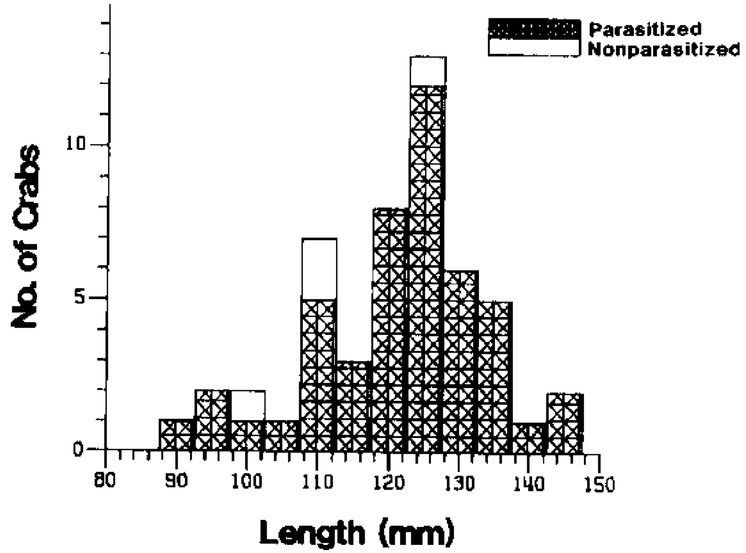

Figure 5.--Length frequency distribution of parasitized and nonparasitized *Paralithodes platypus* females collected from Muir and Adams Inlets, Glacier Bay, in March 1984.

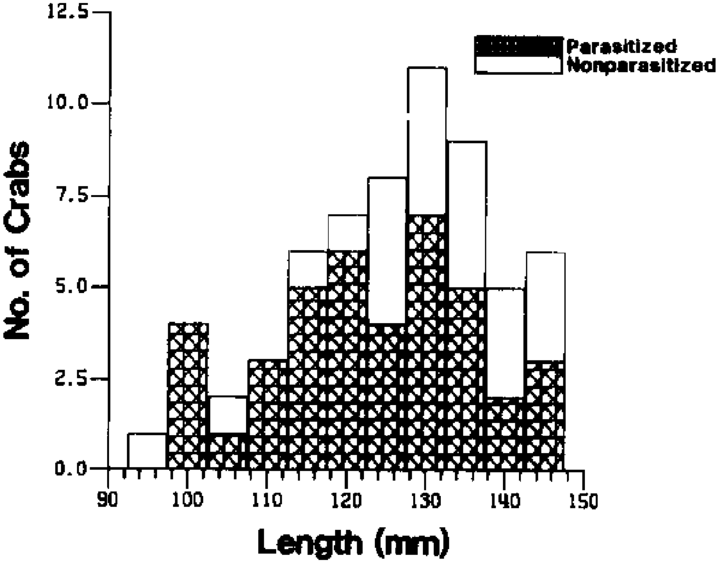

Figure 6.--Length frequency distribution of parasitized and nonparasitized *Paralithodes platypus* males collected from Muir and Adams Inlets, Glacier Bay, in March 1984.

All externae of *B. callosus* conformed to the description by Boschma (1930, 1962) and Boschma and Haynes (1969). The external body of the adult barnacle is a sausage-shaped brood chamber having a conical papilla opening from the outer mantle cavity to the external environment. Usually this papilla opens to the left side of the crab host, but exceptions occurred especially where multiple externae were present. Each externa was attached to the ventral surface of the host's abdomen by a chitinous, horny pedicel extending from the apex of the curved externa. The color of externae varied from a bright red in immature specimens to pale orange in those with more mature larvae. Preliminary spectrophotometric and electrophoretic analyses of red hemolymph from severed externae indicated that the color was due to hemoglobin (S. Shirley, T. Shirley, and T. Meyers, in press). The texture of each externa was leathery but soft and contractile on palpation. This contractile quality, as well as age and stage of development of brooded larvae, caused great variability in the size of externae. Externae were as small as 12 mm in antero-posterior length and as large as 77 mm ($\bar{x}$ = 48.3 ± 13.2 mm). Wet weights of 33 externae ranged from 6.2 g to 66.2 g ($\bar{x}$ = 20.9 ± 11.7 g).

All 47 parasitized female crabs were mature sized (Somerton and MacIntosh 1983a), but none carried eggs on their pleopods. In contrast, all five of the mature-sized, nonparasitized females bore eggs.

Gross necropsies of parasitized and nonparasitized specimens of *P. platypus* indicated atrophy or absence of gonads in parasitized hosts and marked replacement of the hepatopancreas by the internal green rootlets of the barnacle. These rootlets always appeared to penetrate or were closely adherent to all major organs and tissues including the coxal joints of the crab but not the merus musculature. The histopathological effects of this parasite will be reported elsewhere.

Discussion

Briarosaccus callosus has been described parasitizing many species of lithodid crabs worldwide (Arnaud and Do-Chi 1977; Hawkes et al., in press), but the prevalences have never been reported as high as we have seen in Glacier Bay, Alaska (Table 1). In fact, the prevalence in Glacier Bay blue king crabs was probably greater than reported due to early barnacle infections similar to the covert cases of parasitism found in two of our "control" animals. In contrast, extensive field research has been conducted on large concentrations of blue king crabs in the Pribilofs, but no *B. callosus* have been reported (personal communication, D. Armstrong, University of Washington).

Although the Rhizocephala of the northeastern Pacific Ocean are better known than in any other region of the Pacific (Boschma 1953), very little biological information is available on *B. callosus*. Despite the potential importance of *B. callosus* in impacting king crab survival, little is known except that growth and fecundity of *P. platypus* are significantly reduced (Hawkes et al., unpublished manuscript).

Table 1.--Reported prevalences of *Briarosaccus callosus* in king crab hosts.

Host	Location	Prevalence (%)	Reference
Lithodes agassizii	Florida, North Carolina, Colombia	<1.0 <1.0	Boschma (1930) Boschma (1970)
Lithodes aequispina	Bering Sea, Gulf of Alaska	<1.0 66.6 (n=21)	Boschma (1962) McMullen & Yoshihara (1970)
	British Columbia	36.7 (n=1396)	Sloan (1984)
Lithodes antarcticus	Falkland Island Straights of Magellan	<1.0 <1.0	Boschma (1962) Stuardo & (Solis (1963)
Lithodes couesi	Bering Sea Gulf of Alaska (females)	<1.0 0.7 (n=674)	Boschma (1962) Somerton (1979)
Lithodes murrayi	S.W. Indian Ocean	3.5 (n=201) 4.9 (n=144)	Arnaud & Do-Chi (1977)
Paralomis granulosa	Falkland Island Straights of Magellan	<1.0 <1.0	Boschma (1962) Boschma (1962)
Paralithodes camtschatica	S.E. Alaska	2.0 (n=99)	Boschma & Haynes (1969)
Paralithodes platypus	S.E. Alaska	76.0 (n=114)	Hawkes et al. (In press)

Prevalence assessment of *B. callosus* in commercial catches of *P. platypus* was biased because parasitism was greater in the smaller size classes of crabs not retained in the commercial harvest. Indeed, there was an upper size limit to parasitism in male crabs such that those ≥160 mm seldom were parasitized by *B. callosus*. Potential reasons for increased barnacle prevalence in smaller crabs could include differential mortality such that fewer parasitized crabs survive to larger size classes, reduced molting frequencies, reduced number of instars and/or reduced growth represented by a reduction in relative molt increment. However, our field data as well as laboratory studies have shown that the smaller size of parasitized crabs is due to growth inhibition caused by *B. callosus* parasitism (Hawkes et al., unpublished manuscript).

A high prevalence of parasitism by *B. callosus* occurs in areas where the bottom sediment is silt-mud associated with glacial runoff, such as Glacier Bay and Lynn Canal. The turbid water related to this type of habitat may impede the efficiency of gill cleaning by the fifth peripods, thus favoring barnacle attachment. That *B. callosus* infection occurs through the host gills is supported by the observation of barnacle internae almost exclusively within the gill regions of the two covert parasitisms described earlier. In the porcelain crab, Petrolisthes cabrolli Glasell, infection by the rhizocephalan, Lernaediscus porcellanae Muller, is markedly enhanced by damage or abrasion of the gill cleaning limbs (Ritchie and Hoeg 1981).

Populations of crab separated by only a short distance often show different degrees of rhizocephalan infection (Heath 1971; Phillips and Cannon 1978). All three species of Alaskan king crabs of all age sizes should be sampled from other areas inside and outside of Glacier Bay to determine the seasonal extent of barnacle distribution both geographically and within different ages of the crab hosts. Heath (1971) found that numbers of small and large externae as well as scars of Sacculina carcina Thompson varied seasonally in Carcinus maenas from Scotland. In general, the intensities of castrators on crustaceans are very low, but the percentage of infection, with regard to season and locality, may range from 25 to 75%. Such castrated populations are most probably maintained by immigration of nonparasitized crabs from other localities (Kuris 1974). This maintenance by immigration may not be possible for P. platypus in Alaska which occurs sporadically in small isolated populations in enclosed bays and fjords such as Glacier Bay (Somerton and MacIntosh 1983a). The isolated population of blue king crabs in Muir and Adams Inlets of Glacier Bay has such a remarkably high prevalence of B. callosus parasitism in both sexes that it is doubtful it could also sustain a commercial fishery. Commercial fishing removes the larger nonparasitized individuals leaving castrated, slow-growing parasitized crabs which offer no recruitment, compete for food and space, and further disseminate the parasite. A potential corrective management strategy would be to commercially harvest parasitized crabs regardless of size and sex from such areas with high prevalences of B. callosus.

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Preliminary report on egg mortality in Alaskan king crabs caused by the egg predator *Carcinonemertes*

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Introduction

Alaskan king crab, principally the red king crab Paralithodes camtschatica, have recently provided on of the most abundant and valuable crustacean fisheries in the world, with catches peaking in 1981 at 189.4 million pounds. Over the past 3-4 years abundance of red king crab has dramatically declined and a lack of upcoming year classes casts doubt on the ability of this fishery to recover in the near future. This decline has stimulated research by fishery biologists to determine the various factors that might be involved.

Since late 1981 Alaska Department of Fish and Game (ADF&G) biologists have noticed marked decreases in clutch through the brood period on red king crabs in the Kodiak and Cook Inlet regions. Associated with the mortality of eggs in these regions is the presence of large numbers of worms which belong to a group of nemertean worms which prey on the eggs of decapod crustaceans, the genus Carcinonemertes. This group has recently been found in epidemic numbers on Pacific coast Dungeness crabs (Cancer magister) and has been implicated in the long term decline of the central California fishery for that crab (Wickham, 1979).

The initial Kodiak and Cook Inlet egg samples and clutch observations stimulated an extensive sampling of king crab eggs throughout Alaska. The purpose of this collection was to describe the distribution of Carcinonemertes and to quantify its' role in the mortality of king crab eggs in Alaska.

Materials and Methods

Egg samples were collected by ADF&G and National Marine Fishery Service (NMFS) biologists by removing the whole fourth pleopod from each respective female king crab sampled whether it be from the red (P. cam-

tschatica), blue (*P. platypus*), or golden (*Lithodes aequispina*) king crab. Of the six egg bearing pleopods, the fourth was chosen to be the standard since it is one of the largest pleopods near the center of the clutch. Subsequent study will be conducted to determine how well this pleopod represents mortality throughout the clutch. Most of these crabs were caught either in crab pots of trawls during ADF&G or NMFS surveys. Some females were caught in pots by commercial fishermen when surveys were unable to obtain samples. Pleopods were preserved in 5 formalin in seawater. The carapace length, percent clutch size, depth and location of capture for each female was recorded.

Analysis involved a direct count of worms present in each sample. Crab egg mortality was determined by counting the number of whole live eggs and empty egg membranes in a randomly selected subsample of eggs, consisting usually of approximately 1,000 eggs. Crab egg mortality was expressed as the percentage of dead eggs in a clutch. The subsample of eggs was dried and weighed to determine a weight per egg and the rest of the sample was dried and weighed and the total number of eggs in the sample was then computed. Worm density was expressed as the number of worms per 1,000 crab eggs in a clutch.

The sampling program was designed to cover the broadest range possible of commercially significant king crab populations. Attempts were made to procure eggs from at least 30 individual crabs in each region. Pleopod samples were taken from the following ADF&G king crab management areas:

1. Southeastern Alaska
2. Cook Inlet
3. Kodiak Island
4. South Alaska Peninsula
5. Dutch Harbor
6. Adak
7. Bristol Bay
8. Bering Sea

Cook Inlet (Kachemak Bay) and Kodiak areas were sampled at intervals over the 11 month king crab brood period (March through following February) to follow the progress of worm infestation and crab egg mortality. Again, 30 crabs per collection were taken.

For this initial anaylsis of the overall collection approximately 10 samples from as many regions as possible were assayed to identify trends prior to the completion of the entire survey.

Results

Samples analyzed from the Kodiak and Cook Inlet management areas demonstrate an apparent seasonal cycle of nemerteans on red king crabs (Table 1). Nemerteans are virtually absent in spring samples. Numbers of worms increases dramatically through the summer. Crab egg mortality begins to increase after worm density rises and by fall or winter crab egg mortality can be almost total. Sampling in Cook Inlet in 1983 was discontinued beyond August because of a complete lack of viable egg clutches in the population (H.S.Kyle, personal communication).

Table 1. Average nemertean density (worms per 1,000 crab eggs± standard

deviation) and average percent crab egg mortality for red king crab populations repeatedly sampled over the brooding season.

Management Area	Date	(n)	Average Worm Density	Average Crab Egg Mortality
Cook Inlet	Feb.1983	6	17.8±14.5	50.9%
	Jul.1983	10	40.8±41.7	47.4%
	Aug.1983	11	88.7±93.4	99.3%
	Mar.1984	10	.02±.05	.06%
	Apr.1984	9	.01±.03	.30%
	Jun.1984	10	7.6±5.7	7.3%
	Sept.1984	10	39.7±36.9	65.4%
Kodiak	Feb.1984	5	.8±.6	38.6%
	Apr.1984	3	.8±.7	95.4%
	Jun.1984	5	62.9±49.3	7.4%
	Jul.1984	5	15.6±8.0	21.1%
	Aug.1984	5	140.2±109.1	96.9%

Comparison between management areas is complicated by the timing of the collection. Most sampling was done in late summer and fall in the regions where only a single yearly sample was taken. These can be compared with Cook Inlet and Kodiak samples also taken in late summer (Table 2). The greatest densities of nemerteans are found in Southeast Alaska, Kodiak, and Cook Inlet. Samples to the west and in the Bering Sea had very few nemerteans and egg survival was high.

Table 2. Average nemertean densities (worms per 1,000 crab eggs± standard deviation) and average crab egg mortality compared over the management areas analyzed to date)

Management Area	Date	(n)	Average Worm Density	Average Crab Egg Mortality
Southeast	June 1983	10	199.4±284.2	42.2%
Cook Inlet	Jun-Sep 83/84	41	45.2±48.1	37.4%
Kodiak	Jun-Aug 84	15	72.9±83.3	41.8%
South Alaska Peninsula	Sept. 1983	30	0.0	0.0%
Bering Sea	Jun-Aug 83	30	0.0	0.0%
Adak	Nov. 1983	6	.4±.5	3.1%

Golden king crabs (Lithodes aequispina) from the Bering Sea and from near Kodiak were also examined but no nemerteans or crab egg mortalities were found.

At least two species of undescribed turbellarian worms were present in king crab egg samples but they were not correlated with any egg mortality. One species of gammarid amphipod was also occassionally found.

Discussion

This work represents only a preliminary report on the extent of egg mortality in Alaskan king crabs but is significant in having identified several populations suffering from massive egg destruction. Attribution of the egg mortality to Carcinonemertes at this time is tentative, however, this genus is well known as a predator on the eggs of decapod crustaceans and the level of nemertean infestation on king crabs is consistent with the observed egg mortality (Humes, 1942; Kuris, 1981; Wickham, 1979; Aiken, et al. 1983; Roe, 1984). The nemerteans found on Alaskan king crab have also been shown in the laboratory to be a cause of egg mortality (A.J.Paul, personal communication). The turbellarians found on king crab eggs are completely uncorrelated with any egg mortality. Gammarid amphipods have been identified as egg predators on lobsters in Southern California (A.Kuris, personal observation) but if they are also predators on Alaskan king crab eggs their numbers are to low for their impact to compare with that of Carcinonemertes.

The number of nemerteans found in certain populations, particularly Kodiak, Cook Inlet, and Southeast Alaska are remarkable and represent the most massive infestations of Carcinonemertes we have seen on any crab species. Carcinonemertes errans is found on Dungeness crabs (Cancer magister) at levels high enough to implicate it in the prolonged collapse of the central California crab fishery (Wickham, 1979). The average densities found on that host range from about 7-30 worms per 1,000 crab eggs in heavily infested populations. This is approximately 10,000-45,000 worms per crab assuming an average of 1.5 million eggs per clutch. Individual crabs with as many as 100,000 worms can be found (Wickham, 1979). Sample collections of red king crabs with average densities up to 199 worms per 1,000 crab eggs can be found with populations on individual crabs reaching over 250,000. Many populations have measured egg mortalities in excess of 90%. These populations, however, will still be several months away from complete embryonic development. Populations from Cook Inlet had lost their entire reproductive output by September, only slightly over halfway through their 11 month brooding period.

With the Dungeness crab it is relatively easy to obtain an estimate of overall brood mortality for a given population in a brood season due to C. errans (Wickham, 1979). This crab only broods its eggs for a 3-4 month period. Most of the infestation by nemerteans has already occurred by host oviposition. Worms quickly move into the new egg clutch as a single cohort and begin feeding. It is therefore possible to construct a feeding curve for this worm and predict final egg mortality for any given crab at the end of its' brood period (Wickham,1979).

Arriving at a comparable estimate of nemertean impact on the red king crab is more complicated. The seasonal collections at Kodiak and Cook Inlet suggest that nemerteans do not arrive on the egg clutches until well into the brood period. These crabs oviposit sometime in early spring (March-April) and brood the clutch till the following January or February when hatching occurs. Egg samples from Cook Inlet or Kodiak were virtually free of nemerteans at least up to June. Crab egg mortality was almost completely absent and these samples show that egg development was completely normal and the eggs were obviously fertilized. Nemerteans begin to appear in summer and in the earliest heavily infested samples mortality still is relatively low. By late summer or fall nemerteans have increased to extraordinary levels and crab egg mortality is virtually total.

Samples in winter are more difficult to interpret. The February and

April samples from Kodiak have very high mortality levels but only traces of nemerteans. In Dungeness crabs C. errans remains on the eggs for almost the entire host brooding period. A few worms will, however, move off the eggs and back onto the host exoskeleton before hatching of the crab eggs. Most of the worms of this species mature and lay their own eggs with the crab eggs 2-3 weeks prior to crab egg hatching. The nemerteans found in great numbers in Kodiak, Cook Inlet, and Southeastern Alaskan king crabs are very tiny, becoming mature at only 1-2 mm, versus 5-10 mm for C. errans. They begin laying their own eggs only a month or so after they arrive in the host egg clutch and appear to finish their life cycle and leave before the host brood period is complete. This may, however, be because at such high densities the worms destroy their environment and food source and are forced off. At this time we do not know if these worms are capable of producing several generations in a summer or are annuals as in the case of C. errans.

In waters west of Kodiak another nemertean appears on red king crabs. The Carcinonemertes sp. found in eastern waters is small (1-2 mm), possesses the 2 eyes normal for the genus, and does not live in a tube when on the host egg clutch. The worm found in western Alaska is the largest yet found on any crustacean in the Pacific. Mature females are up to 30 mm in length. These worms also have no eyes and live in tubes in the host egg clutch. In earlier histological studies of these eyeless worms we found the presence of an accessory stylet pouch, a feature never before found in the genus Carcinonemertes. Whether this worm is distinctive enough to warrant creation of a new genus, as was recently the case for the nemertean Pseudocarcinonemertes homari found on Atlantic lobsters (Fleming and Gibson, 1981), is not yet clear.

The large species of nemertean appears to be the only one found at Adak but it co-occurs with the small species where their ranges overlap along the South Alaska Peninsula and Kodiak. Both species can even be found on the same host egg clutches. So far this is the first known host to harbor more species of nemertean symbiont. The large species occurs in lower numbers, but in a few host enough are present to cause extensive egg mortality. The overall density of this worm, however, is relatively low.

In Bering Sea waters Carcinonemertes was not found at all. In these populations with no nemerteans there is virtually no egg mortality. Turbellarians can be found on king crabs both in the Bering Sea and also at most other locations. Turbellarians do not cause any detectable egg mortality and at this time it is unclear what their trophic role is. A few golden king crab (Lithodes aequispina) have been examined so far but no nemerteans have been found. These crabs also have no observable egg mortalities.

It is too early for us to have an entire picture of the extent of damage the high numbers of Carcinonemertes found on red king crabs are causing. This study has demonstrated that the timing of sample collection is critical. Sampling early in the brood will miss eventual infestation, while sampling late in the brood will demonstrate egg mortality, but the causative agent may no longer be present. Close synchrony between sampling locations will be necessary to obtain valid comparative data.

From these initial observations it is clear that many important Alaskan red king crab populations are suffering from serious brood destruction. Our tentative observations indicate that enormous populations of nemerteans are the likely source of this mortality. This appears to be a new phenomenon. These nemerteans probably are a natural symbiont on red king crabs but they have never been noticed before now. Most crabs which host members of the genus Carcinonemertes, and we are discovering more all the time, carry very low densities and suffer from egg loss that can only be considered incidental. The Dungeness crab (Cancer magister) is the only other crab now suffering from extensive depredation due to Carcinonemertes and it is significant that this species also has suffered from seriously depressed population levels where it is heavily infested with worms. The possibility that Carcinonemertes may interfere with a recovery of the Alaskan red king crab population makes it essential that we investigate both the cause of the increase in worm density and methods for ameliorating the problem.

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Influence of an oil-contaminated diet on feeding rates, growth, and molting success of juvenile red king crabs, *Paralithodes camtschatica*

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Introduction

In 1980, the most valuable fishery in Alaska was the red king crab harvest in the eastern Bering Sea. This area is proposed for extensive offshore leasing for future oil production. Although an oil spill has never occurred in the productive waters of the eastern Bering Sea, concern arises that future oil spills, during production or transportation, could harm the crab population, particularly larvae and juveniles. Compared to adult crabs, the juveniles are probably more sensitive to oil exposure because of higher rates of metabolism, growth, and molting.

If oil were spilled in the eastern Bering Sea, juvenile king crabs could come in contact with oil-contaminated water, sediment, or food. Earlier studies of juvenile red king crabs compared the effects of exposure to the water-soluble fraction (WSF) of oil with the effects of oil-contaminated sediments (Rice et al. 1983). The quantity and types of hydrocarbons accumulated between these two types of exposures were distinctly different. The WSF, which contains monoaromatic and diaromatic hydrocarbons, was very effective in causing cessation of feeding and death. The presence of oil in the water column can be very toxic but usually is a short-lived phenomenon. In contrast, oil can persist in sediments for years, but the sediment-bound oil is not nearly as toxic as WSF. Oil-contaminated sediments caused few effects, even at high concentrations of oil for 90 d exposure (Rice et al. 1983). Other researchers have measured effects on salt marsh crabs, Uca pugnax, several years after an oil spill (Krebs and Burns 1977).

The effect of oil-contaminated food organisms on juvenile king crabs is unknown. It is known, however, that food organisms living and feeding in oil-contaminated sediment accumulate hydrocarbons and will remain contaminated for long periods of time because oil persists in sediments. By feeding on oil-contaminated food, juvenile king crabs should accumulate hydrocarbons. Uptake of hydrocarbons by juvenile king crabs exposed to WSF and oil-contaminated sediments was measured by Rice et al. (1983). Elimination of aromatic hydrocarbons from the diet by active metabolism should be minimal other species of crabs have poor capacities for metabolizing aromatic hydrocarbons (Burns 1976 Lauren and Rice, in press).

In this study, we examined tissue accumulation of aromatic hydrocarbons and the resultant effects on feeding rates, growth, and molting success, during a 6-mo period in which juvenile red king crabs, Paralithodes camtschatica, subsisted on oiled food.

Materials and Methods

Two-year-old juvenile red king crabs (mean, 13.5 g) were captured near Juneau, Alaska. For several weeks prior to oil exposure, crabs were maintained in the laboratory on a diet of chopped Pacific herring and mussels. The water temperatures during the study increased slowly, from 5°C in May to 9°C in August. Contaminated food was prepared by immersing live, 4-6 cm mussels, Mytilus edulis, in the WSF of Cook Inlet crude oil. We used two concentrations of WSF and two exposure durations to create three stocks of oiled mussels (4, 21, and 36 ppm monoaromatic and diaromatic hydrocarbons). Control mussels (1 ppm) were not exposed to WSF in the laboratory. All four types of mussels were prepared and frozen before feeding experiments began.

For the feeding study, we randomly assigned 80 crabs to individual, plastic compartments, with 20 crabs dedicated to each of the four food treatments. During the study, feeding, growth, and molting success were measured for each crab. Over a 120-d period, we measured daily food consumption by thawing, draining, then weighing food offered and removed each 24 h. The mussels offered were opened but in the shell. Crabs were always fed to satiation. Each week, crab growth was assessed by measuring wet weights and carapace lengths (eye socket to mid-rear). Molting success was noted daily, and we removed exuvia to prevent ingestion. Analysis of treatments for molting success required that crabs complete one entire molt cycle under experimental feeding regimes. For this reason, oiled food was offered for a total of 6 mo.

For the tissue hydrocarbon study, 120 crabs were randomly divided into four treatment groups. To minimize cannibalism, we provided rocks and plastic substrate as hiding places for molting crabs. Crabs were removed periodically (at 4, 10, 60, 90, and 120 d) from each treatment group and frozen for destructive tissue sampling of muscle and digestive gland. Concentration of aromatic hydrocarbons in tissues required a four-step procedure and included chemical digestion with a strong base hexane extraction silica gel liquid chromatography to separate aliphatic- and aromatic-hydrocarbon fractions and gas chromatography for qualitative and quantitative analysis of aromatic compounds.

Results

Survival and molting success of crabs in all treatments were excellent. There were few mortalities, and none were dose related. All crabs molted at least once during the 6 mo of feeding on oil-contaminated food. There were no dose-related effects on the growth of molting crabs. The size of molting crabs increased from an average of 13.5 g wet weight (26.5 mm length) to 35.4 g wet weight (36.6 mm length). After several weeks on the oil-contaminated diet, feeding rates were slightly depressed at the two highest doses of oil (21 and 26 ppm aromatic hydrocarbons in mussels). By Week 15, the daily average of dry mussel eaten was 0.132 g in the control crabs and 0.109 g and 0.104 g in the two high-dose groups of crabs. The feeding rates of all groups of crabs generally rose during the 15 wk, as all crabs grew.

There was some accumulation of aromatic hydrocarbons by the crabs, but most samples had low concentrations that were not different from control crabs. Apparently, no aromatic hydrocarbons accumulated in crab muscle, even in crabs that were fed the high-dose group of mussels. After eating oil-contaminated food for 4 d, crabs had detectable concentrations of aromatic hydrocarbons in the digestive gland. These hydrocarbons were more abundant and diverse than those in control crabs. Although these high concentrations of monoaromatic and diaromatic compounds decreased to control levels by 10 d and remained low for the duration of the experiment, dosed crabs retained an increased diversity of compounds over control crabs throughout the study.

The pattern of aromatic hydrocarbons accumulated by the mussels and the digestive gland of crabs was limited to the distribution of aromatic compounds in the WSF. Monoaromatic and diaromatic hydrocarbons are more soluble than the large polyaromatic hydrocarbons and are the major aromatic hydrocarbon components in the WSF. The mussels accumulated these hydrocarbons, and many of the same hydrocarbons appeared in the digestive gland of the dosed crabs.

Discussion

There were very few effects on juvenile red king crabs feeding for 6 mo on oil-contaminated mussels. Survival and molting success of control and dosed crabs were excellent. There was a trend of decreased feeding rates in the high-dose crabs after 15 wk. The lack of effects is attributable directly to the general lack of hydrocarbon accumulation, even in the high-dosed crabs. Although there were some aromatic hydrocarbons detected in the earlier samples of digestive gland tissues of the dosed crabs, none were detected in muscle tissue.

The lack of significant aromatic-hydrocarbon accumulation in crab tissues is undoubtedly the result of several factors. The primary factor is the low ratio of food consumed to body mass--although mussels contained high concentrations of hydrocarbons, only a small amount of mussel tissue (about 0.1 g) was consumed each day. Therefore, it was several weeks before large quantities of hydrocarbons were ingested. While small quantities of aromatic hydrocarbons were ingested daily, some hydrocarbons were being eliminated, probably at a similar rate. Active metabolism of the hydrocarbons is not required for elimination. Although some metabolism of aromatic hydrocarbon has been measured in several species of crabs, the rates of metabolism have accounted for little or no elimination in two species of intertidal shore crabs (Burns 1976; Lauren and Rice, in press). Furthermore, Lauren and Rice (in press) found that diffusion of naphthalene from the gills of Hemigrapsus nudus crabs was more important than metabolism.

Of the three types of possible exposure to spilled oil, oil-contaminated food causes fewer short-term effects than oil-contaminated sediments or WSF. The differences in effects from the three types of exposures are attributable to the differences in accumulation (Table 1). In an earlier study, Rice et al. (1983) found the effects of WSF on juvenile red king crabs were rapid and significant. At sublethal concentrations, there was cessation of feeding; at higher dose levels, there was death. Monoaromatic and diaromatic hydrocarbons were easily measured in muscle and the digestive gland after only 1 d of exposure. In the same study, crabs exposed to oil-contaminated sediment were not severely affected in 90 d, and the accumulation of hydrocarbons was much slower than in the WSF-exposed crabs. The hydrocarbon accumulations did include large polyaromatic hydrocarbons. Accumulation of polyaromatic hydrocarbons was from ingested sediment and did not cause acutely toxic effects. However, many of these compounds are carcinogenic, and adverse effects could require a lengthy time before effects are evident. The crabs exposed to the oil-contaminated food in our study were exposed to the same types of compounds found in the earlier WSF tests--monoaromatic and diaromatic hydrocarbons. However, the amount (not concentration) of aromatic hydrocarbons ingested was much less in our study than in the WSF exposures.

Table 1. Summary of results from studies exposing juvenile red king crabs to Cook Inlet crude oil; crabs were exposed to water-soluble fraction (WSF), oil-contaminated sediment, or oil-contaminated food. * indicates data from Rice et al. (1983). (Growth and molting success were not measured in the WSF test by Rice et al. (1983), but we assume there were effects because feeding and survival were affected.)

	WSF of oil in water* (28 d)	Oil in sediment* (90 d)	Oiled Food (120 d)
Effects			
Survival	↓ Reduced	NO effect	NO effect
Feeding	↓ Reduced	NO effect	↓ Slight
Growth	↓ Reduced	NO effect	NO effect
Molting	↓ Reduced	NO effect	NO effect
Hydrocarbon uptake			
Mono- and Diaromatic	↑ Lots	↑ Some	↑ Slight
Polyaromatic	— None	↑ Some	— None

If oil is spilled in the environment, juvenile king crabs could be severely affected by short-term exposures to high concentrations of oil in the water column. However, this type of exposure is not very likely because hydrocarbons in the water column are rapidly removed or diluted. Consequently, this type of exposure would be limited in area and length of exposure. In contrast, the effects from sediment and food contaminated by oil are neither rapid nor severe, at least not during the short-term laboratory observations. Once contaminated, however, sediment will remain so for years, and juvenile crabs could be exposed to oil in the sediment or food for long periods of time. The laboratory tests demonstrated that, after consuming oil-contaminated food, crabs will accumulate small amounts of hydrocarbons. Although no molting or growth effects were evident within the 6-mo study, trends of decreased feeding suggest that more serious effects could become evident over a longer period of time.

Conclusions

Feeding rates and molting success are sensitive indicators of the general condition of crabs. We concluded that daily consumption of oil-contaminated food was not detrimental to juvenile red king crabs over a 6-mo period, during which rapid growth and molting occurred. Aromatic hydrocarbon uptake was detected in the samples of the digestive gland taken early in the exposure. Accumulation of high concentrations in crab tissues was not observed. However, the long-term effects of exposure to oil contaminated food or sediment in the environment are unknown, and the small amounts of uptake and the trend of decreased feeding rates are cause for concern.

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Occurrence of juvenile king crabs, *Paralithodes camtschatica* (Tilesius), in Auke Bay, Alaska, on sediments with relatively high concentrations of aromatic hydrocarbons

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Coastal waters in Alaska are important to both Man and crabs. Man favors the quiet waters of inlets and bays for the development of harbors, marinas, and associated upland. These same quiet inlets and bays are also where several crab species, including red king crabs (*Paralithodes camtschatica*) and blue king crabs (*P. platypus*), gather to reproduce and spend the early portion of their life cycles. Some areas, used year after year by crabs, probably are important to the continued reproduction of specific stocks.

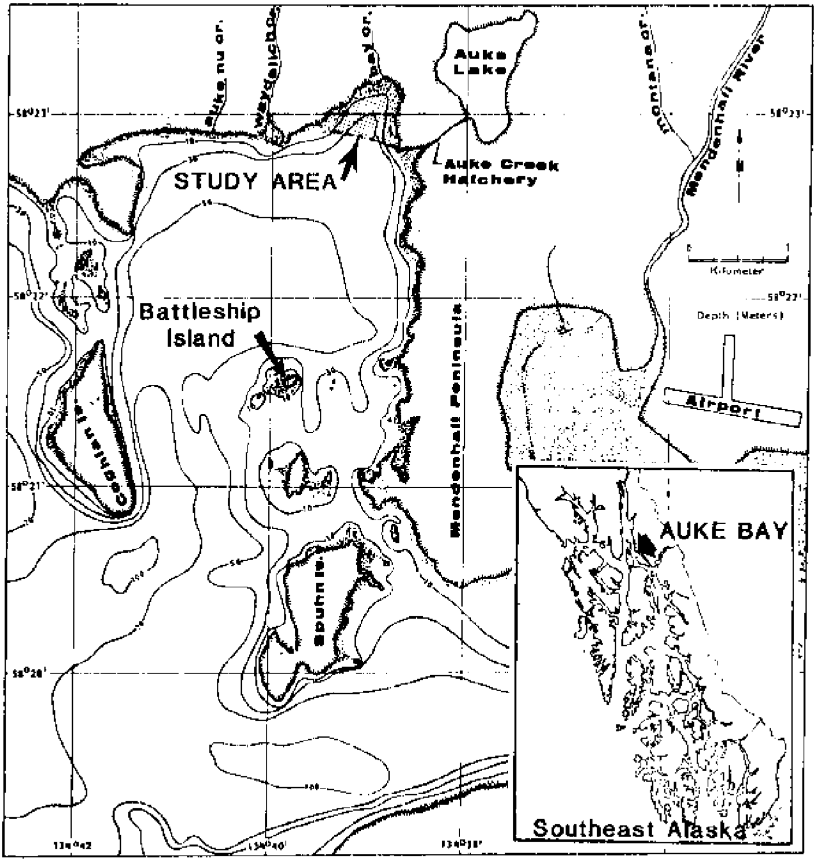
Adult red king crabs migrate from deep offshore waters in the early spring and congregate in nearshore waters, sometimes as shallow as 5 meters, to molt and mate. Female crabs release larvae in nearshore waters before molting and mating with attendant males. Larvae molt through six stages during the 6 to 8 weeks of pelagic existence and may be carried several miles by prevailing currents, before settling in nearshore subtidal waters as glaucothoe and molting into the first miniature juvenile stages. Distance moved will depend on larvae behavior, water circulation, and current velocities (Haynes 1983). Juvenile king crabs take up solitary residence in nearshore vegetation and under cobbles, shale, or discarded debris--usually on hard substrate, or at depths less than 10 meters below mean low water (MLW), or both. The young crabs occupy this niche for about 2 years and then give up their solitary existence to gather in groups called pods. Pods vary in size, from a few hundred to several thousand crabs. Within a few weeks after forming, the pods of crabs move enmasse to deeper offshore waters. This marks the beginning of their life-long, offshore-onshore migration.

Many marinas and harbors exhibit pollution problems which are detrimental to many marine fishes and invertebrates (Karinen 1983a, b; Krahn et al. 1984; Malins et al. 1984). Although much of Alaska's coast is still pristine, future harbor and marina developments in areas occupied by king crabs are likely. These developments may increase concentrations of hydrocarbons, metals, and synthetic organic compounds in sediments and organisms (Malins et al. 1984). The impact on king crab reproduction is not clear. King crabs are quite sensitive to mono- and diaromatic hydrocarbons dissolved in water but appear to be rather insensitive to hydrocarbons in sediments (Rice et al. 1983) and in foods (Gharrett et al. 1985). In this manuscript, I report on the observed occurrence of juvenile crabs and the apparently successful rearing of king crabs on oil-contaminated sediments in Auke Bay, Alaska. The potential for long-term adaptation of king crabs to oiled sediment is discussed.

Methods

The area of primary concern in this study is the northeast corner of Auke Bay, from the Auke Creek delta on the east shore to the Waydelich Creek delta on the north shore (Figure 1).

Figure 1. Study area (shaded) in the northeast corner of Auke Bay, Alaska, and map inset showing the location of Auke Bay in southeastern Alaska. Battleship Island in central Auke Bay was a control site for the hydrocarbon study.



Crab observations

Observations of the occurrence and relative abundance of juvenile king crabs in the northeast corner of Auke Bay compared with crabs along the shoreline of Auke Bay to the south and west were made by divers during the past 12 years (Personal observation and personal communication: D. Carlson, R. Ellis, R. Budke, Northwest Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, Alaska; and M. McKinnon, Alaska Department of Transportation and Public Facilities, Juneau, Alaska). For laboratory studies, numerous juvenile king crabs were collected from pods and from under slate rocks. Habitat types occupied by the crabs were noted throughout the period of observation. Pods of crabs were observed frequently in shallow water beneath the Auke Bay Laboratory (ABL) dock.

Hydrocarbon determinations in sediments and biota

Determinations of hydrocarbons in sediments and pink scallops (*Chlamys* spp.) from the northeast corner of Auke Bay were made during studies in 1982 and 1983. These data were gathered for preparation of an environmental impact statement (EIS) on a floating breakwater and expanded marina planned for construction in 1985. Details on sample collection, analyses, and surface and deep water circulation are provided in two reports on the marina study (Karinen 1983a, b). A description of source, composition, and distribution of hydrocarbons in Auke Bay will be published elsewhere.

The top 2 cm of sediments at 10-27 meters depth were sampled at various locations in Auke Bay during both studies (Figure 2), and duplicate samples were analyzed for aromatic hydrocarbons (naphthalene to perylene) by gas chromatography and mass spectrometry (Brown et al. 1980; Ramos and Prohaska 1981). Sediment samples were taken along the east shore in 1982 and the center of the northeast corner of the bay in 1983. Shale from selected sampling sites was also analyzed for aromatic hydrocarbons.

Similar analyses were conducted on duplicate samples of scallops (*Chlamys* spp.) collected at five sites in Auke Bay (Figure 3) on 5 July 1983.

Comparisons of growth

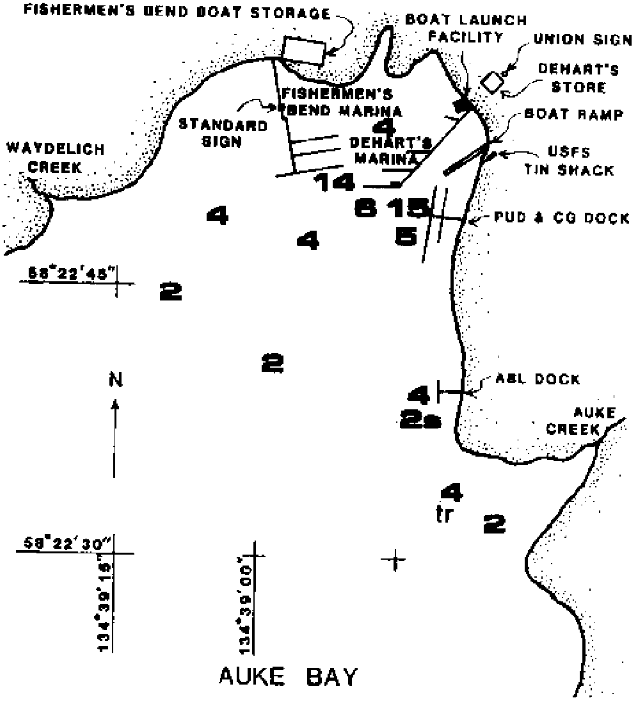
Growth of juvenile red king crabs from the study area (northeast corner of Auke Bay, cross-hatched area, Figure 3) and from the remainder of Auke Bay and surrounding areas was estimated and compared. These data were also compared to published growth records of king crabs from other areas in Alaska. Crabs were captured in the spring and held until molting, usually within a few weeks. Growth was determined by measuring either the carapace length before and after molting or the exuvia and the new length.

RESULTS

King crab abundance

Juvenile king crabs are consistently found in the area between the ABL dock to the Public Utility dock (PUD) (crosshatched area, Figure 3). Individuals are found under slate, shale, and debris, down to 10 meters below MLW. Large flat pieces of slate or shale seem to provide ideal habitat for the crabs. One or more pods of 500-1000 young crabs gather in May and June each year, as the two-year-old crabs abandon their solitary existence.

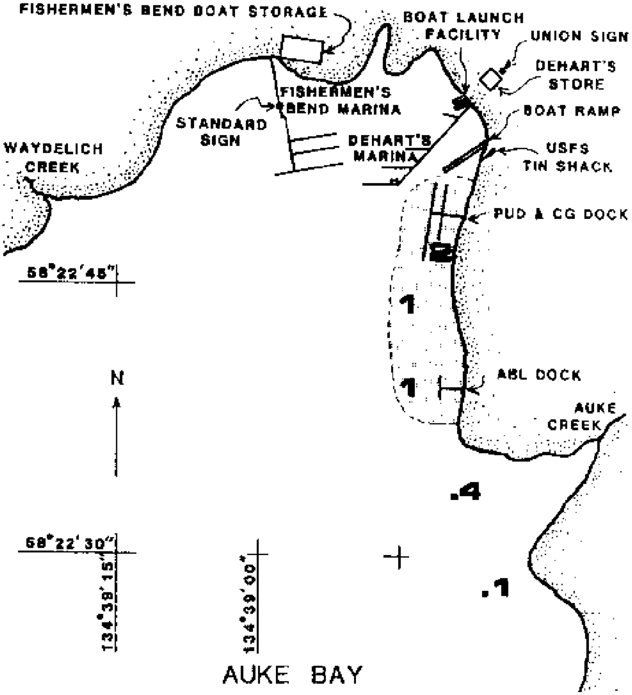
Figure 2. Summed total of selected aromatic hydrocarbons (naphthalene to perylene) in the top 2 m of sediment and in shale. Locations of numbers, letters, or both indicate sample sites. Shale sample sites indicated by 2s and tr. (2s = 2 ppm, tr = trace = <0.1 ppm). Numbers express ppm as dry weight.



In 1982, we surveyed several locations for juvenile king crabs in Auke Bay and the surrounding area. Of all the areas surveyed, the study area in the northeast corner of Auke Bay (Figure 3) showed the greatest abundance of juvenile king crabs (M. McKinnon personal communication).

Year-to-year abundance of juvenile king crabs in the study area appears quite consistent. Even when abundance is low in nearby areas, some crabs can always be found there. Perhaps, the patterns of the currents in Auke Bay concentrate larvae in the study area each year. Abundance of adult king crabs in the study area has generally decreased over the past 12 years, with fewer crabs gathering each year to mate and molt. Tanner crabs (<u>Chionoecetes bairdi</u>), present in large numbers in the early 70's, have virtually disappeared in the study area in recent years. Reasons for these declines are unknown but could be related to harvest rates, production cycles, or oil contamination from increased boating activity.

Figure 3. Summed total of selected aromatic hydrocarbons (naphthalene to perylene) in whole scallop tissue. Locations of numbers indicate sample sites. Numbers express ppm as dry weight. Shaded area is where juvenile king crabs are consistently found.



Hydrocarbons in sediments

In Auke Bay, marina activities in the extreme northeastern corner are probably the major source of hydrocarbons (Karinen 1983b). Total concentrations (ppm) of selected aromatic hydrocarbons in the top 2 cm of sediment (Figure 2) were lowest in the center of the bay (2 ppm) and increased at sites closer to the marinas in the northeast corner (6 ppm). Sediment from sites immediately adjacent to the marinas contained 14 to 15 ppm of selected aromatic hydrocarbons, equivalent to about 600 ppm total hydrocarbons by infrared analysis.

Data on hydrocarbons in sediments for 1982 and 1983 were similar even though different areas were sampled in the 2 years (Figure 2). In 1982, total mean concentration of the selected aromatic hydrocarbons (naphthalene to perylene) in sediments near the ABL dock and the Auke Creek delta was about 4 ppm and may partially reflect circulation of water during ebb tides. Total mean concentration of these aromatic hydrocarbons in sediments near Battleship Island, the control site in central Auke Bay (Figure 1), was <0.1 ppm, which is less than 0.5% of the highest concentration of total aromatic hydrocarbons measured in the northeastern corner of Auke Bay.

Concentrations of high molecular weight, aromatic hydrocarbons (polyaromatics) were also lowest in the center of the bay and increased toward the marinas in the northeastern corner. The concentrations of individual aromatic hydrocarbons at the seven sites nearest the marinas (Figure 2) suggest that the hydrocarbons are from petroleum; these sites had high concentrations of dibenzothiophene, phenanthrene, anthracene, fluoranthene, chrysene, and pyrene. These concentrations were inversely proportional to the distance of the site from the marinas.

Hydrocarbons in biota

Pink scallops (Chlamys spp.) collected nearest the marinas had the highest tissue concentrations of selected aromatic hydrocarbons. Again, the marinas are apparently the source of these hydrocarbons. Phenanthrene, anthracene, fluoranthene, chrysene, and pyrene were the most abundant components, and their concentrations in scallop tissues decreased with increasing distance from the marinas (Figure 3).

Concentrations of aromatic hydrocarbons in Auke Bay biota probably vary during the year. In scallops, concentrations of hydrocarbons are probably highest during summer and fall, when boating activity is the greatest and scallops rapidly accumulate dissolved hydrocarbons. Aromatic hydrocarbons probably persist in Auke Bay scallops for several weeks or months after boating activity in summer ceases because pink scallops depurate hydrocarbons very slowly once a wet weight tissue concentration of about 0.3 ppm has been reached (Short in preparation; Payne 1977). Scallops are a prey item for adult and large juvenile king crabs and, therefore, may be a source of hydrocarbons for king crabs. No analyses of king crab tissue were conducted in this study.

Hydrocarbons in slate and shale

In Auke Bay, slate and shale fragments of various sizes are common. Several near vertical dikes or outcroppings of shale and slate occur along the east shore and within the study area. Outcroppings of shale and slate are also present along the north and south shores, as well as on the small islands within the bay. Some outcroppings along the east shore near the ABL consist of very soft shale with an oily appearance, and in one location, tar or asphalt appears to have been exuded from a vertical dike of shale. No analyses of shale or slate from these exposed outcroppings have been conducted.

Shale fragments from three underwater sites (Battleship Island, Auke Creek, and the ABL seawater intake) were analyzed, and measurable amounts of aromatic hydrocarbons were detected at the ABL intake site (Figure 2). Shale from near the ABL intake contained 2 ppm total selected aromatic hydrocarbons, which were composed mainly of pyrene, fluoranthene, phenanthrene, and chrysene. Whether these hydrocarbons are adsorbed or are an integral part of the shale at the seawater intake is unknown. Shale from the Auke Creek site, however, contained only trace amounts of aromatic hydrocarbons, even though sediments contained 4 ppm aromatic hydrocarbons (Figure 2). Furthermore, shale from the control site at Battleship Island had no aromatic hydrocarbons. These hydrocarbons may therefore be natural components of the shale at the ABL seawater intake.

Comparisons of Growth

In 1984, no direct comparisons of growth were made between juvenile red king crabs collected from the oiled sediment in the northeastern corner of Auke Bay and from the other local areas. However, data collected on growth of crabs held in the ABL in 1983 and 1984 may provide some growth rate comparisons. Crabs were fed mussels during both years and held under similar conditions, except the first group was held on sediment.

Juvenile king crabs collected from Auke Bay and surrounding areas ranged from 25-50 mm carapace length and showed an average increase of 27 ± 4% in carapace length following a single molt, between 24 May and 10 August 1983 when held at 6-9°C. (Rice et al. 1983).

Crabs from the oiled-sediment area in the northeast corner of Auke Bay showed an average increase of 18 ± 2% in carapace length over one molt when held at 10°C for 90 days, July-September 1984. Mean length of these crabs was 36 mm and ranged from 31 to 44 mm (Rice et al. 1985).

DISCUSSION

Three findings of this study seem incongruous upon initial examination: (1) the apparent continued survival and production of juvenile king crabs on oiled sediments in the study area, (2) the apparent reduced growth rate of these juvenile crabs, and (3) the observed decline in use of the area by adult king crab. The absence of adult crabs versus the continued production of juvenile crabs in the area can probably be explained by considering the circulation of water into the study area and the duration of time that king crab larvae are pelagic. This region is probably supplied with larvae by crabs gathering along the east shore of Auke Bay, south of the study area. Nearshore currents flow north along the east shore toward the northeast corner of the bay, forming a circular gyre in the study area (Wing and Karinen in preparation; Karinen 1983b). Slow flow in the gyre may enhance the settling of crab larvae. No information is available on the numbers of larvae concentrated here relative to other areas in Auke Bay, but information from other studies (Haynes 1983) suggests that high concentrations of larvae may be expected. Large numbers of glaucothoe settling in the study area may explain the continued production of juvenile crabs here, regardless of oiled sediments in the area and absence of adults. No information is available on the mortality rates suffered by glaucothoe settling in the area.

Differences in growth rates between juvenile crabs from the northeastern corner and other areas of Auke Bay were indicated;

however, the differences are questionable because growth rates were obtained in two different years. These growth rates compare favorably with those reported in the literature for different areas in Alaska (Weber 1965; Table 1). The differences in growth between areas in Auke Bay (18 vs. 27%) may reflect differences in the environment; e.g., oiled sediment versus non-oiled, but further growth rate measurements are needed to confirm this. The causes for reported differences in growth rates of juvenile king crabs between other areas in Alaska are not known.

Table 1. Summary of growth per molt for juvenile king crabs from various locations in Alaska (data from Weber 1965) and from oiled and non-oiled sediments in Auke Bay, Alaska (data from this study).

KING CRAB GROWTH PER MOLT

LOCATION	% INCREASE	SIZE mm L
COOK INLET	15	21 - 53
BERING SEA	18	8 - 17
BERING SEA	21	8 - 26
UNALASKA	26	4 - 62
AUKE BAY (OILED)	18	31 - 44
(NON-OILED) ?	27	25 - 50

The observed decline in the use of the study area by reproducing adult king crabs may be the result of behavior, survival of juveniles reared in this area, hatching success of eggs brooded on females inhabiting the study area, harvest rates, production cycles, or none of the above. Not enough is known about the homing response of king crabs or the life stage when crabs may be imprinted to return to a specific area, to evaluate the reasons for the decline of returning adults. Tagging studies infer that some homing response is present, but the geographical specificity of the response is not adequately defined.

Avoidance of areas where hydrocarbons are being introduced may affect adult king crab distribution. Studies of Dungeness crabs exposed to oiled sediments (Babcock and Karinen in preparation) suggest a reluctance of females to bury in freshly oiled sediments. Oiled sediments also resulted in lowered reproduction and production of less robust larvae.

Conditions in marinas (anoxic sediments and anoxic near-bottom waters) may also impact hatching success of eggs. Studies with Tanner crabs (Chionoecetes bairdi) indicate that even brief exposure (<8 hours) to anoxic conditions results in 100% mortality of late-stage embryos (personal observation).

The effects of long-term exposure of king crabs to oiled sediments is unknown. Juvenile king crabs in the northeastern corner of Auke Bay apparently have been exposed to sediments containing 200-600 ppm total oil and 4-15 ppm of aromatic hydrocarbons for 2 years without apparent drastic effects. Whether this exposure affects their later growth, survival, or reproductive success is unknown, but these quantities of aromatic hydrocarbons in sediments can cause serious liver disorders in polluted species of fish at various locations in Puget Sound (Krahn et al. 1984; Malins et al. 1984; Malins et al. 1985).

Concentrations of aromatic hydrocarbons in surficial sediments from the northeastern corner of Auke Bay, near the marinas, were similar to those from waterways in Commencement Bay, Washington (Karinen 1983a; Jack W. Anderson, Batelle Northwest, November 1983, personal communication). However, concentrations of aromatic hydrocarbons at Auke Bay were only 10-33% as high as those in some very contaminated sediments from Black Rock Harbor, Connecticut (Jack W. Anderson, Batelle Northwest, November 1983, personal communication).

Juvenile king crabs collected from Auke Bay (mostly from the oiled area) were also little affected by oiled sediments and oiled food in laboratory exposures (Rice et al. 1983; Gharrett et al. 1985) but were affected by water-soluble fraction (WSF) exposures. Exposures to the WSF of Cook Inlet crude oil affected survival, feeding, and energetics of juvenile crabs. The 4-day LC50 was 1.5 ppm total aromatic hydrocarbons (TAH), and the 28-day LC50 was 0.65 ppm TAH. Feeding stopped at 0.5 ppm TAH. In contrast, exposure of these crabs to sediment containing 15,000 ppm total oil (2% V/W) for 3 months did not affect survival, molting success, feeding rates, growth, or energetics.

Availability of certain toxic components of oil to the crabs may explain this unusual lack of response to oiled sediments; however, uptake was observed after exposure to oiled sediments and WSF in these laboratory studies. Aromatic and aliphatic hydrocarbons accumulated in muscle and hepatopancreas tissues of crabs exposed to either 0.5 ppm WSF or 2% oil in sediment. Total aromatics were 50 to 100 times higher in hepatopancreas tissue than in muscle tissue in both types of exposure, but declined with time (290 to 79 ppm in 28 days) in exposures to WSF and increased with time (210 to 370 ppm over the period of 4 to 90 days) in sediment exposures. Differences in response may be due to the differences in mono-, di-, and polyaromatic compounds present in the two types of exposure and the relative availability of these compounds to the crabs. Mono- and diaromatic hydrocarbons are rapidly taken up and rapidly metabolized; whereas, polyaromatic hydrocarbons are less available but persist once absorbed (Rice et al. 1984).

The occurrence of measurable concentrations of aromatic hydrocarbons in slate and shale from Auke Bay suggests the possibility of a very long exposure of crabs to hydrocarbons in this region, if these hydrocarbons in the slate and shale are naturally occurring. The vertical dikes of soft oily shale and apparent exudates of tar and asphalt suggest a natural occurrence, but sorption of hydrocarbons of anthropogenic origin to slate and shale is also possible. Regardless of the source, crabs in the study area have probably been exposed to aromatic hydrocarbons for a minimum of 70 years and may have physiologically adapted to this exposure. Caution is needed in interpreting and applying the data collected on the effects of oil on king crabs. We must determine how other stocks of king crabs respond to oil, especially oiled sediments, and whether long-term exposure as juveniles affects health, reproduction, or survival of king crabs later in their life cycle.

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Application of statistical methods of factorial analysis to the size frequency distributions of crab in the southwestern Gulf of St. Lawrence*

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Editor's Note: *This paper is a contribution of the Oceanography Laboratory of Rimouski and the Marine Resources Study Group.*

Introduction

The exploitation of the snow-crab(Chionoecetes opilio) is recent in the Gulf of St-Lawrence but has grown very rapidly. The catches have increased from 624 mt in 1967 to more than 23 000 mt in 1982 in the southwestern Gulf of St-Lawrence (Elner 1982). During this period, the fishing activity has known several modifications : extension of the fishing area until 1977, increased trap mesh size from 108 mm to 131 mm in 1981, limitation of the fishing activity in 1980 and 1981, the effort being concentrated at the beginning of the season. This fishing activity has had some influence on the structure of the snow-crab population. Some aspects of this influence may be observed by studying the modifications of the size frequency distributions (Bouchard 1983).

Size distributions are commonly used to calculate the mean size and the amplitude of successive cohorts when it is not possible to determine directly the age of the animals concerned. They may also be considered as a certain picture of the exploited population at a precise period and location. A modification of the picture may then indicate a structure modification in this population. Bearing this in mind, the study of size frequency distributions becomes a problem of "shape recognition" in which case factorial analysis methods have proven to be very efficient tools (Benzecri and col. 1980). These analyses are well known in marine ecology where they are considered as powerful classification techniques (Chardy et al. 1976). Their use, however, is not as widespread in fisheries biology. Galois (1975) used both principal components analysis and correspondence analysis to describe some aspects of the dynamics of the shrimp, Penaeus duorarum, on the Ivory Coast. Badra and Do Chi (1976), using correspondence analysis, made a kinetic study of the exploited stock of the Crustacea Squilla mantis in the Mediterranean Sea and, in a latter work, defined the age structure and cohorts in that population (Badia and Do Chi 1978).

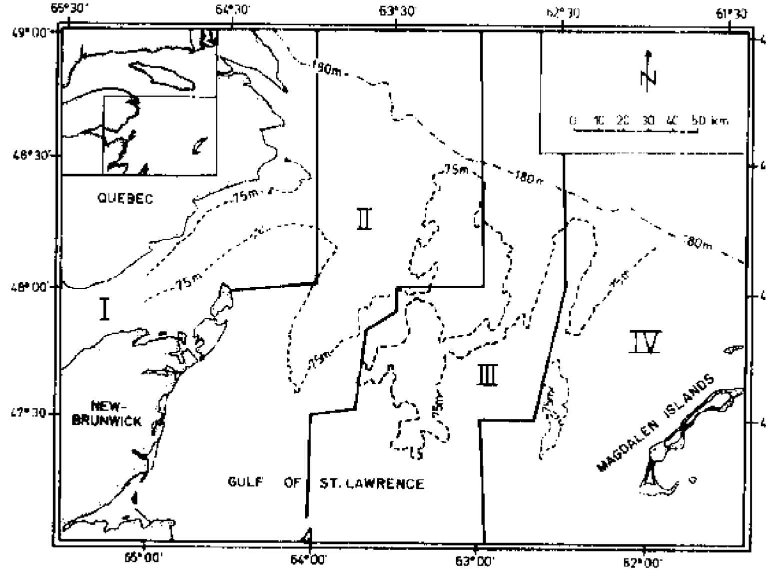
The purpose of the present work is to describe the general trends of the size frequency distributions of the exploited snow-crab populations on the fishing areas of the south-western Gulf of St-Lawrence using the factorial analysis of correspondence.

Material and Methods

Size frequency distributions of male snow-crabs were established from samples of landings in New-Brunswick ports during the fishing seasons 1977 to 1982. Local regulation impose a minimum of 95 mm as shell width, but it is common to find some undersized crabs in landings. A Kruskal-Wallis analysis of variance by ranks has shown that the variation of abundance within year of the undersized crabs with shell width between 85 and 94 mm is superior to the variation between years (Bouchard 1983). For that reason all crabs with size equal or superior to 85 mm were taken in account here.

For statistical purposes, the southwestern Gulf of St-Lawrence is divided into four areas (fig. 1) : Chaleur Bay (area 1), and three gullies west of the Magdalen Islands (areas 2 to 4). These are the preferred fishing areas of the fishermen from Quebec and New-Brunswick (Bailey and Cormier 1983).The most common gear is a rectangular trap, 1.5 m x 1.5 m x 0.6 m, with two lateral opposite entrances and covered with a poplypropylen net which stretched mesh size was 108 mm to 1980 and 130 mm afterwards.

Figure 1. Location of the fishing areas in the southwestern Gulf of St.Lawrence.



Data were collected on a monthly basis in 1977 and 1978. We have no reliable samples for 1979. In 1980, 1981 and 1982, measurements were made bimonthly all through the most important part of the fishing season. Only one sample, taken in october 1980, was collected at sea by scientists using commercial gears. As the data set for area 3 is the most complete, it will be used as reference. We have for this area 29 histograms resulting from measurements of a number of crabs varying from 450 to more than 7000. Comparatively, 8 histograms are available for the area 1 (4 in 1977), 18 for the area 2 and 24 for the area 4.

The factorial analysis of correspondence (also known as R-Q or reciprocal analysis, Legendre and Legendre 1979) is used to describe the contingency table formed by the n=29 lines (sampling periods of area 3) and the p=11 columns (shell widths grouped in 5 mm class) where Kij is the number of crabs of size j observed at a period i. The distance between two sampling periods i and i' is the Khi-square distance (Benzecri and col, 1980) defined by the relation

$$d^2 = \sum_{j=1}^{p} \frac{k}{k_{\cdot j}} \left(\frac{k_{ij}}{k_{i\cdot}} - \frac{k_{i'j}}{k_{i'\cdot}}\right)^2$$

where

$$k = \sum_{i=1}^{n} \sum_{j=1}^{p} k_{ij}$$

$$k_{\cdot j} = \sum_{i=1}^{n} k_{ij}$$

$$k_{i\cdot} = \sum_{i=1}^{p} k_{ij}$$

The distance between two size classes is calculated the same way, reversing i and j. Using this distance, the analysis searches for the "best" simultaneous representation of size classes and sampling periods in a common system of orthogonal axes. The interpretation of the results is based on the plane projection of the clouds of points. Each size class have a fixed position determined by its average profile within all the periods whereas the positions of the sampling periods are modified, depending on their size frequency structure. It will be possible to observe groups of samples having almost the same size profile and it will be logical to observe a particular size class near a group of samples where it is well represented.

The general trends in the modifications to the size composition of a population are the best observed in the data set of area 3. Spatial variations in these trends are stressed by inserting data from other areas as supplementary variables. These latter variables are not involved in the construction of the axes, but their position in space is defined by comparison with the principal variables in using the same Khi-square distance.
The computer program used in this study was obtained from the French Institute for the Exploitation of the Sea (I.F.R.E.Mer) at Brest.

Results and Discussion

General Trends of the Size Frequency Distributions

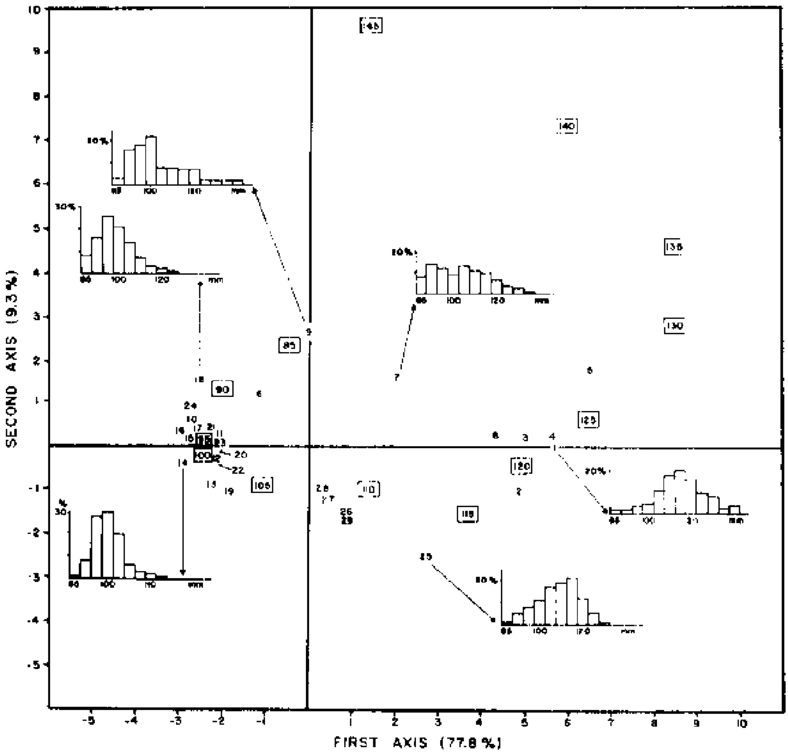


Figure 2. Projection on the plane created by the two first axes of size classes (in a square) and sampling periods of area 3 : 1 to 6, May to October 1977 ; 7, May, 8, June and 9, August 1978 ; 10, May, 11 and 12, June, 13 to 15, July, 17, August and 18, October 1980 ; 19 and 20, June, 21 to 23, July and 24, August 1981 ; 25, June, 27 and 28, July and 29, August 1982.

The first two axes explain respectively 77.8% and 9.3% of the total variability of the data, which indicates that the contengency table is almost completely described on the plane created by these axes.

The plane projection of the size classes (fig. 2) represents a kind of spiral, with the classes 95 mm to 125 mm, which form the major part of the table, being stretched along the first axis : the smallest shell widths are located in negative coordinates, while the largest ones are observed in positive coordinates. These are also 3 principal concentrations of points representing the sampling periods in area 3. A group is located in positive coordinates associated with large shell widths, 120 and 125 mm, and is formed by all but one samples of 1977 (1 to 5) and by the one of June 1978 (8). On the opposite side of the first axis, another group is associated with small sizes, 90 to 105 mm, and is formed by the samples of both years 1980 and 1981 (10 to 25). October 1977 (6) and August 1978 (9) are located close to this group. The samples of 1982 are situated in transition between the two first groups.

The spatial modifications in the picture observed for area 3 is shown by the displacement of the gravity center of each fishing season of each area (fig. 3). We note the general progression of the mean sizes in area 3 : a decrease from 1977 to 1980 and a new rise in 1982. This progression is also observed for the other sectors. Some minor variations appear from one place to the other. Areas 2 and 4 show the smallest shell widths in 1977. This tendency remains for area 2 until 1981 while size profiles seems to be very similar on areas 3 and 4 from 1978 to 1982.

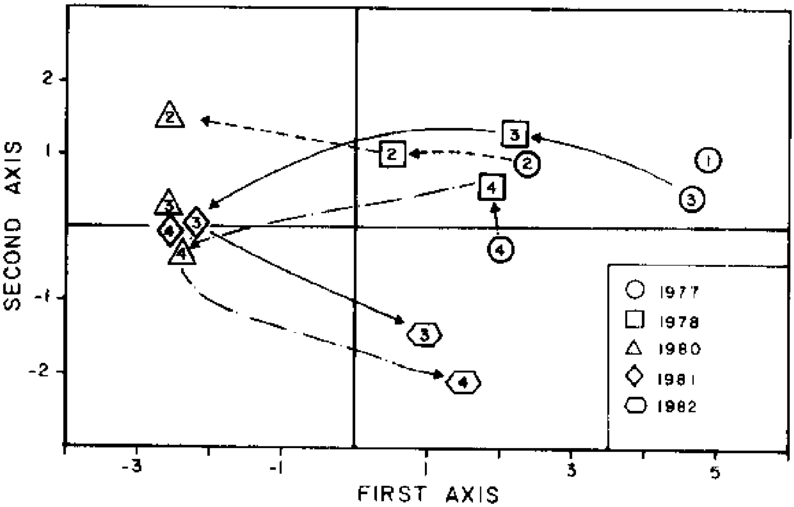
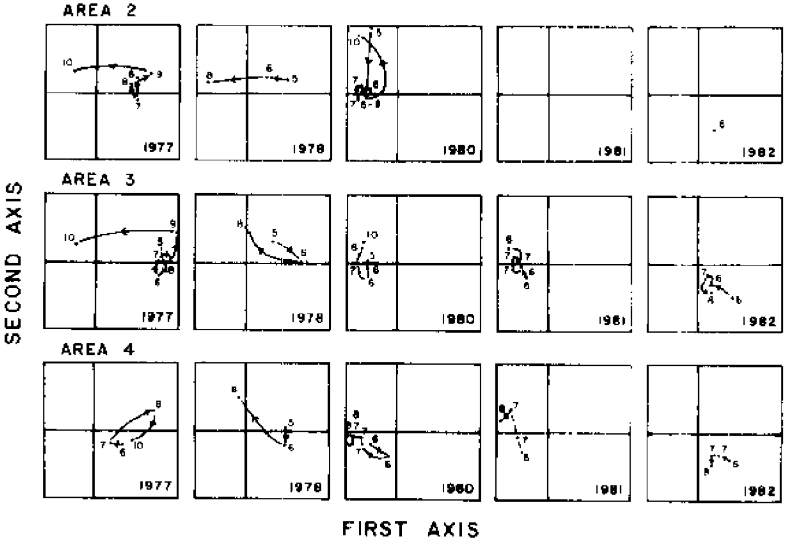


Figure 3. Position of the gravity centers of each fishing season for fishing areas 2, 3 and 4 on the plane created by the two first axes. Refer to Fig. 2 to compare with the positions of size classes.

In placing each fishing season on a relatively precise location on the plane, the first axis seems to translate the general modifications in the size composition of the snow-crab population in relation to exploitation. The large size of crabs landed in 1977 is the consequence of the extension of the fished area between 1974 and 1977 (Lamoureux and Lafleur 1982). After this date, the progressive decrease in the abundance of large individuals, associated with a probable increase in the recruitment (Bailey 1981), induced a decrease in the mean size of exploited crabs. This decrease is shown by the progression of the years of sampling towards the negative section of the first axis from 1977 to 1980. In 1980 and 1981, crab fishing seems to concern only recruited animals of sizes near the legal limit of 95 mm. Crab landings in 1982 show an appreciable size increase, translated by a return in the positive section of the first axis. This may be the result of the modification of the fishing activity observed in 1980 and 1981. In 1980, the state of the international market has induced a stabilization of the fishing effort. In 1981, the mesh size increased from 108 mm to 131 mm and fishing activity was reduced during molting period. These various measures allowed a sizable proportion of small and medium size crabs to escape capture. A later molting would make them accessible to gears in 1982.

Variations within Fishing Seasons

Figure 4. Positions of the sampling periods during each fishing season for areas 2, 3 and 4 on the plane created by the two first axes. The numbers correspond to months. Refer to Fig. 2 to compare with the positions of size classes.



Within each year, alternative displacements of the sample positions are observed (fig. 4). These displacements correspond to modifications of the size structure from one period to the next one. We observe oscillations of variable amplitude expressing the varying phenomena of growth and recruitment within the exploited population. A displacement of a sample-point towards smaller size classes will mean a better representation of these classes in samples which may be translated in biological term as a recruitment. Reciprocally, a displacement towards large sizes will mean a growth within the recruited stock. A loop in the points displacements would mean a renewal, total or partial, in this population. For the area 3, two recruitment periods occur in 1977, a weak one from May to June and a very important one in October, both being interrupted by a growth period. In 1978, after a growth period in June, a recruitment is observed in August. In 1980 and 1981, we may notice a continuous recruitment from the end of June to October. In 1982, recruitment occurs from June to July, followed by a growth period in August.

For the area 2, the situation in 1977 is identical to area 3, but in 1978, recruitment seems to be continuous from May to August. In 1980, the season begins with a strong proportion of very small individuals in May, followed by a growth period in June and another strong recruitment in October. This last sample was collected at sea and it may have artificially increased the proportion of small crabs which would have been normally rejected by fishermen.

For the area 4, the trends appear to be quite similar to area 2. The two periods of recruitment in 1977 still exist but they seem to be weaker. We observe also a continuous recruitment period in 1978, and another one from the end of June to August 1980. In 1981, the recruitment period stretches from June to the end of July. The situation in 1982 is similar to the situation observed in the area 3.

As a general result, the analysis shows an alternation in the growth and recruitment periods. A growth period seems to appear regularly in the middle of the summer. The more regular recruitment period is situated at the end of the summer and goes on throughout the fall. The second period takes place in spring, as it appears from the data of the years 1977, for all the areas, 1978 for areas 2 and 4 and 1982, for areas 3 and 4. The situation of May 1980 in the area 2, with a good representation of very small crabs, may indicate a recruitment before that month.

Spring recruitment and summer growth are in good correlation with our knowledge on snow-crab growth patterns. Following Kon et al.(1968) and Ito (1970), small individuals molt earlier than the older ones. This early molting period would induce the first recruitment followed by the subsequent molting of previously recruited crabs which would produce the increase in the mean size observed in the middle of the summer. Observed recruitment periods correspond also to the variations in the CPUE, which is always maximum at the beginning of the fishing season and often shows a new increase in autumn (Lamoureux 1981, Bailey and Cormier 1983). As immediate prerecruits (75 mm as size) molt only once a year, the autumn recruitment may be due to migration processes, as assumed by Coulombe et al. (1985).

Factorial analysis of correspondence provides a synthetic global view and describes some of the tendencies within the exploited snow-crab population. The conclusions are, however, limited by the precision and the representativity of samples. As a function of fishing intensity, sample sizes are variable. Usually, a small sample does not provides a good representation of the margins of the distributions, which creates a certain bias in modifying the real size distribution profiles. The sampling periods do not cover, in many cases, the whole fishing seasons and autumn data are generally not available for the fishery involved, even if an increasing CPUE is observed then. This fact induces a certain uncertainty on the fall recruitment. At least, we must consider the general problem of landing samples. The catch location is not known precisely and there is another uncertainty of the representativity of samples as a good picture of the real population ; for instance, fishermen usually avoid areas where high densities of small crabs or soft-shelled crabs are observed. Considering those possible bias, the analysis appears to be a good complement to other more classical techniques as it helps to interpret size data and CPUE variations.

Acknowledgements

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Abstract

The factorial analysis of correspondence is used to describe the modifications of the size frequency distributions of the exploited population of Snow-Crab in the southwestern Gulf of St.Lawrence, from 1977 to 1982. Size distributions were obtained from landings samples in New-Brunswick ports. The general trends are observed on one particular area from which the data set is the most complete. We note a constant decrease of the mean sizes from 1977 to 1980, where recruitment forms the main part of catches, and a partial recovery in 1982. Two principal periods of recruitment are also defined by the analysis, the first one at the beginning of the fishing season (spring) and the second one at the end af the summer through autumn. The two recruitment periods are separated by a growth period within the previously recruited stock. Spatial variations in those trends are observed by introducing data sets from other fishing areas as supplementary variables in the analysis. If we except minor variations in the mean sizes, the major trends are constant from one area to the other one. The relations between the results of the analysis and fishery knowledge are discussed.

SESSION IV

ECONOMICS AND MANAGEMENT

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Forecasting the price of crab on the Boston wholesale market

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1. Overview of the Canadian Crab Industry

Crab consumption in Canada has increased steadily over the past twelve years. The estimated total consumption of crab in 1982 was 20 000 metric tons (live weight), an increase of 264 percent since 1970. While part of this growth resulted from an increase in population, per capita consumption tripled at a time when per capita consumption of all fish products went up only by 40 percent. The increased consumption of crab could not occur, of course, without a similar increase in supply. The two sources of supply are domestic landings and imports.

From small beginnings in the 1960's, the Canadian crab industry has emerged as one of the most important Canadian fisheries. By 1983, crab landings were valued at about 58 million Canadian dollars, representing approximately one-tenth of the value of all landings in major Canadian fisheries. In the province of Quebec, for example, the value of crab landings moved from ninth place in 1975 to second place in 1983. During the last 15 years, the growth in the value of domestic crab landings has been due to increased prices and production. In fact, landings went from 7 000 metric tons in 1970 to 43 000 metric tons in 1983. The average landing price per kilo rose yearly from $0,22 (Canadian dollars) to $1,35 during the same time period. The deflated price increased by 50 percent.

Supply has greatly increased because of the expansion in the Canadian snow crab (Chinoecetes Opilio) industry and to a lesser extent because of imports. Canadian snow crab catches off the Atlantic coast and in the Gulf of St-Lawrence rose because of increased fishing effort over both, old and new fishing grounds. Other Atlantic coast crab fisheries are quite small and the Pacific coast dungeness crab fishery has remained rather stable over the past 20 years (about 1 000 metric tons a year).

Canadian imports of crab products, representing several million dollars and a few thousand tons, come mainly from the United States (about one-tenth of the domestic consumption). The major imports are fresh or frozen products.

The Canadian snow crab is sold on the domestic market, but more than 50 percent is exported. Since its beginning, the industry has exported between 50 and 75 percent of all landings, with more than 60 percent of exports going to the principal buyer, the United States. In recent years, the Japanese market has developed to a point where it accounts for 29 percent of Canadian exports in comparison with 7 percent in 1981. This improvement in sales to Japan is primarily due to the drop in American and Japanese supplies of snow crab. Also, the recent economic crisis has strongly depressed the European market for Canadian products.

Generally, landings are sold to processing plants and all products for export markets go through the classic marketing channel: fishermen to processors to brokers (or wholesalers) to foreign countries. The Boston market is the most important one in this marketing channel since the United States is a leading supplier of crab in the world and the main buyer of Canadian snow crab. The Boston price is therefore the negotiation benchmark between processors and Canadian fishermen (Union Forum (1983)). The fishing activity is seasonal and part of the production is kept in cold storage for future sales; the processors must forecast wholesale prices in order to make decisions on inventories and on the price to be paid to fishermen. In this context, forecasting the Boston wholesale price of Canadian snow crab is of vital interest.

Accordingly, the purpose of the present study is to specify and estimate short-term forecasting models based on time series analysis and on more main line econometric methods. First, the models will be described and discussed, then a comparison of the predictive capability of the different models will be illustrated.

2. Methodological Aspects

General discussion

The Canadian snow crab market is composed of three general sectors: domestic landings, wholesale (including imports and exports) and retail. A complete structural model would include a supply and a demand equation for each of these sectors with some additionnal equations explaining the dynamics of the fishing effort measured by traps hauled per unit of time, for example. But, when this model is confronted with the available data some compromises become necessary. Furthermore, it is not certain that the forecasting capability of the model would be very good. Different studies show the poor forecasting efficiency of some structural models (see, for example, Bhattacharyya). One of the most useful simplifications is to make the assumption of perfectly inelastic sypply and to estimate a single price-dependent demand equation (see Malinvaud (1978), pp 669-675 for theoretical aspects and Doll (1972) or Devoretz (1982) for applications). In general, this kind of model is built to estimate price elasticity or to get other structural information.

Existing data for the Canadian crab market consists in supplies entering the market (imports, domestics landings and beginning cold storage) and ex-vessel prices. Quantities moving through wholesale channels or held in storage at retail levels are not reported. This study does not attempt to specify a complete structural model.

For forecasting purposes, it is possible to specify a single equation as part of a more general structural model or to specify a stochastic model based on the Box-Jenkins methodology. In the present case, both methods are used.

A single equation model

The variable we are interested in is the mid-month price of a five-pound pack of Canadian crab meat on the Boston market (see note 1). As stated previously, this price is important for negociations between fishermen and processors.

There have been some sharp price fluctuations on a monthly basis, specially in the past three years: the price of a five-pound pack of crab meat rose from \$3,70 (U.S. dollars) per pound in September 1981 to \$7,50 in April 1983, and dropped to \$5,00 in September 1984 (see figure 1; all figures and tables appear at the end of the paper). The decreasing price in 1979-1980 might be due mainly to a change in the product-mix demanded by consumers (more sections than before) and a change in American landings (see note 2).

Several factors, such as Canadian and American landings and inventories as well as the prices of substitutes like king crab, could be responsible for these price fluctuations.

It might be expected that Canadian landings and inventories would affect the Canadian price negatively. Availability of snow crab in the United States should also influence the price negatively, but prices of substitutes like king crab should have a positive effect. American snow crab landings could logically be considered as an explanatory variable. The coefficient of this variable in a preliminary test, had a sign contrary to the a priori expectations, suggesting that a large part of the American landings could be sold on some independent market and that the East coast market is served through inventories.

A price determination equation could include all quantities of snow crab and substitute products entering the market. The general form of such an equation is:

(1) $PS = f(CL, ASI, AKI, S_i)$

where PS is the wholesale price per pound
CL Canadian snow crab landings
ASI U.S. snow crab inventories

AKI U.S. king crab inventories
S_i seasonal variable (see note 3).

It is also possible to use the Canadian inventories instead of the catches since the quantities transacted between November and April are drawn from inventories through retail, institutional and foreign demand.

As a first approximation, the algebraic form of the relations will be taken as linear functions in the actual values of the variables. The seasonal part of the model can be specified in two different ways: by eleven dummy variables or by sine-cosine functions. The later specification is retained and the estimated model is presented in the next section.

A stochastic model

If one assumes that the price series are the realization of a stochastic process, an autoregressive moving average model can be built for forecasting purposes. This univariate model can be generalized to the multivariate case. Recently, these methods have been applied in fishery analysis for forecasting landings (see Mendelsshon, 1980; Saila *et al.*, 1980; Boudreault *et al.*, 1977). But, time series methods can be useful at other level in the industry.

To specify a univariate model (ARMA), the process is supposed to be second order stationary. This means that the first two moments are time independent. Any nonstationary process can be made stationary by successive differencing to the appropriate order and sometimes by simultaneous seasonal differencing. Also, if the variance is not stable, a logarithmic or other type of transformation is necessary.

The most general form of a multiplicative stochastic model is:

$$(2)\quad \phi(B)\phi'(B^s)(1-B^s)^{d_S}\,(1-B)^{d}x_t^{(\lambda)} = \theta_0 + \theta(B)\theta'(B)a_t$$

where: B is the operator such that $B^p X_t = X_{t-p}$;

$x^{(\lambda)}$ indicates the Box-Cox transform;

$\phi(B) = (1-\phi_1 B - \phi_2 B^2 \ldots)$ is the regular autoregressive factor;

$\phi'(B^s) = (1-\phi_1{}'B^s - \phi_2{}'B^{2s} \ldots)$ is the autoregressive seasonal factor;

$\theta(B)$ and $\theta'(B)$ are the regular and seasonal moving average factor;

θ_0 represents a deterministic drift;

$(1-B)^d$ and $(1-B^s)^{d_S}$ represent the regular and seasonal factors of differencing, necessary in cases where the original series is not stationary; several successive differencing operations may be necessary. (exponents d and d_s in the equation);

a_t is white noise with mean zero and constant variance.

Following the Box-Jenkins methodology, the model is built in four stages: 1) Identification of a specific model with help from autocorrelation and partial autocorrelation functions; 2) parameters estimation of the specified model; 3) diagnostic checking of the models validity; 4) forecasting with the accepted model.

This approach can be generalized to a multivariate model if we make the assumption that the exogenous variables of the equation (1) have an ARMA model. For illustrative purposes, take a bivariate process having a multivariate autoregressive moving average representation:

$$\begin{bmatrix} 1-\phi_{11}(B) & -\phi_{12}(B) \\ -\phi_{21}(B) & 1-\phi_{22}(B) \end{bmatrix} \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} = \begin{bmatrix} 1-\theta_{11}(B) & -\theta_{12}(B) \\ -\theta_{21}(B) & 1-\theta_{22}(B) \end{bmatrix} \begin{bmatrix} a_{1t} \\ a_{2t} \end{bmatrix}$$

where $\phi_{ij}(B)$, $\theta_{ij}(B)$ and a_{it} are defined as before. If the matrices are assumed to be lower triangular, after some algebraic manipulations, we get a transfer function model of the form:

$$(3) \quad x_{2t} = \frac{\omega(B)}{\delta(B)} x_{1t} + \frac{\theta(B)}{\phi(B)} a_{2t}$$

and the ARMA model of x_{1t}. If the usual conditions of stationarity and invertibility are satisfied, it is possible to identify the order of the different polynomials of the equation (3). Different approaches are suggested for establishing the identification of the order of the polynomials (see, Box-Jenkins (1976, chap. 11); Granger and Newbold (1977, pp 244-254) or Haugh and Box (1977)). In the present case, the Box-Jenkins method is used. The equation (3) can be rewritten as follows:

$$(1-\delta_1 B-\delta_2 B^2 -\ldots-\delta_r B^r)\, Y_t = (\omega_0 - \omega_1 B-\ldots-\omega_s B^s) X_{t-b} + \phi^{-1}(B)\theta(B)a_t$$

The forecast series (Y_t or "output") depends on past values of the series and on historical values of the independent variable (X_t or "input"), which precedes the forecast variable by b time periods when $b > 0$. If $b < 0$, the input does not precede the dependent variable and X_t can not be used to predict Y_t. Also r represents the number of lags of the endogenous variable, while s is the number of lags of the exogenous variable.

The identification of a bivariate model supposes the series to be stationary. To facilitate the determination of the r, s and b values, a preliminary identification is made of the Box-Jenkins model for the independent variable which generates a residual series a_t as expressed in equation (2). Applying the same model to the dependent variable results in a second residual series b_t. An analysis of the cross correlation between these two residual series leads to the determination of b, r and s, and a last residual series representing the effects on prices of factors other than the independent variable integrated in the model. The empirical model will be presented in the fourth section.

3. Estimation of the Single Equation Model

The estimation was based on 84 months of data (1975-1981) and used the ordinary least squares method. The initial specification (equation 1) of the price equation failed to yield satisfactory results. The results displayed severe autocorrelation, moderate R-squared and some cold storage holdings coefficients which were inconsistent with a priori reasoning. To remedy this, a model similar to that used by Bockstael (1977) was specified. A lagged price was added to the relation. By so doing, autocorrelation decreased, the R-squared improved significantly and the coefficients of the cold storage holdings assumed the proper sign.

The seasonality component was defined as sine and cosine functions. But, the coefficients of these two functions were not significant. The presence of a lagged price did not change the results.

Hence, the final specification was

$$PS_t = a + b\,PS_{t-1} + c\,ASI_t + d\,CI_t + e\,AKI_t$$

when this equation was estimated, the coefficients c and e were not significant (see equation 6 of table 1). The inclusion of Canadian inventories cancelled out the effects of American inventories (snow crab and/or king crab). Other different specifications were tested and all equations are presented in table 1.

Four of the equations seem to give good estimates of snow crab price. Also, three of the five equations which include both the price in t-1 of American and Canadian inventories as independent variables, give slightly superior results. By contrast, Canadian landings have less influence on the Boston price. The importance of inventories relative to landings can be explained by the fact that landings reach the Boston market only through processing and inventory channels. It is the latter which enter into direct relation with the market. Landings and price form a compound relationship of the type:

landings --- inventories --- price.

A comparison of equations 1, 2 and 5 of table 1 suggests that the snow crab price at Boston depends on a series of factors over which Canadians intermediaries have no control, factors such as: American inventories (equations 1 and 5), Alaskan king crab price (equation 5) and even Canadian supply (equation 2).

Nevertheless, for forecasting purposes, it is preferable to retain these equations using American inventories as an independent variable since it is a factor which totally eludes the control of Canadian producers and brokers.

Table 1: Econometric Forecast Equation; Results (a)

	INDEPENDENT VARIABLES					
EQUATIONS	PS_{t-1}	ASI_{t-1}	CL_{t-1}	CI_{t-1}	PK_{t-1}	AKI_{t-1}
1	1,00 (35,5)	-0,000067 (-2,62)				
2	0,985 (41,81)			-0,000189 (-3,18)		
3	0,983 (40,297)		-0,000025 (-2,52)			
4	0,91 (22,2)	-0,000013 (-0,464)		-0,000201 (-2,99)	0,045 (3,1)	
5	0,929 (21,9)	-0,000057 (-2,24)			0,0363 (2,4)	
6	0,967 (30,6)	-0,00014 (-1,37)		-0,000176 (-2,68)		-0,000039 (-1,0)

Table 1: (Continued)

	STATISTICS & TESTS			
	F	$\bar{R}^2$	$d^{(b)}$	$h^{(c)}$
1	880	0,957	1,83	0,81
2	915	0,958	2,02	-0,009
3	875	0,956	1,87	0,61
4	517	0,964	2,12	-0,59
5	624	0,959	1,87	0,65
6	453	0,957	1,99	0

(a) For each unit of the table, we have indicated the value of the regression coefficient corresponding to that variable and under the coefficient, the value of test "t".

(b) Durbin-Watson statistic.

(c) There is no evidence of autocorrelation for any of the equations; the "h" statistic is normally distributed.

To compare the results of the econometric approach with the results of the other methods, equations 1 ans 5 were chosen as they both incorporate American inventories and because equation 5 shows that Alaskan king crab prices have a significant effect. The latter equation might be criticized from a statistical standpoint because of the high correlation between Alaskan king crab and snow crab prices. But all variables in the equations are significant and of the appropriate signs. For forecasting purposes, it is reasonable to use that equation.

The two equations are:

$$(4)\quad PS_t = 0{,}1575 + \underset{(35{,}5)}{1{,}00\, PS_{t-1}} - \underset{(-2{,}62)}{0{,}000067\, ASI_{t-1}}$$

$$(5)\quad PS_t = 0{,}176 + \underset{(21{,}9)}{0{,}929\, PS_{t-1}} - \underset{(-2{,}24)}{0{,}0000056\, ASI_{t-1}} + \underset{(2{,}4)}{0{,}0363\, PK_{t-1}}$$

The parameters are significantly different from 0 at a confidence level of 95%; the two equations explain about 96% of the variations of price about the mean and the Fisher statistic indicates that the model is significant as a whole. But because a lagged endogenous variable is included, the Durbin-Watson statistic is no longer the appropriate test for the absence of first order autocorrelation in the residuals; the Durbin h-statistic must be used. The values of "h" in the last column of table 1 indicate that we should not reject the absence of autocorrelation for these two equations. Equations (4) and (5) could thus be retained for the calculations of forecasts; they have the appropriate coefficient signs and meet the theoretical requirements.

4. Estimation of stochastic models

Univariate model

An univariate ARMA model of the Canadian snow crab price has been built, in accordance with previously stated element (section 2). This model can be used to forecast the price and also to review the specification of an econometric model.

In the identification phase, the most appropriate model will be chosen after finding the value of (λ) which eliminates possible heteroscedasticity of the series and after finding the values of d and d_s for application of regular and seasonal differencing factors.

The analysis of the graph of the original series (figure 1) and of the autocorrelation coefficients (tables 2 and 3) are both useful for this first step.

The analysis of figure 1 and the values of tables 2 and 3 show that the first differencing is the sole transformation necessary to satisfy the assumptions presented in section 2. It is interesting to note the absence of a strong seasonal component. This result is in agreement with the one obtained with the single equation model. However, the autocorrelations at lag 13 and 18 are high but insignificant.

Figure 1: Snow crab price at Boston

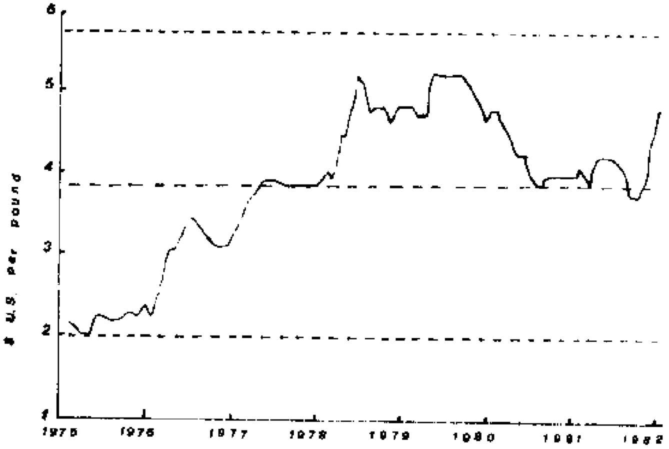

Figure 2: American inventory of snow crab meat

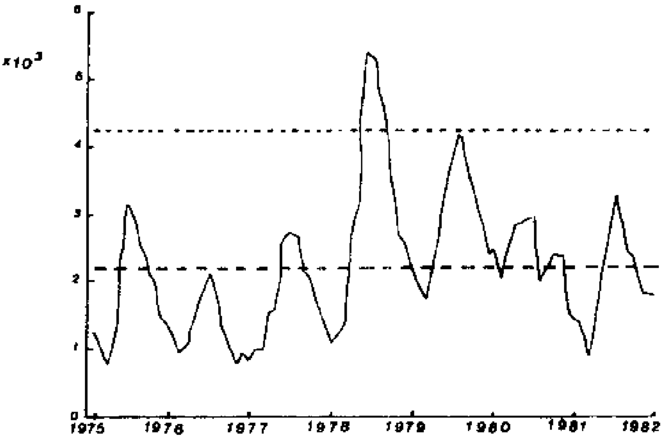

Table 2: Snow crab price autocorrelation (Raw Series)

Lag	1	2	3	4	5	6	7	8	9	10	11	12
Auto	0,95	0,89	0,84	0,79	0,75	0,71	0,67	0,63	0,59	0,55	0,51	0,46

Lag	13	14	15	16	17	18	19	20	21	22	23	24
Auto	0,41	0,36	0,31	0,27	0,22	0,19	0,17	0,14	0,11	0,09	0,07	0,04

Table 3: Autocorrelation of (1-B)PS

Lag	1	2	3	4	5	6	7	8	9	10	11	12
Auto	0,11	0,08	-0,02	-0,11	-0,10	-0,11	-0,03	0,16	-0,09	0	0,17	-0,01

Lag	13	14	15	16	17	18	19	20	21	22	23	24
Auto	0,21	0,02	0,09	-0,01	-0,11	-0,21	-0,02	-0,14	0	-0,03	0,12	0,07

Table 4: Partial Autocorrelation of (1-B)PS

Lag	1	2	3	4	5	6	7	8	9	10	11	12
Auto	0,11	0,06	-0,04	-0,11	-0,08	-0,08	0	0,16	-0,15	-0,03	0,19	-0,03

Log	13	14	15	16	17	18	19	20	21	22	23	24
Auto	0,21	-0,01	0,07	-0,03	-0,02	-0,19	0,03	-0,08	-0,07	-0,05	0,09	-0,06

All partial autocorrelation coefficients of the first difference series are also insignificant. There is no evidence for including autoregressive or moving average terms. The mean of the first differenced series is statistically zero; then the final model is

$$(1-B)\ PS_t = a_t$$

Some tests were made for adding a drift parameter to the right hand side of the equation and for adding a seasonal term (autoregressive factor or moving average factor) but none were significant.

The validity of the model was checked by the usual portemanteau statistics (Ljung and Box, 1978); the value of the statistic is 27 computed on 24 lags. The result must be compared to a khi-square value of 32. Interpretation of this simple model is that the Boston market for Canadian snow crab has the properties of an efficient market in the weak sense (the price is undeflated): historical information does not give any indication of how to improve forecasts of future prices. In section 5, this model will be used as a benchmark for comparison of the different models.

Multivariate modeling

The first step is to build the ARMA model of the input. The preceding econometric models would indicate retaining American inventories as the independent variable.

The series graph (fig. 2) suggests that the mean is unstable and that an important seasonal factor is present. Nevertheless, a transformation to stabilize the variance would not be justified despite the existence of the four values lying outside the established interval at two standard deviations.

The first analysis leads to this model:

$$(6)\quad (1-0{,}34B^9)\ (1-B^{12})\ (1-B)\ ASI_t = (1-0{,}93B^{12})a_t$$

The R-squared of the model is 0,87 and the statistic Q indicates that the residuals are white noise.

Application of this model to the dependent variable leads to the residual series b_t. A comparison of the two series would infer that

inventories at the beginning of the month affects the price of that month, b=0. The analysis leads to this MARMA model:

$$(7)\quad (1-B)PS = -0{,}000012(1-B)\ (1-B^{12})\ ASI_t \ + \ (1 + 0{,}34B^8)\ v_t$$

which can also be written as:

$$(8)\quad PS_t = PS_{t-1} + 0{,}000012\ ((ASI_{t-12} - ASI_{t-13}) - (ASI_t - ASI_{t-1})) + v_t$$
$$+\ 0{,}34\ v_{t-8}$$

The Box-Ljung statistic shows the residuals to be white noise. The presence of the parameter of order 8 in the residual series could be explained by the time elapsed between the end of the king crab season and the end of the snow crab season. The autoregressive parameter of order 9 might be explained by the duration of the Canadian snow crab fishery.

A second multivariate model has been developed using both the king crab price and American inventories.

The results are not reported because the model contains a large number of parameters and provides little improvement over the results of the previous model.

5. Comparison of the Models

Three aspects come to light in a comparison of the models: (1) their ability to explain the total variance of the dependent variable, (2) their absolute precision and (3) their relative precision.

The explanatory ability of the models is indicated by R-squared of the regression models and a comparable value of R-squared in the Box-Jenkins models even though there is some controversy about using this value (see, Coutrot et Droesbeke, 1984). (But no alternative measure has yet been proposed.)

Absolute precision is evaluated by the mean of the absolute value of forecast error (MAE) if the loss function of the decision maker is linear with respect to the forecast error; when the function is not linear, the use of the mean square error is preferable.

Relative precision is measured by the Theil statistic (Leutold, 1975; Theil 1965):

$$U_2 = (\Sigma (A_{ti} - F_{ti})^2 / \Sigma A^2_{ti})^{\frac{1}{2}}$$

where A_t and F_t represent, respectively, observed and predicted value changes. If $U_2 = 0$, the predicted and actual value are equal; if $U_2 = 1$, the model is considered "naïve" where the next value is assumed to be equal to the actual value. If $0 \leqslant U_2 < 1$, this model is preferable to a naïve model; if $U_2 > 1$, the forecast model is not useful, the "naïve" model is preferable.

Let us recall the results of the various models:

(4) $PS_t = 0,1575 + 1,00\ PS_{t-1} - 0,000067\ ASI_{t-1}$

(5) $PS_t = 0,176 + 0,929\ PS_{t-1} - 0,0000056\ ASI_{t-1} + 0,0363\ PK_{t-1}$

(8) $PS_t = PS_{t-1} + 0,000012\ ((ASI_{t-12} - ASI_{t-13}) - (ASI_t - ASI_{t-1})) + \nu_t + 0,34\ \nu_{t-8}$

Table 5 shows a comparison of measurements of the four models. For R-squared and mean absolute error (MAE), the results are comparable. The mean square error (MSE) of forecast and the U_2 are favorable to the econometric model which takes into account both the inventories and the price of king crab.

6. Conclusion

Two important elements enter into the interpretation of these results: comparison of the methods according to three criteria and adequacy of the models for actual forecasting.

Our comparison of the econometric and Box-Jenkins models shows that the model including both inventories and the price of king crab gives the best results; nevertheless, the difference remains weak between this model and a "naïve" model particulary where the Theil statistic indicates that the econometric model contains 93% of the errors incurred by the use of the "naïve" model.

The adequacy of forecast of the two models is difficult to judge since this will depend on the use being made of the forecast.

Nevertheless the results show, for the Canadian industry the importance of taking American inventories into account and also the usefulness of knowing the short-term level of Canadian inventories. The importance of the price in t-1 to predict the price in t should also be retained, the other factors tracing a minimum effect on the difference between these two values. This leads us to believe that the Boston market is an efficient market in the weak sense; the brokers integrate the available data, if only in an implicit and empirical manner.

Finally, this article explores time-series analysis, hitherto fairly untried in fisheries economics, and demonstrates their contribution to the understanding of the snow crab market.

7. Acknowlegments

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NOTES

1. There are different prices every month on the Boston market, but the mid-month price is widely published in Canada. We chose the price of crab meat because the 5-pound pack of crabmeat is an important product for the Canadian industry.

2. Before 1979, the American industry mainly landed the "Chinoecetes Bairdi". Since that year, a large part of the catches are composed of "Chinoecetes Bairdi" and "Chinoecetes Opilio".

Table 5: Comparison of the Models (1)

MODEL	R^2	MAE	MSE	U_2
Equation (4)	0,96	0,24	0,103	1,09
Equation (5)	0,96	0,21	0,073	0,93
Equation (8)	0,96	0,22	0,091	0,99

(1) R-squared is calculated on the estimation period whereas the others (MAE, MSE, U_2), are calculated on the forecast period.

(12 months 1982). This value should be interpreted with caution in the case of a time series model.

3. For all variables appearing in the equations, the description and source of data are given.

VARIABLES	DESCRIPTION	SOURCE
PS	Canadian snow crab price on the Boston wholesale market; mid-month price of a 5-pound pack of crabmeat; \$U.S. per pound	NMFS
PK	Price of a 5-pound pack of king crabmeat on Boston wholesale market; \$U.S. per pound at mid-month	NMFS
CL	Canadian landings of snow crab; metric tons	DFO, Canada; <u>landings</u>
ASI	Total American snow crab inventories; metric tons	NMFS
AKI	Total Alaska king crab inventories; metric tons	NMFS
ASL	American snow crab landings; metric tons	NMFS
CI	Canadian snow crab inventories; metric tons. There are some problems with this series during the winter months: the processors do not report their inventories on a regular basis	DFO, Canada, <u>Shellfish Market review</u>

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Chilean king crab exports in international markets

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INTRODUCTION

Chile, with its 5,000 kilometers of coastline, is one of the countries in the world with the highest potential for the development of commercial fisheries. Chile is one of the five major producers of fisheries products in the world. In 1982 the total landings reached 3,846,372 tons, representing a 9.8 percent increase from 1981.

The contribution of the national fishery activity to the Gross National Product has fluctuated between 1.5 and 2 percent over the past ten years. This percentage should be considered high in comparison with that of traditionally strong fishing countries such as Japan, Norway, Spain or Portugal. Because of the geographical characteristics of Chile, this activity is expected to constitute an important factor in Chile's national economic development.

The exploitation of Chile's diverse fishery resources has resulted in the existence of various well defined fishing activities based on the predominant species that they exploit. This allows the identification of five distinct fishing zones in the country: Northern, Little Northern, Central, Southern, and Austral.

One of the most important fisheries of the Austral zone, corresponding to the Magallanes area and the Magellan Strait, is the king crab (Centolla), *Lithodes antarctica*. The basic objective of this paper is to describe the fisheries of this resource from an industry-exports standpoint.

The fisheries of these crustaceans have, since the 1960s, been one of the predominant fishing activities of the Chilean XII Region. In later years, the X and XI Regions also began extracting the king crab, but 99.6 percent of the total landings in 1981 occurred in Region XII.

Until the year 1973, the king crab fishery was in a developmental stage with an average annual landing of 400 tons. Landings increased rapidly after that year.

Important data for this paper were extracted from IFOP studies and the Instituto de la Patagonia (IP) studies. The Oficina Nacional de Planificacion (ODEPA) and the Chilean Trade Promotion Bureau (Pro-Chile) were very helpful in providing economic data for this report. However, data from different sources were not always consistent. Therefore, the final figures reported in this study are the best approximation.

This report represents a partial abstract of the thesis project for my Master of Science. The original paper includes biological and exploitation aspects also. They will not be covered here because another of the papers presented at this conference deals with these topics in depth.

THE INDUSTRY

Companies

The early years of the Chilean king crab industry were characterized by a few steadily growing companies. After 1979, the number of companies increased.

By the 1980-81 fishing season, there were 13 companies in Chile producing king crab meat for exportation. Some companies halted production of king crab at this time, due to deep internal economic problems being felt in Chile. The companies which continued production were marketing 327 tons a year, mostly in the form of a canned final product. None of these companies were utilizing their full production capabilities.

The number of exporting companies through ODEPA export statistics are shown in Table I.

Of the Chilean king crab exporting companies during these years, we found several new companies that had not been exporters before; also, some of these new companies appear as exporters one year and not the next. This reflects a dynamic movement in the industry. Table II lists the nine companies that remain as regular exporters during most years.

Plant Types and Sizes

During the first 15 years of king crab fisheries development, the fishing grounds were concentrated in one area very close to the processing plants. This was due to low processing capabilities, few freezing facilities and also to the fact that the fishing fleets were small.

Recently, the king crab industry has entered into a period of capacity and geographic expansion. The processing plants have been modified, adding more production lines, freezing and packaging facilities and more efficient fleets.

The available information, in terms of actual processing capabilities of plants in the XII Region, is given in Table III. From Table III, we conclude that two companies are the most important in terms of raw material processing capacity; this is also confirmed by the export statistics. The two companies, Pesquera Magallanes and Pesquera Cabo de Hornos, account for more than 60 percent of the total industry production.

Production Share by Type of Product

King crab is produced in the form of canned and frozen final product in Chile. In Figure 1, we see the production percentages for the years 1977-1982.

Canned king crab averages more than 60 percent of the production for these years. There were sharp decreases in cannery production during the years 1979 and 1982. A decrease in total canned product implies a substitutional effect with frozen products. When companies produce less canned final product, they produce more frozen final product, assuming a constant supply from fishermen.

Fleet Ownership

We know that there are basically five different kinds of vessels used in this fishery. From data collected through personal communications with the companies, plus data provided by SUBSEP, we conclude that the companies own Pesqueros Multiproposito, Cuters and some lanchas. Chalupas and botes are mainly owned by local fishermen that sell their catch to the companies. Next, in Table IV, we describe the fleet owned by the private companies.

Table IV shows differences in the size of fleets maintained by the different companies. The largest fleet is operated by Pesquera Magallanes, followed by Pesquera McLean and Pesquera Cabo de Hornos.

Geographic Distribution of Production Facilities and Company Central Offices

Most king crab processing companies have their central offices in the capital of Chile, Santiago. Santiago is located approximately on latitude 32° south, 100 km inland from the main Chilean port, Valparaiso. A list of addresses for the larger companies follows:

Pesquera Cabo de Hornos
Moneda 812-OF. 704
TX 44001 ITT CZ Cabo de Hornos

Pesquera Magallanes
MacIver 125 Piso 15°
TX 240434 Camel CL
Santiago, Chile

Pesquera Dos Oceanos
Moneda 856-OF. 409
TX 240735 Menen CL
Santiago, Chile

Pesquera McLean
Casilla 32-D
Punta Arenas, Chile

Pesquera Garay
Correo Punta Arenas, Chile

Pesquera Punta Mar
Correo Punta Arenas, Chile

Table I. Number of Exporting Companies 1979-1982

1979	1980	1981	1982
13	15	12	18

Source: ODEPA Statistics

Table II. Chilean King Crab Industries, Season 1980-81 and Production Type Capabilities

Industry	Canned Product	Frozen Product
Pesquera Dos Oceanos		X
Pesquera Cabo de Hornos	X	X
Pesquera Garay		X
Pesquera Magallanes	X	X
Pesquera Punta Mar		X
Coop. Pescadoes de T del Fuego	X	
Pesquera Polo Sur		X
Soc. Pesquera McLean	X	

Source: Instituto de la Patagonia

Table III. Industrial Processing Capabilities in King Crab Industry XII Region

Company	Frozen Rm tons/day	Canned Rm tons/day
Pesquera Dos Oceanos	30.0	----
Pesquera Cabo de Hornos	30.0	7.5
Pesquera Garay	4.0	----
Pesquera Magallanes	28.0	40.0
Coop. Pescadores Tierra del Fuego	----	3.0
Pesquera Pdo Sur.	4.0	----
Soc. Pesquera McLean	----	12.0
Pesquera Vasquez	19.0	----

Source: Sernap. Personal Communication

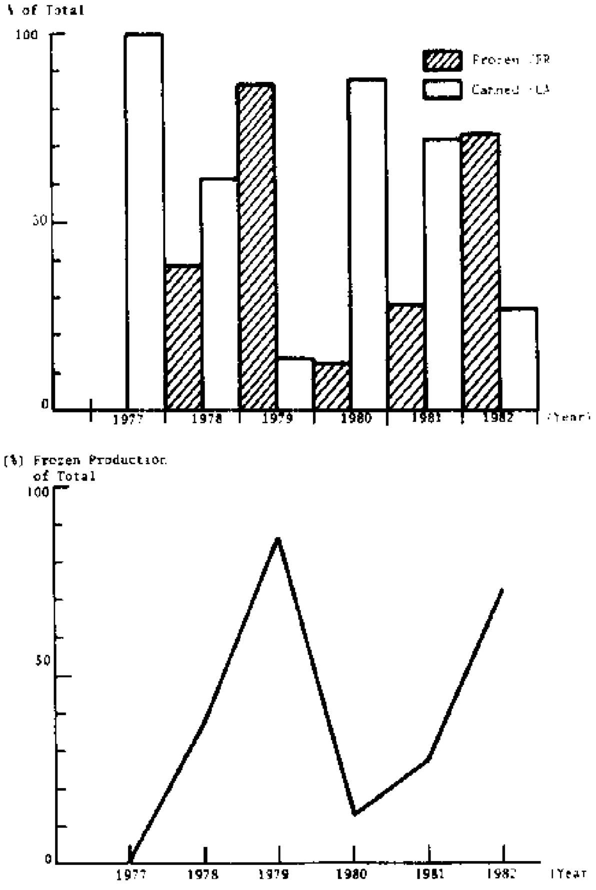


Figure 1. Production Share, (Frozen-Canned) Chilean King Crab
Source: ODEPA Statistics

Table IV. Fleet Owned by the King Crab Fishing Companies

Name	Fishing System	Gross Tons	Carrying Capacity (M3)	Year	Construction	Engine h.p.
Pesquera Magallanes						
Zeus	Trap	22	25	1977	Steel	220
Minerva	Trap	22	25	1977	Steel	220
Pluton	Trap	22	25	1977	Steel	220
Alacran II	Trap	140	86	1960	Steel	500
Dona Mercedes	Trap	98.16	54	1964	Steel	320
Camelio I	Trap	98.16	54	1964	Steel	325
San Pedro	Trap	105.60	83	1963	Steel	300
Pacifico I	Trap	125.20	80	1963	Steel	320
Halcon	Trap	24	180	1974	Wood	220
Delfin	Trap	24	160	1974	Wood	220
Albacora	Trap	30.81	15	1973	Wood	220
Don Pablo	Trap	----	---	----	Wood	24
Dona Carmen	Trap	----	---	----	Wood	24
Dona Ema	Trap	----	---	----	Wood	24
Dona Generosa	Trap	----	---	----	Wood	24
Claudia	Trap	----	----	----	Wood	24
Liliana	Trap	----	----	----	Wood	24
Dona Genoveva	Trap	----	----	----	Wood	24
Silvia	Trap	----	----	----	Wood	24
Rossana	----	----	----	----	Wood	no engine
Chaguita	----	----	----	----	Wood	no engine
Paola	----	----	----	----	Wood	no engine
Silvana	----	----	----	----	Wood	no engine
Don. Humberto	----	----	----	----	Wood	no engine
Pesquera Cabo de Hornos						
Victoria	Trap	34.17	36	1979	Steel	165
Jeanar	Trap	62	36	1972	Wood	170
Akade	Trap	75.65	100	1960	Steel	200
Palao Miat	Transport.	130.55	100	1969	Steel	365
Alce	Trap	16	107	1977	Wood	20
Pesquera Dos Oceanos						
Cecilia I	Trap	20	5	1970	Wood	75
Cecilia II	Trap	25	8	1982	Wood	120
Nord See	Trap	64.54	40	1963	Steel	240
Zeebruge	Trap	34.27	17	1970	Wood	155
Destendes	Trap	34.27	17	1970	Wood	155
Gloria	Trap	----	3	1981	Steel	60
Pesquera Vasquez						
Sagitario	Trap	----	----	----	Wood	25
Viegjolbo	Trap	----	----	----	Wood	25
Gauchita	Small	----	----	----	----	----
	Boat	----	----	----	Wood	----
Bucanero	Trap	----	----	----	Wood	36
Acuario	Trap	----	----	----	Steel	20
Machote	Trap	----	----	----	Wood	40
Angelica	Trap	----	----	----	Wood	20
Patricio	Trap	----	----	----	Wood	20
Coop. Pescadores Tierra del Fuego						
Copetif	Trap	24.42	32	----	Wood	87
Pesquera McLean						
Navarino	Trap	14.55	16	1946	Wood	190
Petrolaue	Trap	35	75	1957	Steel	155
Cristian I	Trap	30.10	19	1977	Wood	125
Cristian II	Trap	20.0	24	1978	Wood	150
22 de Septiembre	Trap	9.9	----	----	Wood	22
Porfin	Trap	----	----	----	Wood	22
Virginia	Trap	----	----	----	Wood	22
Matita	Trap	----	----	----	Wood	22
La Nina	Trap	----	----	----	Wood	22
Diana	Trap	----	----	----	Wood	22

Source: Sernap - Personal Communication

Pesquera Vasquez
Correo Punta Arenas, Chile

Soc. Pesquera Polo Sur
Correo Punta Arenas, Chile

Coop Pescadores de T del Fuego
Almirante Senoret
s/n Puerto Porvenir, Chile

Production Facilities

Most production facilities are located in Region XII, 45° south to 55° south. In this region, most processing plants are located in the city of Punta Arenas. The geographic distribution of the plants is as follows:

Pesquera Magallanes
Pesquera Cabo de Hornos
Pesquera Dos Oceanos -- Punta Arenas
Pesquera Garay
Pesquera Vasquez
Coop Pescadores Tierra del Fuego -- Puerto Porvenir
Pesquera Polo Sur -- Puerto Natales
Pesquera McLean -- Bahia Virginia Navarino Island

Figure 2 shows the location of the companies' processing plants in Region XII.

Labor Force

For the season 1980-81, the industry generated employment for about 1500 people that worked in processing plants. The estimated number of fishermen in this fishery was 550, most of them working for the industry and laboring onboard cutters and Pesqueros Multi-proposito.

KING CRAB EXPORTS

Chilean exports of king crab began in 1960, with a small number of destination markets and a small volume of exports. The export value of king crab has shown a large increase between 1972 and 1980. In terms of the percentage of total Chilean exports, king crab represent just 0.015 percent of the total exports by the fisheries sector of the economy in 1972. By 1980, this value had increased to 1.22 percent. This represents over a 100,000 percent increase in eight years.

Chilean king crab is exported to many areas in a variety of canned and frozen products, but mainly to South America, North America, and Europe.

Exports by Volume and FOB Value

As stated before, the Chilean exports of king crab registered a strong increase between 1972 and 1980. In Figure 3, we can see this increase with just $4,600 (FOB) exported in 1972 and $6,144,000 (FOB) exported in 1982. A possible explanation for this increase in exports could be the favorable conditions of demand in the international market and the creation of new companies in Chile that increased the supply of the product.

In terms of volume exported, the statistics available range from 1977

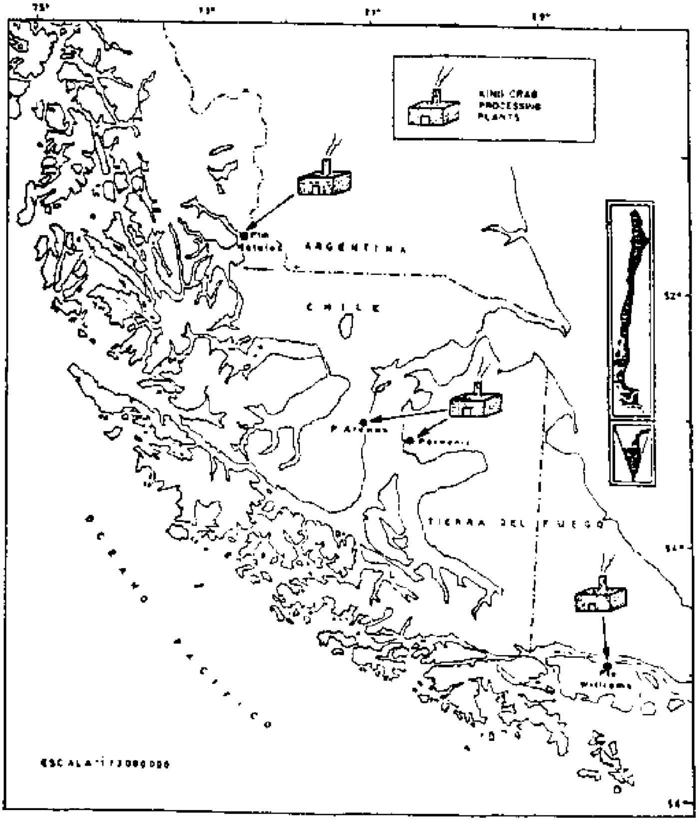


Figure 2. Geographic Distribution of Processing Plants
Source: SERNAP, Pro-Chile and Personal Communication

to 1982 and show an increase in volume exported from 148,558.0 (kn) in 1977 to 308,534.0 (kn) in 1980. In 1982, exports were 496,193.0 (kg).

According to Figure 4, we can see a decline in the export of king crab in 1981. This is possibly due to the international economic recession period in developed countries, the principal buyers of Chilean king crab. Not only high value exports such as king crab decreased, but all Chilean exports decreased during this time.

Nineteen-eighty-two was the peak year for Chilean exports of king crab, with 496,193 (kg) of the final product exported. The increase in 1982 exports might be explained by favorable conditions of demand in the international markets.

Seasonal Variations of Chilean Exports

As a basis for determining whether there is any seasonal variation in the exports of king crab from Chile, monthly data given by ODEPA from the years 1979 to 1982, estimating the exports in volume (kg) were analyzed. The results of this analysis can be observed in Figure 5, in which exports for each month are plotted.

From these figures, we can see that most of the exports are concentrated in the first and last quarter of each year. More than 60 percent of the exports occur within this period. Especially significant is the year 1979, in which 90 percent of the exports occurred. Also, we noticed that in three of the four years studied, the first quarter of the year registered a higher export level than the last quarter.

International Market Share

Chile exports king crab to a variety of world markets. To analyze the importance of these markets, they were divided into: Europe, North and South America, and the Orient countries.

From 1977 to 1982, the major portion (61 percent) of the king crab exports, canned and frozen products, went to the European markets (Figure 6). The remaining 38 percent was distributed between South and North America, with a very small percentage going to the Orient.

We need to define the market share in terms of canned products versus frozen products to determine in what proportion the different kinds of products are allocated to different markets.

Canned

As seen in Figure 7, the major portion of canned products goes to the European market, which averages 84 percent from the years 1977-1982. Most of the remaining percentage of exports goes to North and South America, with a small percentage going to markets in the Orient.

Frozen

In terms of frozen products (Figure 8), the exports are mainly distributed in North America, (particularly the United States) which averages 71 percent of the frozen king crab exports between the years

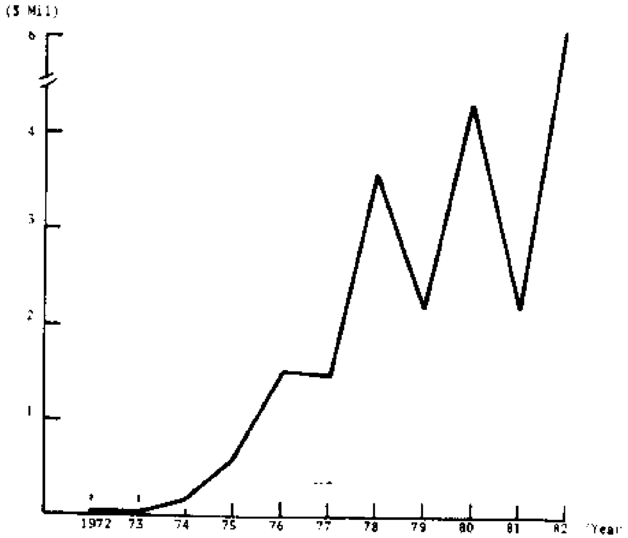


Figure 3. Chilean Exports of King Crab in $ (FOB) - 1972-1982
Source: ODEPA and SUBSEP

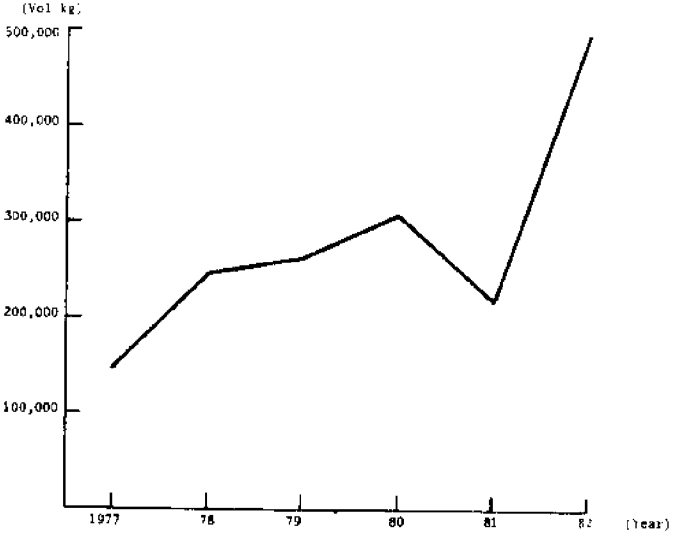


Figure 4. Chilean Exports of King Crab in Volume (kg) - 1977-1982
Source: ODEPA and SUBSEP

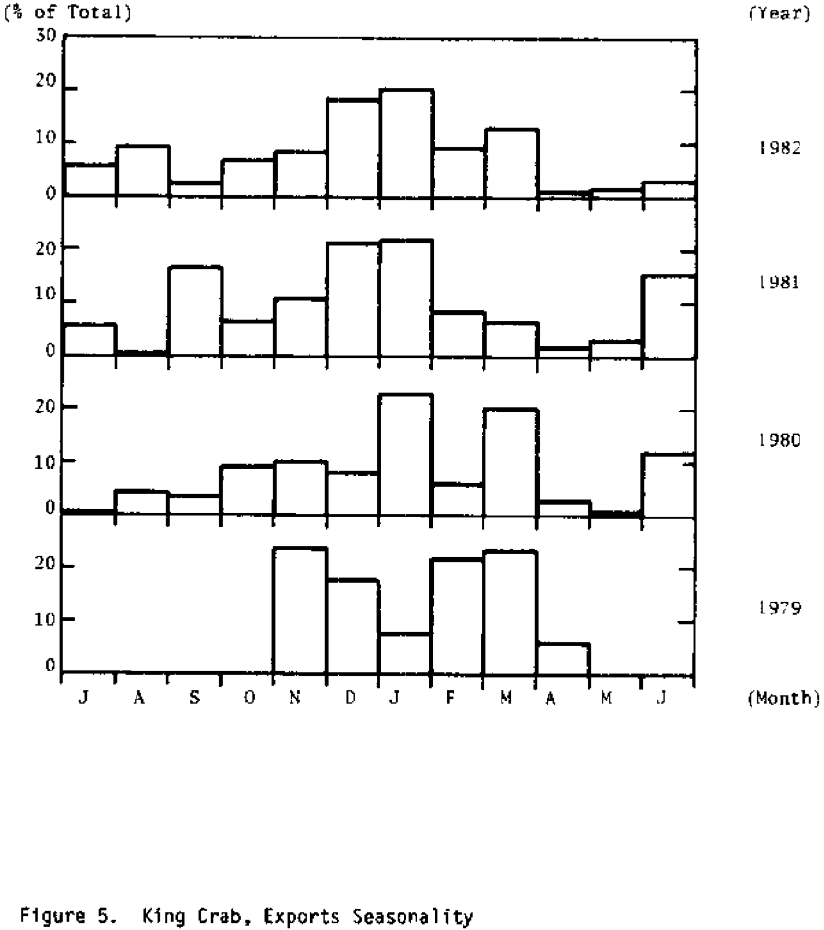


Figure 5. King Crab, Exports Seasonality
Source: ODEPA

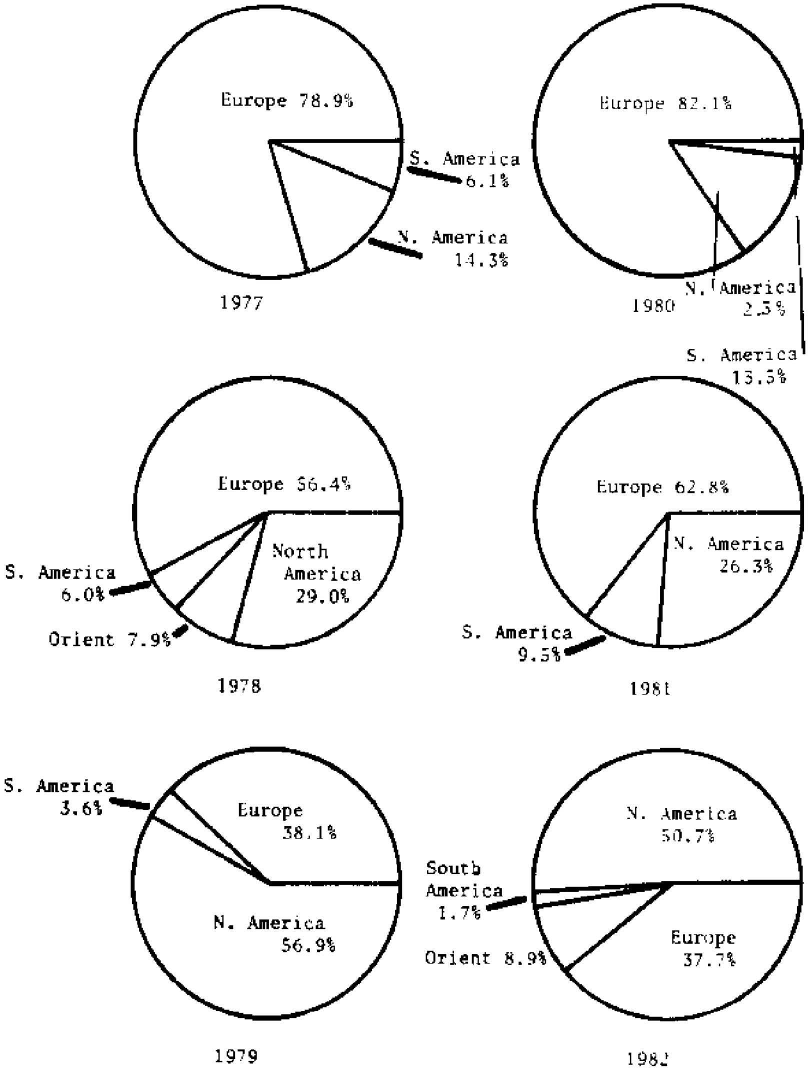
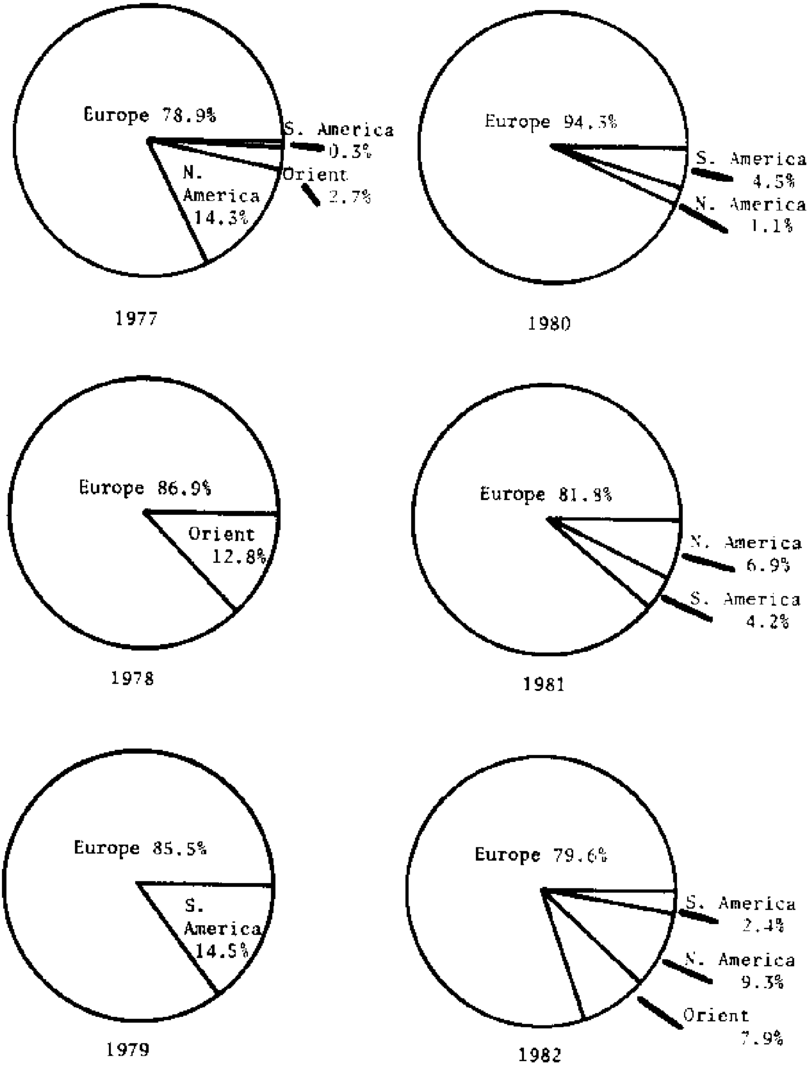


Figure 6. Percentage of Exports by Market of Total Volume Exported
Source: ODEPA



1977

1980

1978

1981

1979

1982

Figure 7. Canned Production - Market Share (Exports)

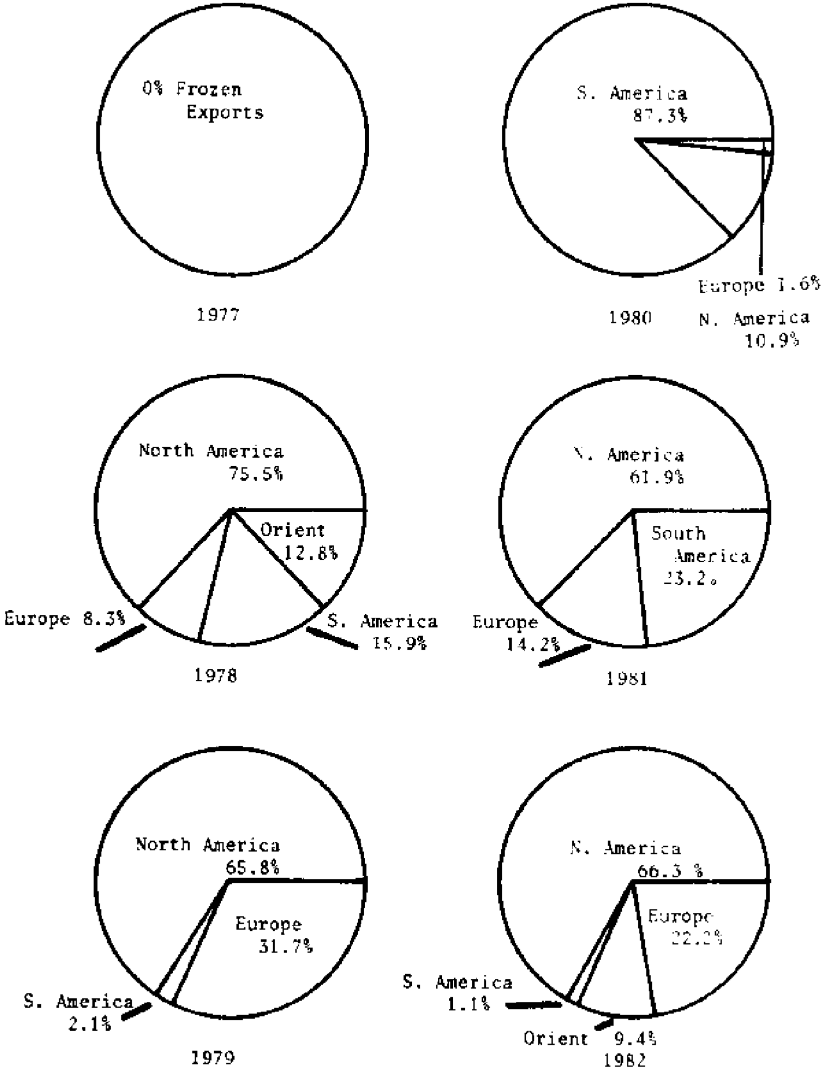


Figure 8. Frozen Products - Market Share (Exports)

1977 and 1982. There is not a clearly defined second market area for this type of product.

Product Qualities and Types

From the variety of countries to which Chile exports king crab, we can infer that there is also a number of different product forms and types that have to be exported in order to satisfy the different tastes and preferences of the consumer markets.

We have a wide range of products that can basically be divided into frozen and canned. From this division we have the following specific products exported:

Canned

Table V gives us the most common specifications for exports of canned king crab. Reviewing the export statistics given by ODEPA, we find that the net weight and the number of cans per box vary greatly so we see box net weights of 3.6kg, 4.3kg, 4.8kg, 4.9kg, 5.0kg, 5.7kg. 8.6kg, 9.6kg, 11.5kg, and 20kg. This fact reaffirms that companies have a great degree of flexibility to cope with specific market demands for this product. Probably this flexibility is due to the high price that king crab reaches in the markets mentioned earlier.

Frozen

For the frozen products, we also found different kinds of products as in Table VI.

As with the canned products, we also find variety in box weights, for example: 5kg, 9.0kg, 10.7kg, 15kg, 20kg, 27kg, 27.2kg, 27.3kg.

The block composition is typically 40 percent red meat, 60 percent white meat, and the structure is:

Red Meat Topping
White Meat
Merus

This block structure is also called "Sandwich Type".

Marketing Aspects

In terms of value, the king crab exports represent only one percent of the total Chilean fisheries exports.

The domestic market for king crab in Chile is almost non-existent. The statistics of distribution at a wholesale level do not show any sales at all in Santiago, which is a major center of consumption for seafood products. Faced with this situation locally, the industry has focused on international markets. There is, as we have seen, a demand for Chilean king crab in Europe and in the United States.

A problem faced by the Chilean producers of king crab is the confusion between the Northern and Southern Hemisphere versions of the species, which have different qualities and scientific names. From personal communication with exporters in Chile and importers in the United States and Europe, we have learned about this confusion and the implications for this product. There is no visible association or organization in Chile that has dealt specifically with this problem, but we do hear complaints from Chilean producers about lower prices for their products.

Recently, Chilean companies have engaged in market research to try to solve these types of problems. They have hired private consultants they also use the new offices of the Chilean Trade Promotion Bureau in San Francisco, and New York City, both part of the Chilean diplomatic service in the United States.

The U.S. - Chile King Crab Relationship

As we know, U.S. production of king crab has substantially declined in the last four years (Table VII).

The landing figure for the year 1983 is the lowest in the history of the resource.

If we compare the landing figures with the animal size frequency found in the last evaluation for the king crab resource in Alaska (NMFS, 1982), the conclusion is that there is not going to be an immediate recovery for this resource. Through personal communication with one of the main researchers in this study, it was possible to confirm that the low catches are projected to continue for three to four more years. What is even worse is that apparently we have not reached the trough of the curve in terms of catch level, so we can expect further declines in catches for the next few years.

This creates a situation in which the quantity of king crab demanded is greater than the supply, with a consequential upward pressure on price.

U.S. producers, wholesalers, and retailers are faced with the problem of looking for a new source of supply to meet the market demands.

Up to this point, and exploring the potential suppliers for the U.S. market, Chile appears as a feasible possibility.

Now I would like to focus on some market aspects of the United States vs. Chile that were found to have an interesting correlation and are of interest to our analysis.

Chilean Industrial Production Share and U.S. Imports from Chile

We can see from the graph in Figure 9 that the U.S. imports of king crab from Chile in tons and the Chilean production of frozen products in volume tons of the total production are correlated.

We know that U.S. king crab imports are mostly of frozen products; we also know that the Chilean production is either frozen or canned. From the graph, we can see a high correlation between the two variables: whenever U.S. imports of king crab increase, there is increase in the frozen production in Chile (see correlation in Appendix). This fact is possibly due to the high prices reached by the frozen products.

Shifts in the Market Share of Chilean Exports

Chile exports king crab to a wide variety of markets. In order to

Table V. King Crab Can Packaging

Commodity	Type of Can	Weight GRS Net	 Drained	Packaging	Box lg.
King Crab, in brine	Tin 307x113	180	130	24x180	4.3
King Crab, in brine	Alum 67	240	175	24x200	5.7
King Crab, pate	Alum 69	100	90	48x100	4.8
King Crab, pate	Alum 69	210	150	24x210	5.0
King Crab, white		110		48x110	5.2
King Crab, mix		110		24x2x110	5.2

Source: Pesquera Magallanes and Pesquera Cabo de Hornos

Table VI. Frozen King Crab Packaging

Commodity	Type of Block	Packaging	Box (kg)
Frozen Meat	500 gr.	18x500	9.0
Frozen Meat	250 gr.	36x250	9.0
White Meat	500 gr.	18x500	9.0
White Meat	250 gr.	36x250	9.0
Cooked Meat			10.7
Legs & Claws			5.0
Claws			5.0
Meat with Shell			27.0
Whole Shell			27.0

Source: Pesquera Cabo de Hornos

Table VII. U.S. Landing of King Crab

Year	1979	1980	1981	1982	1983
Thous. lbs.	149,660	185,034	88,054	34,500	18,000

Source: National Marine Fisheries Service analyze the market share of the United States, we present the graph in Figure 10. In Figure 10, we see that the largest amount of exports to North America as a percentage of the total are for the years 1979 and 1982, with lower exports in 1977 and 1980. This data coincides with the data from Figure 9, in which high exports and low exports occur at the same time.

The Increasing Chilean Supply

Another related aspect of the situation is the potential for increasing supply in Chile. From Figure 11, it is clear that since 1981 U.S. production has been declining and Chilean production has been increasing. If we consider the factors leading to that increase, including the number of companies entering the king crab market in Chile and the new fishing grounds, then we can predict a continuing increase in production in Chile, assuming that U.S. production continues its declining trend.

Correlation Between Variables

As a way of integrating some of the variables mentioned, they are shown in Figure 12: Chilean landings of king crab, Chilean exports of king crab to the United States, total Chilean exports of king crab, and production of frozen products in the Chilean industry (by tons).

The data shown is from the years 1977-1982. From this graph, we can observe a correlation between Chilean landings, Chilean exports to the United States, and frozen production in Chile. In order to prove this correlation, linear regression for these variables was developed with this data. The program used is: HP-41 CV, STAT 1-BSTAT.

The results were:

R_1) x = frozen production in Chile (tons)
y = Chile exports to United States (tons)
$r = 0.99$

R_2) x = frozen production in Chile (tons)
y = total Chilean exports (tons)
$r = 0.83$

R_3) x = frozen production in Chile (tons)
y = U.S. landings of king crabs (total pounds)
$r = -0.50$

R_4) x = Chile exports to United States (tons)
y = U.S. landings of king crabs (total pounds)
$r = -0.58$

The results suggest that there is a high correlation between the production of frozen products in Chile and the Chilean exports to the United States. If the Chilean exports to the United States increase, then the frozen production in Chile increases. Also, if the total Chilean exports increase, we observe an increase in production of frozen products.

On the other hand, there is an inverse relationship between the U.S. landings of king crab and the Chilean production of frozen king crab.

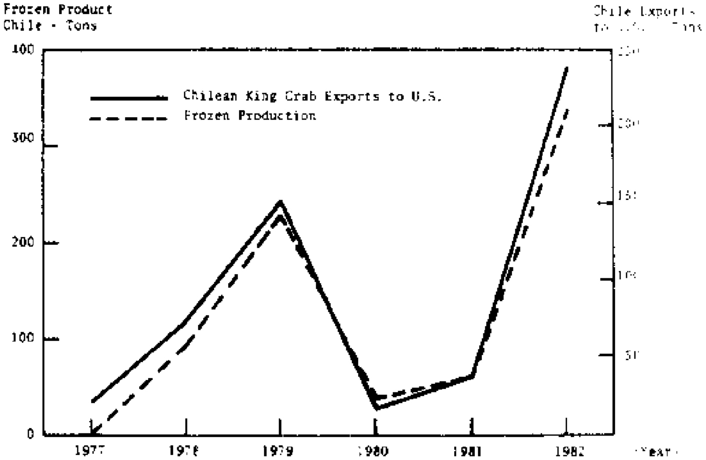


Figure 9. The Relationship Between U.S. Imports and Chilean Production
Source: ODEPA

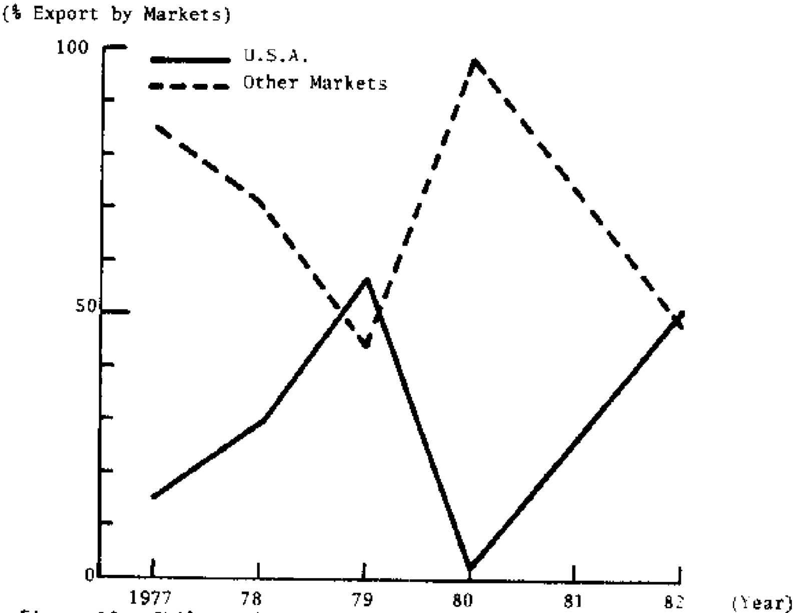


Figure 10. Chilean King Crab Exports to the United States and Other Markets

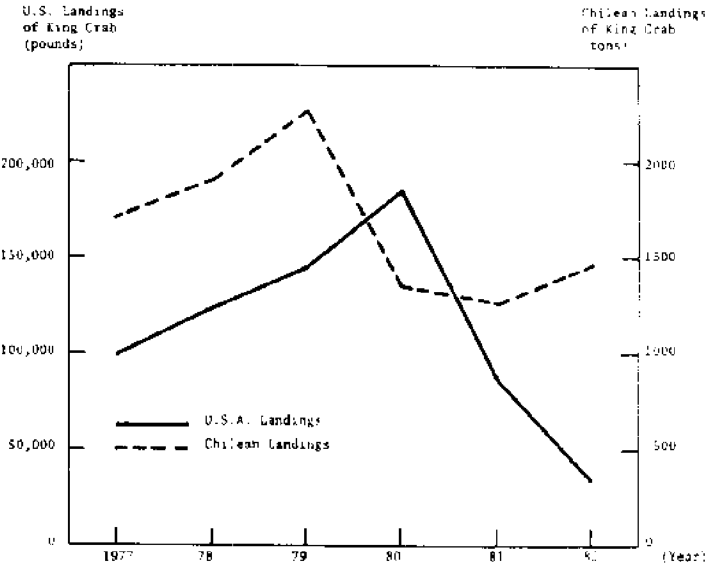


Figure 11. Chilean and U.S. Landings of King Crab
Source: Seafood Business Report and SERNAP

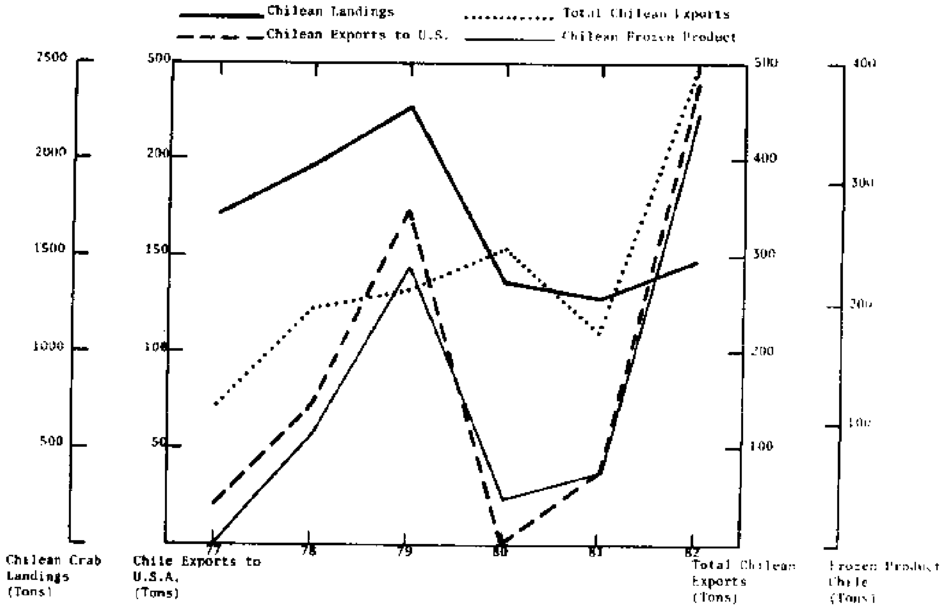


Fig. 12 The Relationship Between King Crab Trading and Production Variables

This means that if the U.S. landings decrease, then we observe an increase in the Chilean production of frozen products. The same inverse relationship was found for the U.S. king crab landings and the Chilean exports to the United States. If the U.S. landings decrease, we observe a higher level of Chilean exports to the United States.

These relationships are very important because they indicate an increasing interdependence between the United States and Chile for the development of the international king crab market.

The Company's Attitudes

The Chilean king crab industry is important in satisfying the market shortage in the United States. Through personal communications with industry executives, we have learned about recent mergers between Chilean king crab companies and frequent meetings between the executives of the main companies in both countries which are intended, according to our contact's own words, to end in joint ventures in which the Chilean king crab would be sold in the U.S. market under the brand name of important and prestigious U.S. companies in the business.

We have also learned that, due to some problems with the Food and Drug Administration with respect to the legal name under which the Chilean king crab could be sold in the United States, few of the marketing and business efforts of the U.S.-Chilean companies have come to fruition up to now.

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APPENDIX

1. Chilean Landing Series (tons)
2. Chile, Production Share of King Crab (%), (kg)
3. Chilean Exports of King Crab (U.S. $ - FOB), (kg)
4. Linear Regression Data

Chilean Landing Series (tons) A-1

YEAR	LANDING
1970	428
1971	372
1972	391
1973	355
1974	511
1975	609
1976	1,028
1977	1,721
1978	1,408
1979	2,265
1980	1,351
1981	1,280
1982	1,473

Chile Production Share King Crab (%), (kg) A-2

YEAR	FROZEN	%	CANNED	%	TOTAL
1977	0	0	148,558	100.0	148,558
1978	95,118	38.4	152,378	61.6	247,496
1979	231,182	86.4	36,121	13.5	267,303
1980	36,521	12.5	270,013	87.5	308,534
1981	61,791	28.1	158,256	71.9	220,047
1982	361,423	72.8	134,770	27.2	496,193

Chilean Exports of King Crab (U.S., $-FOB), (kg) A-3

YEAR	1*	2**	3***
1972	4,600		
1973	3,100		
1974	161,900		
1975	596,700		
1976	1,512,300		
1977	1,470,672	148,558	21,309
1978	3,577,536	247,496	71,820
1979	2,197,397	263,303	152,329
1980	4,634,248	308,534	1,576
1981	2,206,339	220,047	38,268
1982	6,144,000	496,193	239,790

1* Chilean Exports of King Crab (U.S. $-FOB)

2** Chilean Exports of King Crab Volume (kg)

3*** U.S. Imports of Chilean King Crab (kg)

LINEAR REGRESSION DATA*

A-4(a)

	1977 1	1978 2	1979 3	1980 4	1981 5	1982 6
X_i	1,721	1,908	2,265	1,351	1,280	1,473
Y_i	0	95.12	231.182	36.521	61.791	361.423
Z_i	21.309	71.820	152.329	1.576	38.268	239.790
D_i	148.558	247.496	263.303	308.534	220.047	496.193
E_i	99,600	127,930	144,660	185,034	88,054	34,500

X_i = Landings (tons) Y_i = Frozen product-Chile (tons)
Z_i = Chile export to U.S. (tons) D_i = Total Chilean export (tons)
E_i = U.S. Landings king crab (thousand pounds)

* 41CV Hewlett Packard, Stat 1-Prog-8 Stat

LINEAR REGRESSION DATA

A-4(b)

X_i/Y_i	Y_i/Z_i	Y_i/D_i	Y_i/E_i	Z_i/E_i
$\bar{x}$ = 1666.33	$\bar{x}$ = 131.01	$\bar{x}$ = 131.01	$\bar{x}$ = 133.01	$\bar{x}$ = 87.52
$\bar{y}$ = 131.01	$\bar{y}$ = 87.52	$\bar{y}$ = 280.69	$\bar{y}$ = 113.30	$\bar{y}$ = 113.30
sx = 275.73	sx = 138.05	sx = 138.05	sx = 138.05	sx = 91.46
sx = 342.99	sx = 126.03	sx = 126.03	sx = 126.03	sx = 83.50
sy = 138.05	sy = 91.46	sy = 118.12	sy = 52.14	sy = 57.14
sy = 126.03	sy = 83.50	sy = 107.83	sy = 47.60	sy = 47.60
vx = 22.55	vx = 105.38	vx = 105.38	vx = 105.38	vx = 104.51
vy = 105.38	vy = 104.51	vy = 42.08	vy = 46.02	vy = 46.02
sxy = 11224.98	sxy = 12468.95	sxy = 13596.33	sxy = 3619.13	sxy = 2761.64
sxy = 9354.16	sxy = 10390.79	sxy = 11330.27	sxy = 3015.94	sxy = 2301.37
gxy = 0.22	gxy = 0.99	gxy = 0.83	gxy = -0.50	gxy = -0.58
Σx = 9998.00	Σx = 786.04	Σx = 786.04	Σx = 786.04	Σx = 525.09
Σy = 786.04	Σy = 525.09	Σy = 1684.13	Σy = 679.78	Σy = 579.78
Σxy = 1365924.62	Σxy =131135.04	Σxy =288613.10	Σxy = 70959.46	Σxy =45687.79
Σx^2=17365860.00	Σx^2=198271.43	Σx^2=198271.43	Σx^2=198271.43	Σx^2= 8778.48
Σy^2= 198271.43	Σy^2= 87782.48	Σy^2=542473.62	Σy^2= 90611.40	Σy^2=90611.00

Proc. Int. King Crab Symp.
Jan. 1985, Anchorage, Ak.

Management of Alaskan king crab stocks in relation to the possible effects of past policies

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Abstract

The historical development of management measures for Alaskan king crabs is reviewed and interpreted in light of their effects on stocks and fisheries. Current management policy is analyzed according to how well it can meet underlying goals under various stock and fishery conditions. Results suggest that management measures to protect product quality and prevent growth overfishing have been more effective than those designed to ensure stability of harvests.

Introduction

The development of management measures for king crabs in Alaska dates from about 1941 (possibly earlier), when the first legal size limit was established. Prohibitions against retaining females and soft-shelled males quickly followed. All three regulations were in effect throughout Alaska by 1942. Since that time, management policy and implementing regulations have evolved from a system designed primarily to prevent waste of resources, protect reproductive capacity, and increase product quality, toward a system also intended to stabilize catch and optimize exploitation rates. The set of regulations that has developed places considerable emphasis on biology, but economic factors are also involved (Katz and Bledsoe 1977). Stated policies of the Alaska Board of Fisheries (ABOF, State of Alaska) and the North Pacific Fishery Management Council (NPFMC, U.S. Federal Government) are similar, although the Fishery Management Plan for western Alaska king crab (NPFMC 1984) contains considerably more social and economic rationale than is contained in ABOF policy statements (ADF&G 1970, 1975, 1985).

In this report I outline management policies and regulations and present examples of how well they work in achieving underlying goals. The examples are largely from the Bristol Bay stock of red king crab

(Paralithodes camtschatica) and its fishery. My treatment of economic factors is general or even cursory because I lack expertise in this area, and because formal economic analyses have played a small role in king crab management policy. The analyses presented are a preliminary step in examining whether regulations imposed on king crab fisheries are likely to achieve their intended purposes, rather than being a proposal to change policies.

Management Agencies, Policies and Goals

Alaskan king crab fisheries began in the 1930s and were managed by the federal government (U.S. Fish and Wildlife Service) until 1959 when Alaska became a state. During this period, fisheries were being developed by the United States, Japan, and the Soviet Union. In 1959, the state of Alaska assumed authority over domestic fisheries, while the federal government continued its involvement through scientific research and through fishery negotiations with Japan and the Soviet Union. Foreign king crab fisheries were primarily confined to the Bering Sea and domestic fisheries occurred mainly in the Gulf of Alaska or the eastern Aleutians. The United States ratified the 1958 Continental Shelf Convention in 1964 and declared king crabs as "Creatures of the Continental Shelf" that were, hence, manageable in waters beyond the three nautical mile (5.6 km) territorial sea. Bilateral fishery negotiations were established with Japan and the Soviet Union in 1964 and have been held biennially ever since. Bilateral negotiations and the declining abundance of king crabs led to the cessation of foreign king crab fishing in Alaskan waters after 1974. Since 1974, all king crab fisheries in Alaskan waters have been managed by the state of Alaska.

In 1976, the U.S. Congress passed the Magnuson Fishery Conservation and Management Act (MFCMA), which mandated federal management of fishery resources between three and 200 nautical miles (5.6 to 370.4 km) off U.S. shores and established regional fishery management councils as planning and regulatory bodies. The NPFMC has developed a fishery management plan (FMP) for king crabs (NPFMC 1984) in western Alaska (excluding the Gulf of Alaska east of 165°W longitude) that enables continued state management within MFCMA guidelines and with federal oversight. The U.S. Department of Commerce (1984) published a final rule to implement the NPFMC plan that takes effect "upon receipt by the Secretary [of Commerce] of a statement signed by the Governor of Alaska accepting delegation on behalf of the State." The plan is not yet in effect although the NPFMC and the ABOF have been meeting jointly to consider regulatory changes in Bering Sea and Aleutian Islands king crab fisheries since 1981.

Within Alaska, fisheries are managed by the ABOF and the ADF&G. The Board of Fisheries consists of seven members appointed by the governor. The board considers regulatory changes proposed by the public or by ADF&G, receives testimony concerning proposals and decides on regulatory changes. The board may modify proposals according to its discretion on the basis of testimony. The ADF&G deals with all fish and game resources of the state and is headed by a commissioner appointed by the governor for a five-year renewable term. Within ADF&G, the Division of Commercial Fisheries is primarily responsible for king crab management although, in some areas of the state, the Division of Subsistence may also be concerned. The latter organization is the portion of ADF&G that is assigned to deal with harvest of fish or game for personal use as food rather than for sporting or commercial purposes. Subsistence utilization of fish and game has the highest priority in allocating resources, followed by commercial and then sporting use. For king crab, this prioritization is only of practical importance in northern areas of the Bering Sea such as Norton Sound (ADF&G 1983).

The process of establishing or reviewing regulations relies heavily on public discussion and testimony. Any interested party may submit a proposal to change existing regulations. Proposals are reviewed by the ADF&G staff and by local advisory boards. Local advisory boards consist of fishermen, processors and other interested parties and are located in communities throughout Alaska. They review proposals and recommend changes in them as well as recommending whether or not proposals should be passed by the ABOF. The ABOF considers recommendations of local advisory boards and ADF&G staff comments, as well as the proposals, at its spring meeting (March or April). Most of the socioeconomic input to king crab management results from the testimony and discussion that accompanies review of proposed regulatory changes.

Regulations are published annually (e.g. ADF&G 1985) and contain a statement of "Policy on King Crab Resource Management", which is as follows:

> "The policy of the Board of Fisheries is to manage the Alaska king crab fishery in a manner that establishes stability and eliminates, as much as possible, extreme fluctuations in annual harvest that have at times characterized this fishery. The Board recognizes that this policy will not maximize physical yield because maximum physical yield will not necessarily produce the long-term optimum economic yield."
>
> "Achievement of such management depends on the maintenance of crab stocks that are comprised of various age classes of legal-size crab rather than creating an industrial dependency upon annual recruitment. Maintaining controlled fishing on several year classes will reduce fluctuations associated with variable recruitment."
>
> "The resource should be monitored annually to provide information reflecting abundance of pre-recruits, recruits and post-recruits. As the population abundance and structure change, the harvest rates on the legal portion should also change so as to ensure that an appropriate portion of crab are carried over to subsequent years' fisheries. The Board may permit the harvest of additional older crab nearing the end of their life span, when such crab are considered surplus to the breeding requirements of the stocks."
>
> "The resource should be managed conservatively when there is insufficient information about the stocks."
>
> "The benefits of maintaining several year classes in the fishery are most apparent when weak recruitment enters the fishery. When year classes have been partially protected by controlling harvest rates, there will be enough older crab to reduce the decline in catch and maintain adequate brood stock."

> "Sustained levels of king crab production also require the protection of stocks from harvest during periods of their life cycle. Closure of the fishing season is necessary during annual migration into shallow water at which time king crab become soft through molting, school and subsequently mate. It is further recognized that following periods of peak molting, king crab are unacceptable for commercial utilization until they have sufficiently reestablished an acceptable meat to body weight ratio, the shells have hardened adequately, and can be handled with minimal mortality or damage. The Board will establish fishing seasons based on the best biological information within each area."

As I interpret it, this statement contains goals of 1) establishing stability in landings; 2) producing long-term optimum economic returns; 3) protecting reproductive potential; 4) maintaining product quality; and 5) ensuring that appropriate information is available. The first two of these seem to be equated in the concept of "stability". Stability is to be achieved by maintaining several year classes of legal-size crab through controlling fishing. Reproductive potential is also associated with stability but is separable from it because its maintenance involves unharvested portions of populations. The remaining two goals are discrete, although the information gathered is clearly intended to foster stability.

The federal plan (NPFMC 1984) contains a "primary objective": "maintaining the resource base by optimizing the reproductive potential of individual king crab stocks"; and "secondary objectives": 1) "optimize the net value of the fishery"; 2) "minimize socioeconomic impacts of conservation and management"; 3) "minimize adverse interactions among fisheries"; and 4) "optimize the cost effectiveness of management and enforcement." Rationale given for the primary objective espouses protection of reproduction potential but recognizes that maximizing reproductive potential may be unnecessary (or even detrimental) at high levels of stock abundance (Reeves and Marasco 1980). Rationale for optimizing net value (1) encompasses the board policy of stability, but also includes the concept of avoiding management measures that place "additional burdens on industry." The objective of minimizing socioeconomic impacts (2) includes protecting "harvesting and processing systems and community infrastructures" from "economic dislocation" or adverse "social impacts" and also ensures continuation of subsistence fisheries. Minimizing adverse interaction among fisheries (3) includes scheduling fishing seasons, dealing with problems involving incidental catch, and avoiding conflicts over fishing grounds. Optimizing management and enforcement costs (4) means limiting costs "relative to the value of the fishery" and espouses management measures that are clearly intended to ensure compliance with regulations.

I could not assume that the ABOF policy statement contained all the goals of the state's king crab management system because some regulations (requiring gear to be stored in specified areas, for example) do not relate to any part of the policy. On the other hand, the FMP has not been implemented but contains the rationale for various state regulations that the plan supports as management measures. Taking the ABOF policy statement in combination with objectives in the FMP, I believe the goals of king crab management are 1) to minimize fluctuations in landings; 2) to optimize economic returns from the fishery; 3) to protect reproductive potential in king crab populations; 4) to ensure high product quality; 5) to ensure availability of information for management; 6) to minimize conflicts between fisheries; 7) to avoid adverse socioeconomic impacts; and 8) to ensure efficient operation of management and enforcement. There is also a general goal of preventing waste, which pervades management or conservation of all fishery resources.

Regulations

Individual regulations usually serve more than one management goal. I will discuss regulations approximately in the order that they were implemented, to allow consideration of the historical development of goals. I have omitted discussion of regulations that deal primarily with administrative procedures. The historical development of regulations was traced from regulations published annually by the U.S. Fish and Wildlife Service and later by ADF&G (e.g. 1985).

Reporting requirements

Reporting of king crab catches by individual vessel operators was required as early as 1941 (possibly earlier). Current requirements include: reporting the company that purchased the catch; the vessel that landed it; the type of gear used; the amount of gear (number of pots, pot lifts); the weight and number of crab landed (including "dead loss"); the dates of landing and capture; and the location of capture. Processing companies are required to report this information for each landing purchased, and vessel operators are required to provide information to the processor at the time of sale. All reports ("fish tickets") are confidential. Reporting requirements serve the goals of ensuring adequate information and of efficient management and enforcement.

Size limits

A size limit of 140mm carapace width was instituted in Cook Inlet by 1941 (possibly as early as 1939) and applied throughout Alaskan waters in 1942. I can find no particular rationale for this size limit, but it may have served to protect females or to prevent the landing of small males that contained little meat. In 1950, the size limit was raised to 165mm in the belief that this size would allow males to spawn at least once before entering the fishery. On the basis of growth and mortality studies in the Kodiak area, the size limit was raised to 178mm in 1963. In 1969, size limits of 146mm and 178mm were applied to the Bering Sea. The lower size limit was in force when foreign fishing was in progress, because foreign fishermen landed smaller crab and the lower size limit allowed U.S. fishermen to compete. In 1972, the upper size limit in the Bering Sea was changed to 165mm in recognition of lower growth rates in the Bristol Bay area. In 1975, a "split season" with a 178mm size limit in the first season and a 203mm size limit in the second season was implemented in Kodiak to allow harvests of extremely large (old) crab that were considered surplus to the reproductive needs of the population. A split season with 165mm and 178mm size limits was allowed for the Bering Sea in 1979.

Size limits are currently set on an area-by-area basis in recognition of differing growth rates. They range from 121mm (Norton Sound) to 191mm (Kodiak second season). They generally are set to ensure that males have two opportunities to molt and mate before entering the fishery and hence serve to protect reproductive potential. Perhaps fortuitously, they also serve to maximize the yield per recruit and hence prevent growth overfishing. Split seasons and size limits are methods of controlling harvests and ensuring multiple age classes of legal size crab; and hence fostering stability. Since smaller crab molt more frequently and contain less meat, size limits also protect product quality.

Prohibition against landing females

This was implemented in Cook Inlet in 1941 and extended to all Alaskan waters in 1942. A separate regulation requires that females (and sub-legal males) must be immediately returned, unharmed, to the sea. These prohibitions primarily serve to protect reproductive potential. The federal plan would allow harvesting of females under some conditions when they were considered surplus to the reproductive needs of the population. This is probably a moot point since the processing industry has never shown any interest in utilizing female crabs.

Gear type

In the early years of the fishery, king crabs were harvested with trawls, tangle nets, and various traps. Tangle nets (a type of bottom gill net) were prohibited in 1954, although their use by foreign fishermen continued in the Bering Sea. Trawls were prohibited in Cook Inlet in 1954, and the prohibition extended to all Alaskan waters by 1960. Currently, king crabs may only be taken in pots or ring nets; and almost all are taken in pots. All pots must have the owner's registration number painted on their buoys. The use of biodegradable twine in pots, to prevent "ghost fishing" by lost gear, has been required since 1981. Crabs and other animals taken in pots can usually be returned to the sea alive. These restrictions contribute to stability in landings, by preventing the destruction of sub-legal males; to protection of reproductive potential, by preventing destruction of females; and to maintenance of product quality, because crab are rarely damaged and hence may be kept alive until processed. Since other species taken in pots are not frequently damaged, the use of pots minimizes conflicts between fisheries. Some species, such as halibut, however, are more likely to be damaged than others, so inter-fishery conflicts are not eliminated. Also, pots may prevent the use of moving gear (trawls, seines, dredges) on some grounds.

Amount of gear

A limit of 15 pots per vessel, instituted in Cook Inlet in 1955, was increased to 30 pots in 1960. Pot limits have been variously applied in different areas of the state except for the Bering Sea and western Aleutians. Currently there is a pot limit of 100 per vessel in the Kodiak and Southeastern Alaska management areas. The first pot limits were set to protect local fleets of small boats from competition with larger, more mobile vessels that could carry more pots. Pot limits tended to increase as smaller vessels, usually salmon seiners, were replaced with larger, multipurpose vessels. Katz and Bledsoe (1977) and Miller (1976) provide a discussion of the allocative effects of pot limits relative to vessel size and mobility. Pot limits have not been approached on the basis of optimizing costs in the manner described by Miller (1983). Pot limits may make fisheries easier to manage because, by slowing vessel catch rates, they make monitoring catch and effort easier. They are not easily enforced. Current regulations require that each pot be marked with a tag that is issued annually by the state in areas where pot limits are in force. Pot limits may serve to increase product quality by ensuring that processing plants are not overloaded and vessels are not kept waiting during unloading. Because they tend to protect local fleets (hence communities) from competition with large, mobile vessels, pot limits may serve the goal of avoiding adverse socioeconomic impacts.

Fishing seasons

Legal seasons were established in 1966 (July 1 to April 30) and are now applied in all areas where red and blue (P. platypus) king crab fisheries occur. Fisheries for golden king crab (Lithodes aequispina) frequently have no closed season. Their primary purpose is to avoid harvesting during molting and mating periods, and to allow time for tissue growth after molting. Current opening dates range from August 1 in Norton Sound to November 15 in Southeastern Alaska. Closures usually occur when the optimum yield has been reached (see below), and seasons have generally been less than eight weeks long since 1975. The timing of fishing seasons relative to one another has allocative effects (Katz and Bledsoe 1977) that partially are dependent on registration requirements (see below). Current fishing seasons clearly serve the goals of maintaining reproductive potential and ensuring product quality. Fishing seasons serve the goal of stability by preventing the destruction of soft-shelled crabs. Because crab seasons currently occur later in the year than salmon seasons, conflicts between fisheries through competition for processing space are minimized. In general, they occur soon enough after the salmon fishery that processing plants are not idle for a long period of time. The timing of seasons thus fosters optimization of economic returns.

For Bristol Bay, the general relationship between fishing season and meat content of king crab has been known since at least 1953 (Fig. 1). The current fishing season begins on September 25. Some increase in product quality might be achieved by delaying the season opening. The current season represents an accommodation between fishermen wishing to avoid poor weather in late fall or winter months, and processors seeking higher meat yield. Data in Figure 1 are also interesting in the context of this symposium because the F/V Deep Sea was owned by Lowell Wakefield.

Gear storage

In most areas, king crab pots may be stored in waters shallower than 46m during closed seasons. Stored pots must have all bait removed and their doors tied open. Gear storage may be prohibited in shallow areas where salmon seining or other fisheries are active. In the Bering Sea, where distances between ports and fishing grounds often exceed 370km, there are specially designated pot storage areas in the open sea. Pots may be stored on the fishing grounds for 72 hours after the season is closed if bait is removed and doors are tied open. At various times in the past, pots could be placed on the fishing grounds for a specified period of time prior to the fishing season, but such pre-season gear placement is no longer allowed. Designated storage areas prevent conflict with fisheries using mobile gear, make enforcement of fishing seasons easier, and may contribute to economic returns from the fishery.

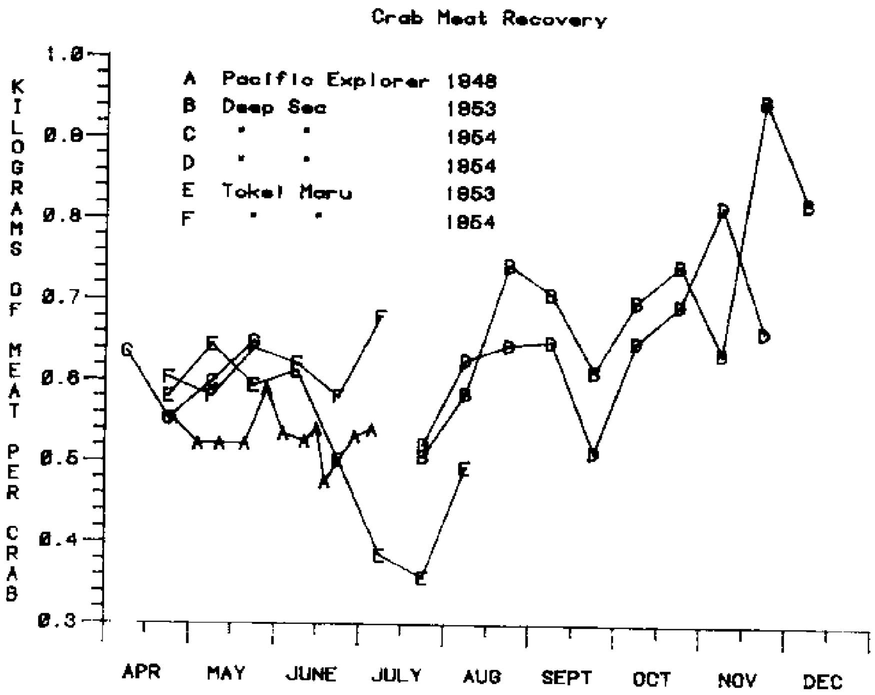

Figure 1. Meat recovery data by season during the early development of U.S. king crab fisheries in the eastern Bering Sea.

Vessel inspections

All vessels must have their holds inspected by ADF&G personnel within 24 hours of the season's opening, and no king crab may be aboard at the time of inspection. This requirement aids in enforcement and in obtaining information needed for monitoring the fishery.

Area registration

All commercial fishing vessels must be licensed to fish in Alaskan waters. In king crab fisheries a vessel must also be registered to fish in a given area (since 1959). Management areas are Southeastern Alaska (A), Prince William Sound (E), Cook Inlet (H), Kodiak (K), the Alaska Peninsula (M), Dutch Harbor (O), Adak (R), Bristol Bay (T), and the Bering Sea (Q). Registrations are not valid until the vessel is inspected and no vessel may be registered for two areas at one time. Currently, areas are designated as superexclusive (E, H, M), exclusive (A, K, O, T), or non-exclusive (R, Q). A vessel registered in a superexclusive area may not fish for king crab in any other management area during the same year. A vessel registered in an exclusive area may also fish in one or both nonexclusive areas during the year if it is validly registered. Vessels registered in nonexclusive areas may also fish one exclusive area. Area boundaries are constructed to separate discrete stocks of crabs although an area may be subdivided into districts if more than one stock exists in an area.

Registration requirements clearly serve to ensure availability of information on individual crab stocks and are an aid in management or enforcement, but they have been very controversial because of their allocative effects (Miller 1976; Katz and Bledsoe 1977). Exclusive and superexclusive registration requirements tend to disperse effort and protect local fleets. Protection of local fleets may serve the goal of avoiding adverse socioeconomic impacts but possibly is in conflict with the goal of optimizing economic return. Katz and Bledsoe (1977) point out that "... the pressure of product demand ultimately resulted in new vessels being built, as justified by the competitive situations, in each area, under the new [exclusive] regulations. This effect is particularly noticeable in Kodiak and Dutch Harbor, the ports having the best access to the richest stocks. Thus total vessel numbers, for the region as a whole, seem to have increased beyond the numbers which would have entered the fishery had free mid-season mobility between areas been allowed." If one allows that this is so, then exclusive registration requirements have fostered increased capitalization in the harvesting sector of the industry and perhaps tended to decrease economic yields. Since neither the ABOF policy nor the NPFMC plan deal with capitalization as a factor in defining "optimum", it is difficult to show that increased capitalization is necessarily in conflict with "optimizing" economic returns.

Catch limitations

The ABOF adopted a quota policy in 1970. Between 1966 and 1970, landings of king crabs fell from 81,702 to 31,233 metric tons, and it was perceived that regulations were inadequate to prevent "extreme fluctuations in catch" (ADF&G 1970). Quotas were set prior to the season but could be modified during the season with the concurrence of the ABOF. In 1975, the quota policy was changed to a "system of flexible quota ranges" called "guideline harvest levels" (ADF&G 1975). The 1970 and

1975 policy statements contain statements that are almost identical to current policy concerning stability and the "maintenance of various age classes of legal-size crab." Guideline harvest levels are ranges about a central quota value, determined by applying a target exploitation rate to the estimated biomass of legal crab. The range reflects uncertainty in estimates and also provides the area management biologist considerable flexibility (see below). In the FMP, the term "optimum yield" (OY) is used for the central value in a guideline harvest range. It is determined by considering both the abundance of legal-size crab and of mature (fertilized) females. Catch limitations are almost entirely concerned with the goals of stability and optimization of economic return.

In-season adjustments

The Commissioner of Fish and Game has the power to open or close the fishery in a management area, or portion of an area, by issuing an "emergency order." Emergency orders are generally issued by area management biologists, with approval of the commissioner. Emergency order powers came in to being in 1975 when the system of quota ranges was adopted. They allow the use of in-season fishery data to determine when a fishery is to be closed. Factors relevant to conservation such as areas being fished, catch per unit effort, the amount of dead crab being landed ("dead loss"), or the proportion of soft-shelled crab in the catch may be considered. The fishery also may be closed if there are frequent occurrences of illegal fishing. In-season adjustments through emergency orders, depending on their nature, may serve any management goal, but always serve to increase the efficiency of management and enforcement.

Controls on other fisheries

Time or area closures and gear restrictions have been imposed on other fisheries for the purpose of protecting king crabs or king crab gear. These include prohibiting scallop dredging in areas considered to be critical king crab habitat, and have included similar restrictions on trawling. Restrictions also include specifications for tanner crab (_Chionoecetes_ sp.) pots that are intended to reduce incidental catch of king crabs. Controls on other fisheries serve various goals but are usually directed at minimizing conflicts between fisheries.

Transportation of live crabs

It is illegal to transport live "king crab, species _Paralithodes camtschatica_" out of Alaskan waters except by air. Evidently this regulation was adopted before blue king crab (_P. platypus_) fisheries became important (Ca 1975). The regulation seems to be directed at protecting the Alaskan processing industry and hence may serve the goal of avoiding adverse socioeconomic impact.

Agreements for use privilege

As a condition of license, licensees agree to abide by state laws both within the territorial sea (0.0 to 5.6 km) and in "adjacent high sea areas".

Annual Cycle of King Crab Management

I have chosen to illustrate the management cycle as it has occurred for the Bering Sea region over the past five years. The Bering Sea region is divided into the Bristol Bay (T) and Bering Sea (Q) management areas (Fig. 2). The Bering Sea management area is divided into the Pribilof and Northern districts, and the Northern district is further divided into the St. Matthew, St. Lawrence and Norton Sound sections. While this nomenclature is confusing, areas, districts and sections serve to separate king crab stocks. Area T is an exclusive management area while Area Q (the remainder of the Bering Sea) is non-exclusive. The three largest stocks in the Bering Sea region are Bristol Bay's red king crab; the Pribilof Islands' blue king crab; and St. Matthew Island's blue king crab. Taken together, these stocks provided over 99 percent of all king crab landed between 1953 and 1984 (Table 1). The region has a long history of king crab fishing (Otto 1981) and resource assessment activities (Hayes 1983; Otto, in press).

The annual cycle of management (Fig. 3) starts with a staff meeting attended by ADF&G and National Marine Fisheries Service (NMFS) biologists and ends after the fishing season with an analysis of current stock conditions. At the January staff meeting, proposed regulations and current stock conditions are discussed on a stock-by-stock basis. These discussions and attendant data or analyses form the basis of reports to the ABOF and the NPFMC. Local advisory board meetings also usually occur in January or February. Tentative guideline harvests and changes in regulations are decided upon at the joint ABOF-NPFMC meeting. Guideline harvest levels (including OY) are tentative because they are based on predictions from the previous year. If a proposal is received to change a given regulation, it opens discussion of that regulation in all management areas, and public testimony or recommendations of local advisory boards are reviewed for all areas. For example, a proposed change in fishing seasons for the Pribilof Islands opens discussion of fishing seasons for all Alaskan waters. This procedure tends to prevent one user group (say the "Dutch Harbor fleet") from gaining advantage over other groups through a change in regulations (the degree of overlap in time between fishing seasons in different areas, for example, has allocative effects).

Surveys are generally conducted during the summer months and provide new information that may require changes in guideline harvest levels. If new information places the OY outside of the range decided on earlier in the year, guidelines are changed through the commissioner's office (with ABOF consent if necessary) and generally presented to the NPFMC in September. If changes in the guideline harvest are large (requiring closure of the fishery, for example) or if other regulations are affected by new information, the commissioner may be required to seek ABOF approval for emergency rule making. Usually the guideline harvest levels are simply adjusted to reflect current stock conditions.

After a fishing season has opened, decision making is concentrated with the area management biologist (Fig. 4). The area biologist for both areas of the Bering Sea region, excluding the Norton Sound section, is located in Dutch Harbor. The biologist for the Norton Sound section is located in Nome. Area biologists monitor the fishery through fish tickets, interviews with vessel operators and processing plant managers, reports from fishermen on the grounds, and sampling catches. Information gathered during the fishery allows some adjustment of OY

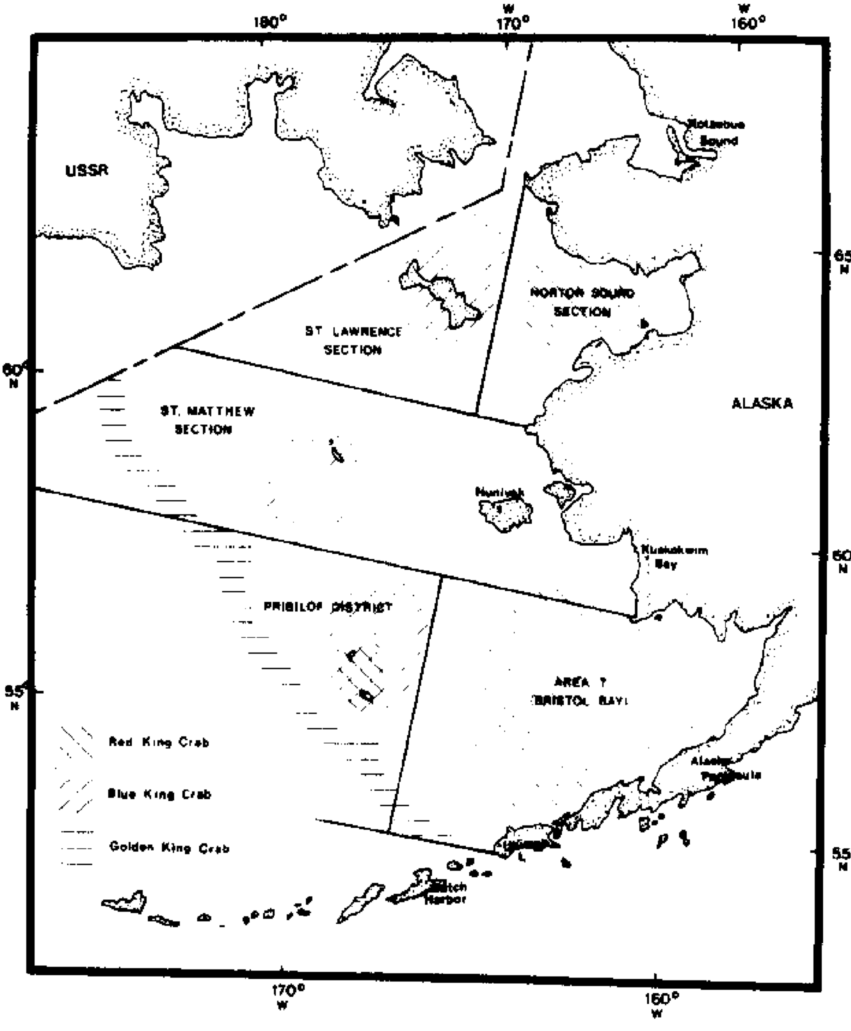

Figure 2. Distribution of eastern Bering Sea king crab stocks and Alaska Department of Fish and Game management areas. Bristol Bay (Area T) is separated from the rest of the Bering Sea (Area Q). Area Q is divided into the Pribilof and Northern Districts (unlabeled) at 58°39'N. latitude. From Otto (in press).

Table 1. Historical landings of king crabs in the eastern Bering Sea (1000's of metric tons, Bristol Bay red king crab; Pribilof and St. Matthew Islands blue king crab)[1].

Year	Bristol Bay U.S.	Bristol Bay Total	Pribilof Islands[2] U.S.	Pribilof Islands[2] Total	Saint Matthew Island	Other[3]	Total
1953	0.907	6.013	---	---	---	---	6.013
1954	1.056	4.724	---	---	---	---	4.724
1955	0.852	4.795	---	---	---	---	4.795
1956	0.860	4.629	---	---	---	---	4.629
1957	0.267	4.144	---	---	---	---	4.144
1958	0.003	3.694	---	---	---	---	3.694
1959	---	5.263	---	---	---	---	5.263
1960	0.271	11.435	---	---	---	---	11.435
1961	0.208	18.535	---	---	---	---	18.535
1962	0.034	24.195	---	---	---	---	24.195
1963	0.339	26.045	---	---	---	---	26.045
1964	0.413	29.024	---	---	---	---	29.024
1965	0.799	19.580	---	---	---	---	19.580
1966	0.452	19.498	---	0.912	---	---	20.410
1967	1.407	15.066	---	1.095	---	---	16.162
1968	3.940	15.772	---	0.725	---	---	16.496
1969	4.719	8.634	---	2.487	---	---	11.120
1970	3.882	9.166	---	0.582	---	---	9.747
1971	5.894	8.143	---	0.558	---	---	8.701
1972	9.863	11.868	---	0.136	---	---	12.004
1973	12.208	13.347	0.579	0.600	---	---	13.946
1974	19.172	22.797	3.224	4.009	---	---	26.807
1975	23.281	23.281	1.104	1.104	---	---	24.385
1976	28.994	28.994	2.999	2.999	---	---	31.993
1977	31.737	31.737	2.929	2.929	0.546	0.235	35.446
1978	39.743	39.743	2.901	2.901	0.900	0.960	44.504
1979	48.910	48.910	2.719	2.719	0.096	1.330	53.055
1980	58.944	58.944	4.976	4.976	0.100	0.956	64.976
1981	15.237	15.237	4.119	4.119	2.099	1.237	22.692
1982	1.361	1.361	1.998	1.998	3.831	0.436	7.626
1983	0.000	0.000	0.995	0.995	4.288	0.598	5.881
Totals:	315.754	534.573	28.543	35.843	11.859	5.752	588.028
Percent:	53.697	90.910	4.854	6.096	2.017	0.978	

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[1] Data: 1953-1974 (Otto 1981), 1975-1983 (Alaska Department of Fish and Game 1984, Powell et al. 1983), minor differences in totals due to rounding.

[2] May include small amounts of Pribilof Island red king crab until 1979.

[3] Entirely Norton Sound red king crab 1977-1979; mostly Norton Sound and Pribilof Islands red king crab in 1980-1982; catches were 28.1 percent Norton Sound red king crab, 3.4 percent St. Lawrence Island blue king crab, 4.0 percent Pribilof Island red king crab and 64.4 percent golden king crab in 1983, when Bristol Bay was closed to commercial fishing.

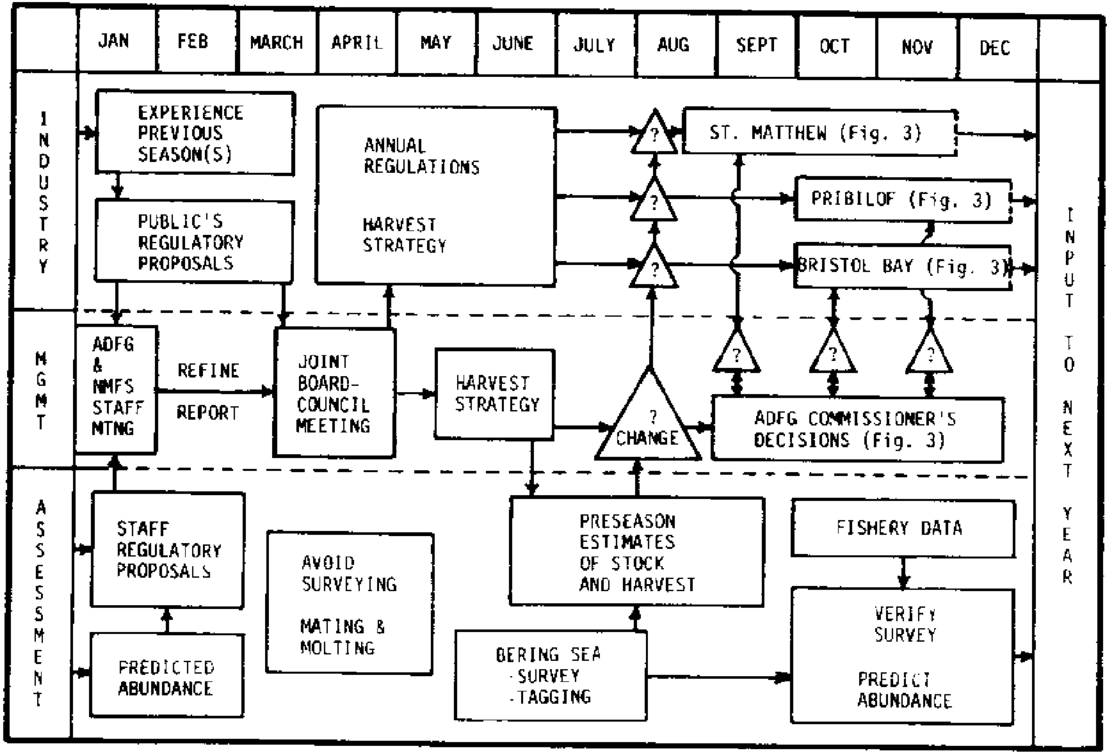


Figure 3. Annual cycle of management decision making for king crab stocks and its interaction with fisheries and resource assessment (modified from North Pacific Fishery Management Council 1984).

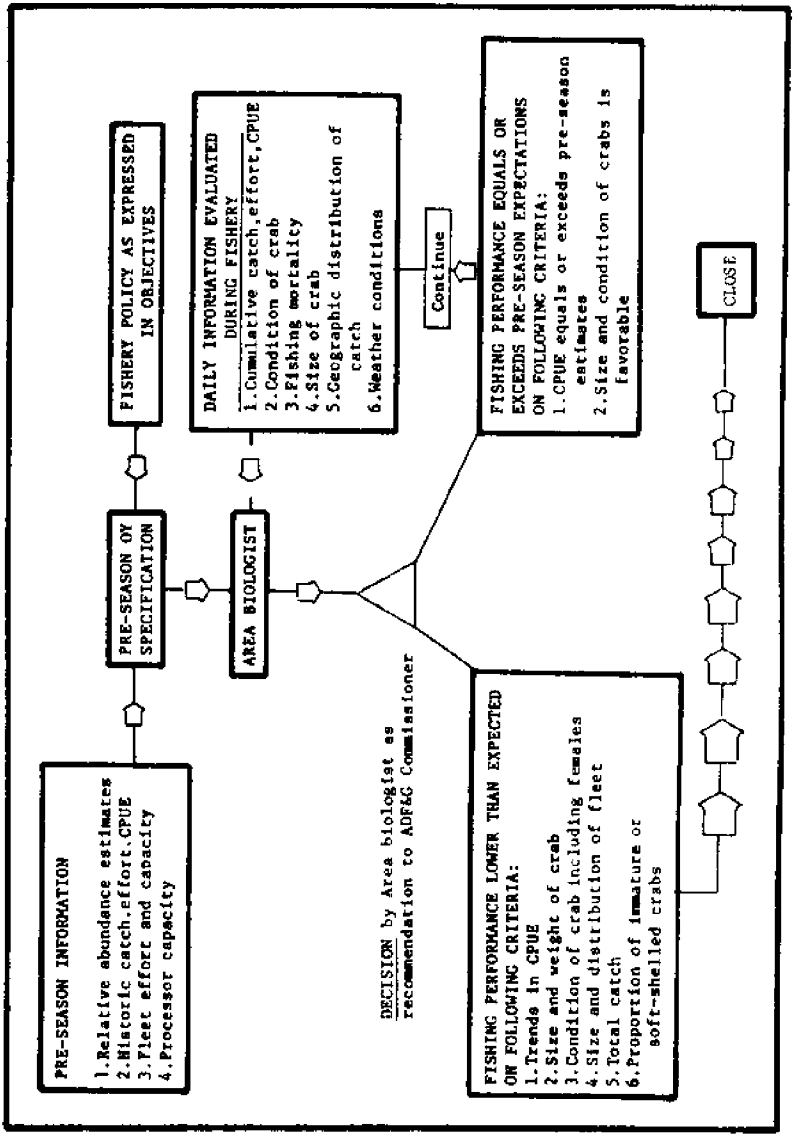


Figure 4. In-season management decision making by Alaska Department of Fish and Game (ADF&G), based on pre-season specification of optimum yield (OY). Cycle at right continues until OY is reached. Area management biologists may issue field orders closing fisheries, but final decisions are made by the commissioner or his designee. Modified from North Pacific Fishery Management Council (1984).

within the guideline harvest range. The fishery is closed, either when the OY is reached or when detrimental conditions prevail, by issuing an emergency order. Emergency orders are publicized through radio transmissions, notices posted at processing plants, or press releases to public media. An owner or operator of a vessel legally registered in an area closed by emergency order may formally request, within five days after the closure, that the commissioner reopen the area. The commissioner must "personally review pertinent information on the condition of king crab within the area" and announce his decision within 14 days.

Goals Revisited

Management of king crab is a democratic process and relies on public input both to formulate and to change policy or regulations. One consequence of extensive industry participation is a tendency for industry to trust the management system and abide by regulations. In Bering Sea king crab fisheries, the dominant user group is a large (27 to 50 m) vessel fleet that is based in Oregon and Washington. Members of this group often feel that they are at a disadvantage in dealing with the ABOF. Published comments by the Seattle-based North Pacific Vessel Owner's Association on the final rule (Department of Commerce 1984) reflect this concern: "The FMP's socioeconomic criteria favor Alaska's interests. 'Pro-Alaskan' factors are going to weigh heavily in any board decision." While this perception on the part of nonresident fishermen does not seem to have resulted in any special enforcement problems, it should be kept in mind relative to socioeconomic effects of regulations. I hasten to point out, however, that the allocative effects of regulations described by Katz and Bledsoe (1977) probably apply to "large" versus "small" boats without regard to the residency of the owner.

Management and enforcement in Alaska are expensive. The management process includes extensive public testimony that entails considerable travel in a very large state. The cost of enforcement-related travel and of maintaining vessels at sea is also great. While minimizing the costs of management and enforcement is a worthy goal, it is probably one that can be approached only in a general way. One reason for this is that costs, particularly of management, are poorly known and variable. Much of the cost of management is borne by the public. Because public testimony plays an important part in the regulatory process as well as providing socioeconomic input, competing interests must see to it that their testimonies are put before the board. Depending on the perceived economic importance of a given regulatory change, testimony may entail many or few participants, attorneys or consultants. Costs related to effects of regulatory changes also may be high and are not well known because the participatory nature of management tends to foster rapid change rather than a constant regulatory regime. Eaton (1985) states: "The costs are high: high for the tax payer who subsidizes the confusion; high for the fisherman who must re-tool his operation every time the political winds blow ...". Enforcement costs are similarly variable to the extent that they depend on the frequency and location of violations, and ultimately on the operation of a complex judicial system in which expenses are rarely known in advance.

I cannot ascertain the degree to which current regulations foster "long-term optimum economic yield" (ADF&G 1985) or "optimize net value" (NPFMC 1984). The ABOF policy seems to equate stability with an economic optimum as does the FMP, although the latter document also recognizes that management may place burdens on industry that should be minimized. The ABOF policy and FMP agree that optimum yield should be less than "maximum physical yield." Much resource economics literature (e.g. Clark 1976) supports the idea that highest economic yields are generally achieved at levels of exploitation below maximum sustainable (physical?) yield, but largely because of the relationship between fishing costs and revenue rather than because fluctuations in stock abundance are minimized. Upon reflection, I believe that the goal of optimizing returns from the fishery is functionally identical to the goal of avoiding adverse socioeconomic impacts.

Adverse socioeconomic effects related to king crab management arise through fluctuations in abundance, effects of regulations, changes in regulations, and a lack of clear socioeconomic goals. I will discuss stability in landings as a separate topic. Changes in regulations are frequently triggered by a large decline in landings and become institutionalized as stocks rebuild. For example, quotas and a policy of multiple year class management followed drastic declines in landings in the late 1960s. When regulations are changed the fishing industry adapts to them, and it becomes expensive to revert to a simpler system. Further, there is a tendency to believe that the regulatory change caused the stock to rebuild even if no functional relationship has been established. The combination of vested interest in a set of regulations, with the perception that they in some sense caused increased landings, makes it politically infeasible to abolish regulations. As landings peak and then inevitably decline, new regulations tend to be layered upon the old. Eaton (1985) and Hingston (1985) provide useful discussions of the impacts of regulations and regulatory procedures on the harvesting and processing industries.

As an example of a situation where fluctuating abundance interacts with the effects of regulatory change, Katz and Bledsoe's (1977) scenario regarding exclusive registration is instructive. A fleet of 236 vessels in the exclusive Bristol Bay area landed 58,940 metric tons (mt) of king crab in approximately six weeks during 1980, while total statewide landings were 76,520mt (ADF&G 1984). Statewide landings have exceeded the 1980 Bristol Bay catch only four times in the past 15 years, and it is apparent that the fishing power concentrated in the state's largest king crab fishery could easily have accommodated landings in all other statistical areas. By 1982, Bristol Bay landings had fallen to 1,360mt, and the fishery was closed in 1983. The only thing that prevented a massive influx of effort into other exclusive registration areas was that they experienced coincident and equally severe declines in landings. Kodiak, Dutch Harbor, the Alaska Peninsula, and Cook Inlet were all closed in 1983.

Conflicts between king crab and other fisheries include preemption of fishing grounds, competition for processing or unloading facilities and problem of incidental catch. Limitations on pot storage have generally reduced the preemption of fishing grounds by king crab pots during the closed season, as well as aiding in enforcement of seasons. Establishment of areas closed to foreign trawling was negotiated in the late 1960s, and this continues to reduce the incidence of lost gear. The current timing of king crab seasons precludes substantial competition for processing plants and loading docks. The problem of incidental catch remains, both from catches of other species (particularly halibut) in king crab pots and the catch of king crabs in other fisheries.

The International Pacific Halibut Commission includes estimates of incidental catch of halibut in king and tanner crab fisheries in its annual reports. Gear research has shown that king crab pots with tunnels located on the top rather than the sides catch fewer halibut than conventional "side loading pots." Side loading pots are prohibited in a small area near Yakatat (Southeastern Alaska). Large portions of Cook Inlet, Kodiak and the Alaska Peninsula areas are closed to scallop dredging in order to protect king crabs. Conflicts between king crab fishermen and domestic trawlers continue, but incidental catch data are largely non-existent, except in fisheries where U.S. trawlers deliver to foreign processing vessels ("joint ventures") that are monitored by NMFS Foreign Fishery observers (Nelson et al. 1981).

In Bristol Bay, controversy over incidental catch such as king crabs in trawl fisheries has a long history. Conflicts between foreign trawlers and domestic trawlers were largely resolved by closing most of the area to foreign trawling. The development of joint venture fisheries for yellowfin sole (Lemanda aspera) in the Bristol Bay area (Fisher 1981) has caused king crab fishermen considerable concern. Proposals to the ABOF to close portions of Bristol Bay and other areas to bottom trawling led to adoption of a "Bottom Trawl Fisheries Plan" (ADF&G 1985) that requires domestic trawlers to report location and submit written information on their operations, to allow ADF&G to place observers on their vessels, and to abide by "any other requirements" needed for "conservation and development of fishery resources." Reports by NMFS observers on foreign processing vessels (Nelson et al. 1984) do not indicate that incidental catch in joint venture fisheries are a substantial cause of mortality in Bristol Bay red king crab (Otto, in press). Observer reports are derived from sampling catches contained in the cod ends of trawls delivered intact to foreign processing vessels. Since this is the only method of delivery, observer reports cover the entire fishery. A method of deliminating closed areas based on the relative value of king crab incidental catch to directed trawl catch has been described (Somerton and June 1984), but areas that would be closed using this methodology covered less than 30 percent of the grounds fished for yellowfin sole in 1980 and 1981. Meetings sponsored by the NPFMC between domestic fishermen have resulted in efforts to reduce the incidence of king crabs (crab per ton) in trawl catches (Fisher 1985). Continued growth of domestic trawl fisheries, continued low abundance of king crab, and the fact that incidental catch (all sizes and sexes) is approximately equal to the current directed catch (legal size), however, virtually guarantee continued conflict between bottom trawl and king crab fishermen over incidental catch.

Biological and fishery data are collected annually by the NMFS and ADF&G, and comprise most of the information used in the annual management cycle (Fig. 2). Pre-season estimates of stock abundance, fishery data (Fig. 4), and forecasts of stock abundance (post-fishery) form the basis for estimating OY and guideline harvest ranges. Evaluation of reproductive potential is derived from annual estimates of mature male and mature female abundance coupled with the frequency of ovigerous females and the frequency of females carrying full, as opposed to partial, clutches of eggs. The adequacy of biological data varies from area to area, depending on budgetary constraints. Landed value and prices paid are reported to the ABOF annually by ADF&G, but most of the economic input to management decisions is through public testimony. There is a need for collection of economic and social data, attendant analysis and better integration of socioeconomic information in the management process.

In the Bristol Bay area, abundance estimates observed from NMFS trawl surveys are combined with ADF&G fishery data to provide estimates of pre-season abundance, size-specific catch and future abundance (Otto, in press). In general, the correspondence between fishery data and survey abundance has been good, but as the stock has declined, forecasted abundance has tended to exceed survey abundance estimates taken one and two years later (Fig. 5). This situation has resulted in an increasing reliance on pre-season abundance estimates from summer trawl surveys in setting guideline harvest levels for the following fall's fishery. Information on the distribution and abundance of king crabs is provided to industry and management prior to each fishing season and has generally been accurate. In some views, information has been excessively timely because it tends to equalize the fishing power of experienced and inexperienced fishermen, perhaps indirectly increasing capitalization to the detriment of the fleet as a whole. For example, Eaton (1985) describes the "road map" phenomenon: "There was a time when successful Bering Sea fishermen had one thing in common: years of experience on the grounds and a black book of hot spots that took years to compile. Then came the pre-season trawl surveys that ostensibly measured the future, provided the basis for the quota, and made the locations of major concentrations part of the public record. The biologists helpfully provided loran coordinates for the stocks they discovered. The experience of the professional was largely nullified, much to the delight of the speculators."

The protection of reproductive potential represents a management commitment to long-term stability of king crab populations and (hopefully) continued abundance of legal-size crab. Regulations protect females and ensure that legal-size males have had an opportunity to breed. The abundance of females, sex ratios and egg production are monitored annually. In some cases, indications of low egg production have been used as grounds to decrease landings. The net effect of protecting reproductive potential is poorly known because some measure of protection has been afforded by regulations and fishing practices since the inception of king crab fisheries. Regulations protecting reproductive potential are widely applied in crab fisheries (Miller 1976) and are also applied to lobster fisheries (Bennett 1980; Dow 1980). Edwards (1979) traces the history of such regulations to a British Act of Parliament in 1876 restricting the sale of crabs that were carrying external eggs. The relationship between reproductive potential (egg production) and subsequent landings in king crabs is not well established but it is clear that high egg production is associated with both strong and weak year-classes (Incze et al, in press).

In Bristol Bay, the abundance of mature females has generally been well correlated with that of mature or legal males (Fig. 6). Studies conducted in Kodiak (Powell et al. 1974) showed that a mature male could mate at least four times during the spawning season and it seems unlikely that sex ratios in the Bristol Bay area placed constraints on reproduction. Bristol Bay red king crab enter the fishery at an average age of eight years, a carapace length of about 135mm and a carapace width of 165mm (Balsiger 1974). High stocks in the late 1970s were the result of low spawning stocks in the early 1970s (Fig. 6). Reeves and Marasco (1980) chose a dome shaped (Ricker) model to describe the relationship between the abundance of female spawners and

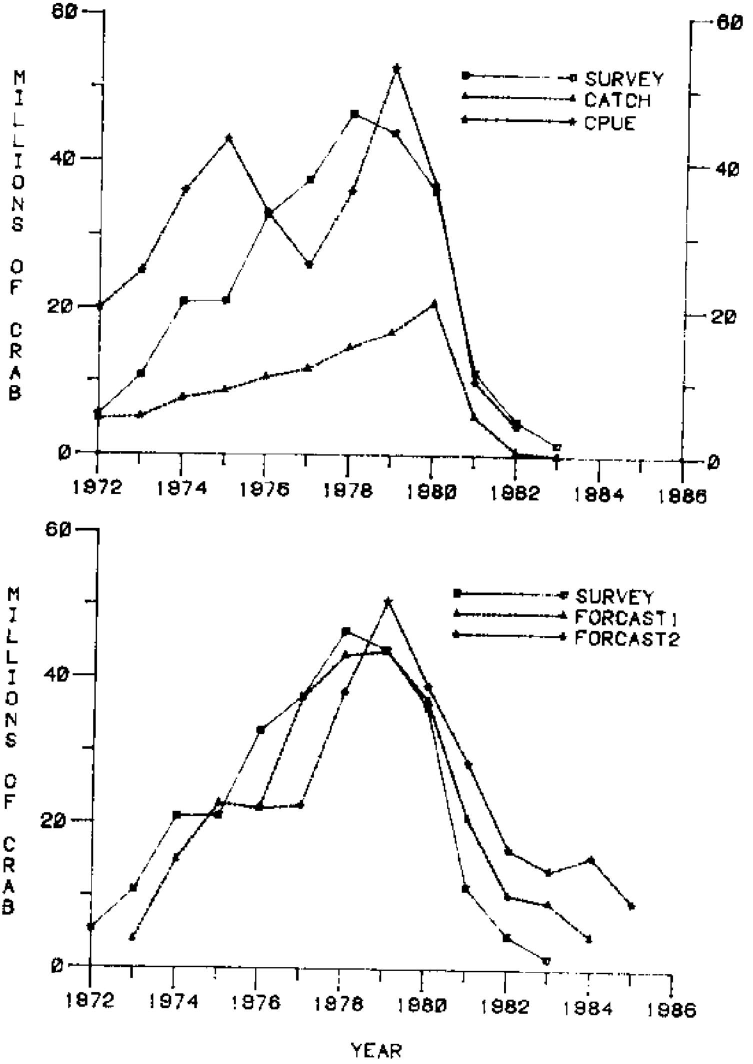


Figure 5. A comparison of abundance indices for Bristol Bay red king crab. Top panel shows estimated abundance of legal males from the survey in comparison with nominal catch and catch per unit (pot lift) effort in the U.S. fishery. Bottom panel shows survey abundance in comparison with predicted abundance from surveys taken one (FORCAST1) and two (FORCAST2) years previously. From Otto (in press).

the subsequent abundance of five-year-old males. Reeves and Marasco concluded that intermediate levels of stock abundance (20 to 40 million fertilized females) were optimum. Incze et al (in press) conclude that strong year-classes can result from low or high stocks of mature females and indicate that environmental factors and variation in natural mortality were at least as important as the abundance of spawners in determining recruitment to the fishery. Since adult males grow an average of 16mm in carapace length (Webber and Miyahara 1962) in each molt and mature at 103mm (Somerton 1980), current size limits allow most males two opportunities to breed before they enter the fishery at 135mm carapace length. I conclude that the protection of reproductive potential in Bristol Bay red king crab is adequate, but cannot say that this has added to the stability of the population under current or past regulations.

Stability in landings has been the major goal of king crab management since at least 1970 (ADF&G 1970). Prior to 1970, king crab in various areas of Alaskan waters were managed by size, sex, season and year restrictions, but these did not appear to prevent "extreme fluctuations" (at that point in time, severe declines) in landings. The 1970 policy espoused quotas and the maintenance of several year classes of legal-size crab both for fishery and reproductive purposes. In 1975, the ideas of flexible quota ranges, carrying over a portion of legal crab from one year to the next, and harvesting extremely old male crab (surplus to reproduction), were added. The ABOF policy has remained unchanged since. Recent drastic declines in landings in Alaskan waters (see Introduction to this volume) and consequent loss of revenues, have stimulated debate over current regulations, as to whether returning to pre-1970 policy would do just as well, or whether more restrictive regulations are necessary. It is clear, however, that the current regulatory system has not prevented severe declines in the abundance of red king crab in any area of Alaska.

The history of catch per unit effort data for Bristol Bay red king crab suggests strong fluctuations in abundance over the past 33 years (Fig. 7). Data suggest that peaks in abundance were separated by about 20 years, and that the most recent decline in abundance was the most severe in the history of the fishery. Elsewhere, I have discussed the reason for this decline and concluded that variable year class strength and increased natural mortality, rather than directed or incidental catches, were responsible (Otto, in press). My conclusions largely derived from increasing discrepancies between forecasted abundance (based on abundance, natural mortality estimates, and size-specific catch) and survey estimates in the years since 1980 (Fig. 5), and from the tendency of fished and unfished portions of the population to follow similar trends in abundance (Fig. 6). The reasons for increased rates of natural mortality are poorly understood, but probably include high abundance of known predators (particularly cod), newly discovered and potentially epizootic diseases, and possible environmental effects. Environmental effects may be indirect; they may trigger epizootic disease or make king crab more vulnerable to predation. The reason that management has not been able to prevent the recent declines in abundance is that the factors responsible for the decline had little to do with fishing, and hence were uncontrollable by fishery regulations.

Accepting that the major causes for the fluctuating abundance of Bristol Bay red king crab were not controllable by regulating its fishery, I then began to examine whether some measure of stability in

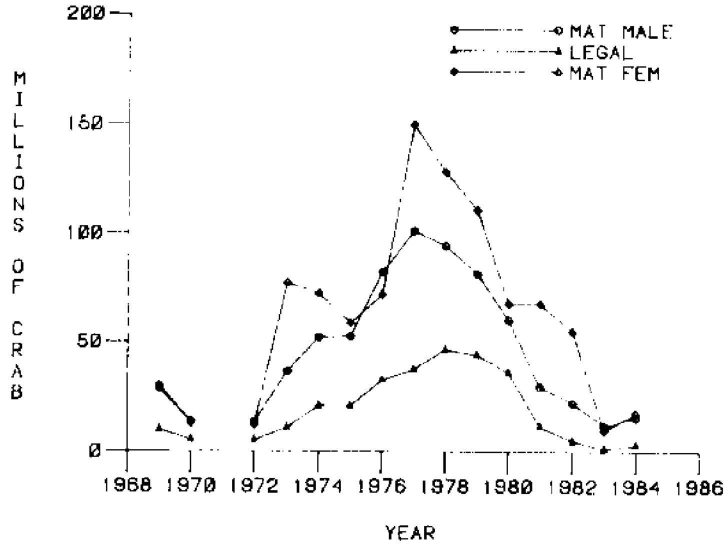


Figure 6. Abundance estimates of mature males, mature females and legal males from NMFS trawl surveys of red king crab in Bristol Bay.

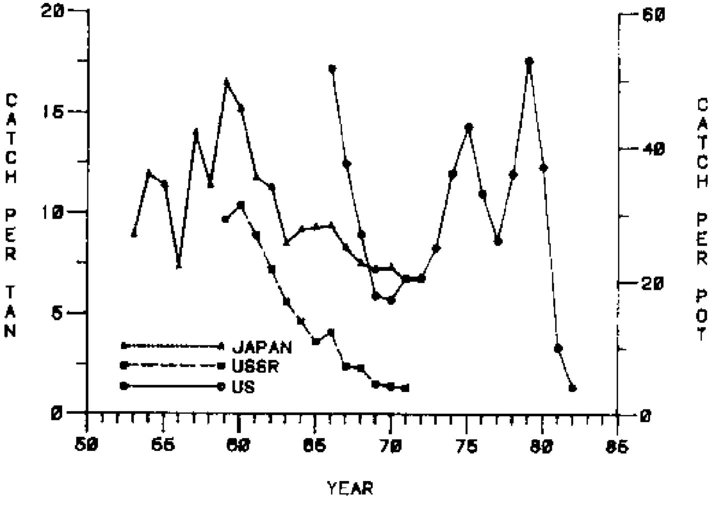


Figure 7. Nominal catch per unit effort in the Bristol Bay red king crab fishery, showing fluctuating abundance with major lows in 1970 and 1983 (fishery closed). Data for Japan and the U.S.S.R. are for tangle net lifts (one tan is approximately 40m of net). Data for the U.S. are in pot lifts (average dimensions of pots are 2.1 x 2.1 x 0.9 m). From Otto (in press).

landings could result from regulating the catch. Some preliminary results of this examination follow.

A cornerstone in the ABOF policy is the maintenance of several year-classes and the carry-over of legal-size male crab. As a first step in examining the efficiency of this procedure, I modeled the fate of a hypothetical year-class of male king crab, using growth and mortality rates derived by Balsiger (1974). Since the average growth per molt of male Bristol Bay red king crab is very nearly constant at sizes above 80mm carapace length (Webber 1967; Webber and Miyahara 1962), net growth of a year-class above this size results from the balance between the rates of molting and death. Balsiger's estimates of skip molting and natural mortality ratios by 5mm carapace length and the ratio of molting to death (Fig. 8) show that relative growth of a year-class is maximized at about legal size (135mm) and hence indicate that some carry-over of newly recruited crab might be feasible.

I "recruited" 10 million 80mm carapace length males (four year olds) to a model and then followed their growth and mortality. Results (Fig. 9) showed that, in the absence of fishing, the life span of a year-class would be about ten model years (14-year-old crab); and that the size of male crab becomes variable with increasing time. Expressing the fate of 10 million "recruits" in number and weight (millions of grams), I then examined recruitment in time. Results showed that biomass was maximized at four or five years model time (Fig. 10, top). Recruitment (135mm length) occurs over about four years but peaks at model time four (eight years of age). Substantial weights of crab from a single year-class would be recruited at ages seven, eight, nine and 10. In nature, recruitment would probably occur over a longer period because the width of a year-class size mode is about 15mm (Webber 1967), while crab entered the model in a single 5mm group.

Modeling the growth and decay of a hypothetical year-class indicates that legal-size Bristol Bay red king crab will probably consist of more than one year class at any given time. This is because of variability in growth per molt (each 5mm size group contributes to five larger size groups) and the rate of skipping molts (anecdysis). Each year-class contributes to recruitment over a period of at least four years. The ABOF policy of maintaining several year-classes of legal-size crab is hence satisfied, regardless of exploitation rates, unless there are at least three successive year-class failures. However, this does not mean that "an industrial dependence on annual recruitment" will be avoided.

Growth and mortality data suggest that newly recruited crab could be held over for at least a year, thereby contributing to the stability of legal-size stock abundance. Attempts to do this have involved establishing a target exploitation rate. Quotas or guideline harvest ranges are set by applying the target exploitation rate to the pre-season estimate of legal-size crab biomass (including its 95 percent confidence interval). In my experience, establishing target exploitation rates usually has meant attempting to harvest 40 percent of the legal biomass, or 40 percent of crab in a "recruit" size range (legal size plus one molting increment) and 60 percent exploitation to larger ("post recruit") crab. The latter schedule could only be applied in a split season (see above). In 1982, the ABOF adopted a "harvest strategy" that consisted of a variable set of exploitation rates (Table 2). According to the harvest strategy, the target harvest ratio would

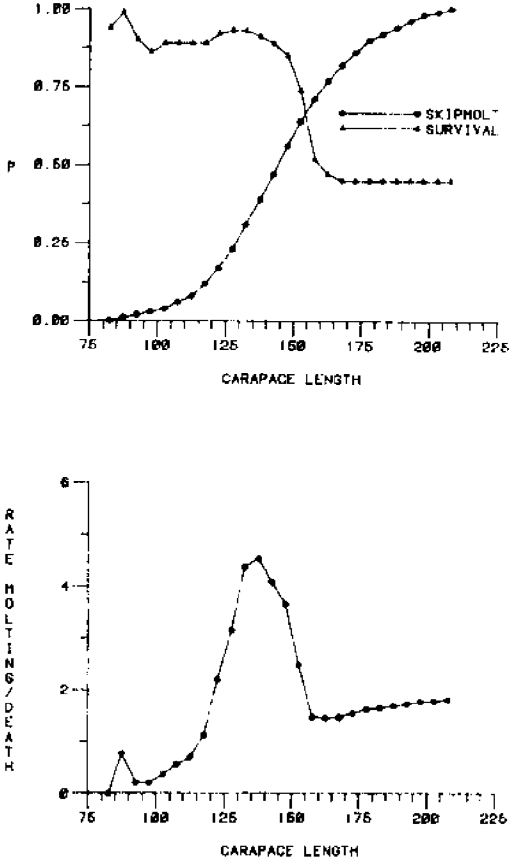


Figure 8. Annual probabilities of an ecelysis (skipmolt) and survival by 5mm carapace length group for male Bristol Bay red king crab (top); and the ratio of molting rate to death rate (bottom). After Balsiger (1974).

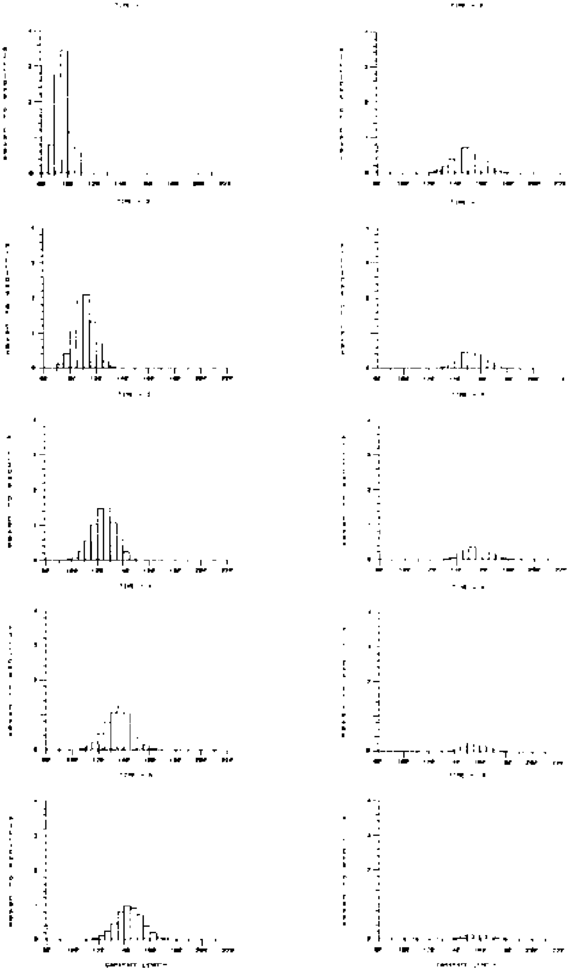


Figure 9. Simulated growth of 10 million male Bristol Bay red king crab for 10 model years. Crab enter the model at 80 to 84mm carapace length (about four years old).

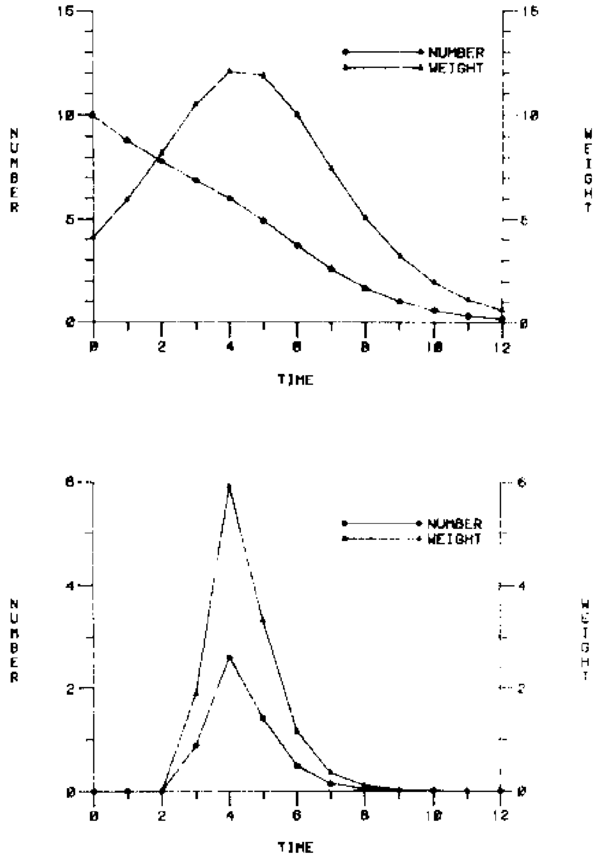


Figure 10. Simulated growth and decay of hypothetical cohort of 10 million Bristol Bay male red king crab (top; numbers in millions, weights in millions of Kg); and the timing of recruitment of the cohort in model years. Actual ages would be model time plus four years.

Table 2. Target exploitation rates (%) for Alaskan king crab stocks (harvest strategy)[1].

Population Size	Pre-recruit Abundance	Approximate exploitation rates of legal crab at given levels of post-recruits		
		Low	Moderate	High
Depressed	Declining	Less than 20	Less than 25	Less than 25
	Stable	30	30	35
	Increasing	30	30	35
Average	Declining	40	40	40
	Stable	40	45	45
	Increasing	40	50	50
Peak	Declining	40	45	50
	Stable	50	55	60
	Increasing	60	60	60

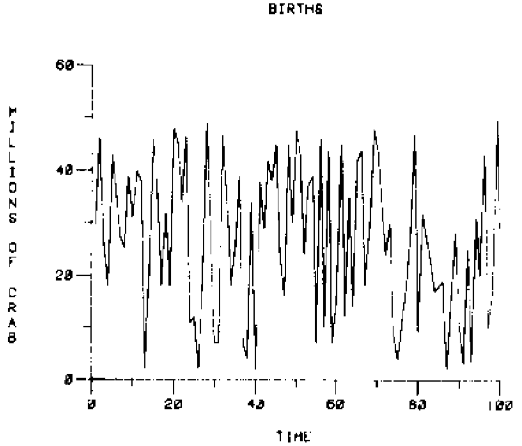
[1] Modified from ADF&G (1985). Definitions: a) population size refers to males and females; b) pre-recruit refers to males that are within one to two molting increments of legal size; c) post-recruits have been legal for one year (escaped one fishery); and d) low is less than 1/3 of legal biomass, high is more than 2/3 of legal biomass.

depend on the existing stock structure and particularly on expectations of recruitment. This strategy has components of carrying over legal-size crab, rebuilding stocks, and perhaps protecting reproductive potential.

I was unwilling to pick a stock-recruitment function for Bristol Bay red king crab, but needed to model variability in year-class abundance in order to examine the effects of target exploitation rates on stability of landings. Fishery data (Fig. 7) suggested that strong year-classes might occur about every 20 years. Survey data suggested that male and female abundance were well correlated (Fig. 6), so I needed to model only male abundance. I modeled recruitment in two ways: 1) recruitment to the model was a uniform random variable between limits of two million and 50 million recruits; or 2) recruitment was a uniform random variable, with an upper limit defined by a sine function with a period of 20 years. The second model allows recruitment to vary but requires the probability of high recruitment to increase and decrease. I then combined each of the two recruitment processes with the growth and mortality calculations described above to form two population generation models and specified a run time of 100 model years.

Typical results of the computer runs from each population generator are plotted in Figure 11 and 12. Modeled recruitment (births) is shown in top panels, and result in numbers of males (>80mm) and legal-size males in lower panels. The random recruitment model produces total male and legal-size male populations that are quasi-cyclic, with variable periodicities that might approximate 20 years in some time segments (Fig. 11). The cyclic model produces more variable populations, with variable amplitudes (Fig. 12). In both models, low levels in the total population precede lows in legal abundance, and fluctuations in legal abundance are less abrupt than those of the total population, due to the smoothing effect of growth patterns (over-lapping size modes and timing of recruitment). Legal-size populations in both models are of about the same magnitude as survey estimates (Fig. 6) and are believable relative to fluctuations in catch per unit effort (Fig. 7). Comparing results between recruitment models suggests that king crab fisheries and biological research on king crab stocks have too short a history to tell the difference between random and cyclic recruitment.

After examining random and cyclic population generation models, I introduced target exploitation rates. These were introduced without considering variability in "actual" exploitation. What would be the effect of a given harvest strategy on stability of landings if target exploitation rates were precisely followed? I considered three harvest strategies: 1) 40 percent exploitation of each 5mm size group above legal size; 2) 40 percent exploitation of "small" legal crab and 60 percent of "large" legal crab (split season); and 3) the current strategy (Table 2). In the split season schedule, I defined small legal males to be those within 25mm (about the maximum molting increment) of legal size. The three harvest strategies were combined with each of the two population generators, to form six models. Each of the six harvest strategy models was allowed to equilibriate for 40 runs and then to run for 100 runs (years). Terms used in Table 2 for population size were interpreted as average (within one standard deviation of mean total male abundance), depressed (less than average) or peak (greater than average). Pre-recruit abundance was taken as declining or increasing, depending upon whether model abundance of crab within 15mm of legal size changed by 20 percent in a negative or positive direction



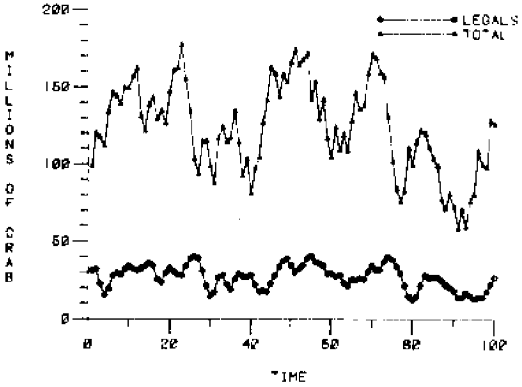
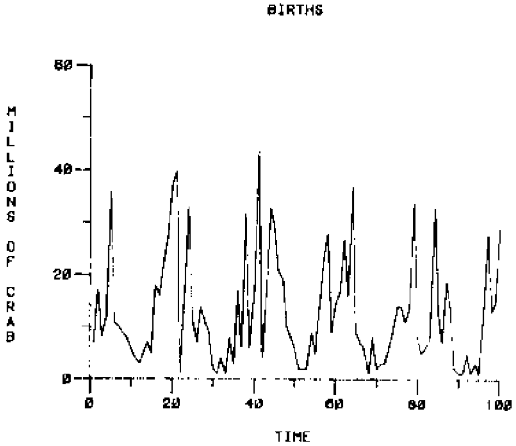


Figure 11. Modeled random recruitment of Bristol Bay red king crab males (uniform probability model over range of 1.0 to 50 million recruits, top); and modeled male population at ages greater than four years for 100 model years, assuming growth and decay shown in Figure 10 (bottom).



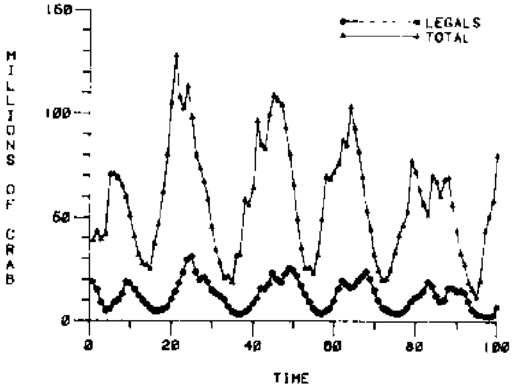


Figure 12. Modeled cyclic recruitment and resultant populations (uniform probability model with lower limit of 1.0 million and upper limit determined by sine curve over time).

over a three-year period. Each of the six harvest strategy models was run 10 times, with 100 years of harvest in each run. I then compared mean landings and the coefficient of variation of mean landings (standard deviation as a percentage of the mean) between models, and plotted the results (Fig. 13).

Results of 10 runs for each harvest strategy show little difference in 100 year mean landings, but strongly indicate that the current harvest strategy produces more variation in annual landings than either 40 percent exploitation or a split season strategy. Coefficients of variation for the latter two strategies were similar. Mean landings in the random models were higher than those in the cyclic models, as one would expect from the relative magnitude of legal populations generated in preliminary runs (Figs. 11 and 12). Model output is, unfortunately, in numbers of crab landed rather than weight. I suspect that split season management would produce slightly larger average landed weight than the other two strategies.

The models are preliminary because they ignore the obvious possibilities of density dependence of mortality and recruitment, as well as the confounding of size-related and age-related mortality. On the other hand, these possibilities have never been used in setting ABOF management policy. Density dependence of natural mortality could well result from either predation or (especially) disease. If the current ABOF harvest strategy reflects, in part, a desire to protect reproductive potential, then increased variability in annual landings might be acceptable. This would require that reproductive potential be well related to future recruitment. Incze et al (in press) suggest that reproductive potential is not well related to recruitment. A better understanding of the relationship between reproductive potential and recruitment, as well as density dependence of mortality, is needed. In the absence of such understanding, preliminary results suggest that the current harvest strategy is not in accord with maintaining stability in landings.

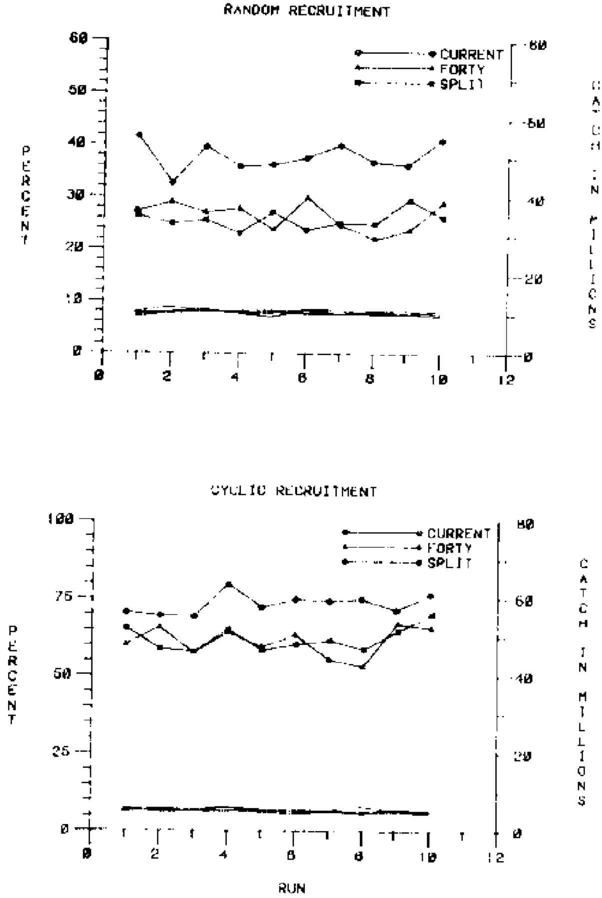


Figure 13. Results of simulated exploitation under random and cyclic recruitment. Each data point represents a 100-model-year run (similar to Figures 10 and 11). Lower lines in each panel are catch; upper lines are co-efficients of variation. Simulated exploitation under current (Table 2), 40 percent and split (40 percent, 60 percent) exploitation (see text).

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SESSION V

DATA NEEDS WORKSHOP

Data needs workshop

Editor's Note: *The transcription of this workshop was edited and condensed by Bob Otto, A. J. Paul and Nina Mollett.*

OTTO: That concludes the formal session. Now we want to hold a data needs workshop. Each session chairman has been asked to participate on the panel, but the workshop is not going to be productive without extensive participation from the audience. We need to review what we've done and what needs to be done. I have a few observations, and invite the session chairmen and the audience to add theirs.

We have had some difficulty deciding just what king crabs are. Do we wish to refer to king crabs as the subfamily Lithodinae or are we really talking just about Lithodes and Paralithodes? We have received a lot of new information on the distribution of species that perhaps traditionally have not been called king crabs.

Another point that came out here is the growing importance of Lithodes. We need to study the apparently different reproductive strategies of the two genera (Lithodes and Paralithodes) as well as correlated oceanographic effects, and to collect biological information, including data on predation, parasites and diseases. Particularly with respect to Lithodes, we have a rather large gap in our knowledge of larval life history and larval ecology. We also have little information on the timing of molting and on the general problem of reduced fecundity in Lithodes relative to Paralithodes. For example, the Alaskan golden crab's fecundity is approximately 10 percent that of the red and blue king crabs.

In our consideration of zoogeography, we didn't consider parasites and diseases. We talked about predation, but not about exclusion of species from certain areas on the basis of diseases. It is striking to compare the high rates of Briarosaccus infestation in southeastern

Alaska with the very low rates in the Bering Sea. A more practical consequence of thinking about diseases and parasites is to ask just how advisable it is to transport live crab from one place to another.

PAUL: In the life history session, I was heartened by the number of papers received on species other than red king crab. Prior to this symposium, there was very little published information on the biology of golden or blue king crabs. However, the red king crab constitutes the major fishery, and there was a disappointing lack of papers dealing with the major question: Why aren't there any crab? Perhaps those papers don't exist because we lack answers.

I noted some interesting data gaps. For instance, the timing and location of egg hatching, and concurrent oceanographic observations, would be of value. Observations on larval mortality rates are really needed. Expansion of the existing reproductive studies is also needed. Better estimates of size at maturity over the whole geographic range are needed. We also need a current bibliography on king crabs.

I would also like to propose a large-scale international recruitment study. It would have to have certain prescribed limitations because of financial exigencies, but we should consider picking study areas that are experimentally manageable. The Bering Sea is too large and remote, but some more isolated areas of Alaska, Auke Bay or Kachemak Bay for instance, might be experimentally manageable. If the study was done on an international basis, each group working on similar problems with agreed upon objectives, and there was a free and rapid transfer of information, we might gain knowledge fairly rapidly. We might be able to initiate the study with research primarily on the first benthic stages. Larval work is expensive, but if we could start with early benthic stages and perhaps look at the recruitment process, the study might be successful. I feel we need sequential observations of mortality in successive year classes for at least ten years. A shorter-term observation period probably won't gain us very much.

We need to have some seasonal and interannual identification of predators and their potential impact on mortality. I would also like to see annual measurements on a routine basis of temperatures and egg production by king crabs. We have many other data needs as well.

INCZE: A.J. (Mr. Paul), in your list you left out the larval stages because, while there's a lot that we can learn about larvae, we're a long way from applying that information to actual recruitment problems. Perhaps larval biology can be worked on independently.

You're saying that if we organize an international study with people working in selected areas within their own countries, a good starting point would be the first benthic stage?

PAUL: Yes, because one needs a certain oceanographic sophistication to work with the larval forms, as well as a long study period. There would be a gain of knowledge, but the time period required might be relatively long. If we start with a benthic stage, however, I think that the data base will build at high speed and that the gain of knowledge will be relatively rapid.

INCZE: You're looking for stages where the mortality rate is more dramatic and perhaps is the greatest?

PAUL: Perhaps one could identify critical life phases and the mortality factors that relate to those critical phases.

OTTO: One of the problems is that larval study is incredibly intensive, and there aren't many people around who can do the sorting and identification accurately. The cost of doing larval work on the same scale that we now have in our work with benthic stages would probably be an order of magnitude greater.

INCZE: One of the things that came out of both A.J. Paul's review and my talk is that, with regard to the larvae and their requirements in nature, we actually need to start the work in the laboratory. There is no point in trying to understand larval biology from field studies right now. There are a lot of things we could learn from field studies, but among the things we need are a very basic understanding of what the larval requirements are in the way of prey. Prey limitation isn't the only cause of larval mortality, but it may be one of them, and it's one of the ways to look. I don't think it would be reasonable to propose large scale observations of the sea, because we aren't even sure what the appropriate things are to measure. And as you point out, they would be terribly expensive.

STEVENS: In order to better understand crab population dynamics, it would be very useful to have an accurate technique for determining age. There isn't any way to age crab.

OTTO: About the only way we can look at the age structure is by tagging, and that is an expensive process. If we tagged the same species each year, moved the crabs and dispersed them in the population at random, we could perhaps come up with the age composition at any time in subsequent years.

PAUL: Has anybody thought about coded wire tags, like they use in salmon?

OTTO: The problem with wire tags is that detection equipment is expensive, and that the fishery is moving from centralized shorebased processing to widely dispersed catcher-processors, which makes logistics difficult.

SHIRLEY: Isn't that an argument for using very discrete areas for a recruitment study, such as small bays where the population may only be in the thousands, so that you could really have a fishery on a research basis? You could go in and fish yourself, put tags on small crab and check everything that comes out. To do that in our commercial fisheries on a large scale would be impractical.

JAMIESON: I think that's the only way to go. Make it a research experiment.

PAUL: Yes. That's why the first thing on my list is to pick areas that are experimentally manageable.

REEVES: I'd like to make a comment on the aging point. One thing we need to ask is how precise we have to be. We can try to improve our techniques to the nth degree, and lose something in the process. For example, in my talk, I relied on an indirectly determined age composition, and while it is not entirely accurate, for the purpose of examining mortality trends, changing age composition slightly to allow for the inherent inaccuracy didn't seem to affect trends much. For some purposes, parameter estimates that are not entirely accurate will suffice, a point we have to keep in mind, because we're always dealing with scarce resources.

OTTO: Our two representatives from industry asked me to comment on their points of view. A real question in anything you do is "How much is enough?" Where do we stop with what is essentially fisheries research and get into basic research that we see no immediate application for? Industry is most interested in a better way of forecasting. I think this ties in with the idea of studying earlier portions of benthic life histories. If there were one single thing that would help industry, it would be to give them a larger lead time on changes in population abundance.

ARMSTRONG: I get the impression at these sorts of meetings that there is no real sense of how you relate people's interest in basic biology to the needs of management. I am perplexed, particularly in considering funding sources, as to how issues that are inherently interesting to me will be saleable and usable to managers, and it's not always a straightforward and easy connection to make. There is, however, a surprising lack of basic biological information. Some of it may not have immediate management applications, but to remain ignorant of processes, ecology, and basic life history will always hamper managers from thinking imaginatively of different ways to do things.

I have come up with a long list of research needs that I think are important, many of which A.J. Paul mentioned. But I wonder if we're inhibiting ourselves from discussing research needs by worrying that they may not be of interest to management agencies. Do managers care about basic biological information? Will they take it and use it, alter plans, strategies, allocate differently, experiment with it? I like doing ecological, physiological work, but is it of utility to people?

I think the issue of settlement, substrate, critical habitat and whether or not newly settling year classes reach it is one of the first places to start the project suggested by A.J. Paul. I would back off on large-scale larval surveys, too, because wherever the larvae may be located, what is probably more important is whether or not they reach the critical areas.

DAVIS: From a management standpoint, knowledge of the basic biology of crabs is extremely important. Here in Alaska, pressures caused by an industry that is designed to exploit the crab resource to its maximum require that managers work without this basic knowledge, and in many cases, we have data bases with large gaps that we are eager to fill.

I am envious of our South American colleagues in the sense that they have new, growing fisheries and are still trying to get some sort of handle on what their resource is and how large it is. They're not faced with industrial pressure. They have time to investigate some purely biological types of problems and questions, and build a data base. Then if they do find that their resources are commercially valuable, the biological information will likely play a very important role in management of those resources.

Since finances are limited, I can fully appreciate the expressed problem of some interests being bypassed by funding agencies in favor of other projects that may appear to have more of an immediate management benefit. Management is very interested in building our basic knowledge of a particular resource. Much of the information that has been discussed and presented at this symposium has created more questions than answers. All of us will leave here with some new ideas as to how to approach our existing data base and how to expand it, and that's going to benefit management in the future.

ARMSTRONG: Bob Otto, what would you do differently with new first-time basic biological, ecological information concerning red king crab in the southeast Bering Sea? With unknown issues now clarified to some degree, would management do something that's appreciably different than what it is doing now in concert with ADF&G? How is that translation made from biological data to actual application in management?

OTTO: Management has never looked more than one or two years ahead because we lacked the ability. Also, the economics of the fishery has been such that you really couldn't look that far ahead and make meaningful decisions. Decisions were made on an ad hoc basis, while from a long-term perspective, we were filling gaps as more and more information became available. Longer-term thinking in management largely dealt with protecting reproductive potential, maximizing sustained yields, or stabilizing catches. The management of king crabs is, however, incredibly fine-tuned. This is one of the tightest kinds of management systems around. Few of the world's fisheries are managed with anywhere near this kind of knowledge and intensity.

I think that the single most crushing problem in management is how many crabs can be caught, now and maybe next year. What kind of product are we talking about? How much? There's a lot going on here that's peripheral to figuring out how many we're going to catch.

Some of the original work done on red king crab in the early 1930s and 1940s is classic. They looked at distribution, breeding, fecundity, morphometry and many other things we've talked about, and in the space of a few years put together a pretty credible picture of the red king crab's basic biology. The thing I might have done differently in the Bering Sea would have been to start studies on other species of king crab much earlier.

Another thing I would have done earlier would have been to start looking at a broader spectrum of things. We fisheries biologists tend to be whole animal biologists, looking at larvae and benthic forms and perhaps predation. We tend to think of what they ingest, and don't spend a lot of time thinking about the parasites inside them, nor about the physiological mechanisms that drive these animals. Now we find ourselves with a crash in population, and we don't have the answers because we weren't looking in the right places.

Al Sparks' work points out rather clearly that diseases and parasites can be an immense force. Studying animals as whole entities and considering them as black boxes or things you can count isn't going to solve that kind of problem.

SPARKS: One of the things that was astounding to me, after I became involved in fisheries, was the lack of consideration given diseases and their effects on the population structure of both fish and invertebrate resources. Catastrophic mortalities in human populations, known as epidemics, and catastrophic mortalities in animal populations, known as epizootics, have a great deal of similarity over a wide taxonomic spectrum. A third of the population of Europe died of bubonic plague over a ten-year period. This happened when cities were first becoming large aggregations of people.

Look at the large aggregating herds of east African ungulates such as wildebeests. These animals tend to build up extremely large populations, to the point at which the range will not support them, even though they migrate during the year. Once they reach their peak population, rinderpest emerges. Rinderpest is a viral disease that hides somewhere in the population for a long period of time. First you can't find any evidence of it and then you go out on the plains of east Africa and may see 75 percent to 80 percent of the population die over a two or three month period.

We learned at Texas A & M Research Foundation that a coccidian protozoan, "dermo," can cause 99 percent of the oysters in high salinity areas in Louisiana to die during their second summer if they are not harvested. That is 99 percent dying from disease alone, aside from predation. The oyster industry in Delaware Bay was totally wiped out over a six-month period during the 1950s. It went from a multimillion dollar industry to zero production, and still has not fully recovered. This was caused by a hoplosporidan protozoan parasite commonly known as MSX.

On the West Coast, I don't think there's any question that Trichomaris invadens, black mat disease, played a significant role in the tanner crab crash. I'm not in the position to say what, or even if, any disease organism is really of critical importance in the crash of king crab. But I think it's a real possibility because, like the tanner crab, king crab are aggregating populations. They build up to extremely dense populations and then there's a die-off, perhaps caused by devastating diseases. The population is knocked way down, animals are dispersed, transmission becomes more difficult, and then the disease begins to occur much less frequently. Essentially, a pathogen will disappear from the host population until the numbers build back up to a peak again.

These are just some things that I think perhaps, as fishery biologists, you've not been exposed to. I'd like to get those concepts into your thinking.

MEYERS: I have a couple of comments on what might be done in future studies of king crab. Looking at younger age classes of crabs, particularly at the larvae to see if there are some limiting factors in early life history, would be very important. Also, we don't know exactly what diseases are present in Alaskan king crabs, and that's another aspect of study that would be good to continue by cataloging crab diseases and parasites present in the populations and keeping an eye on them from year to year. Such studies might allow some predictability when and if the populations reach their former size again.

WICKHAM: Population declines are clearly an effect of increased population densities. To the extent that we can manipulate crab population abundance through the fishery, whether by taking legal animals or by affecting the population structure dramatically, would it not make more sense to begin to think in terms of reducing recruitment to the fishery on a long-term basis? Trying to control recruitment to prevent having larger classes, trying to keep populations from getting too large, and, on a more continuous basis, developing more reliable production. I'm just wondering if thoughts along those lines wouldn't really make sense from a management standpoint.

OTTO: With regard to king crabs, management policy is clearly directed at trying to stabilize catch. This has not been translated into the question of optimum population size. It is unlikely that it will be, because it is doubtful that the variables that control population size are ever going to be under management control.

INCZE: The king crab resource during the late 1970s and very early 1980s actually was a product of just a couple of very successful year classes. The population fished for many years was really the product of one or two events, and you may run into a problem of erratic harvest if you try to crop down your numbers early in the game. With king crab, the 1971 or 1972 year classes were very strong, and there doesn't appear to have been another really successful year class until 1978. That one succumbed to the general catastrophic decline that seemed to affect the whole population.

HAYES: One of the problems we deal with in fishery management is population phenomena that occur in relatively short time spans. One phenomenon is the sporadic nature of recruitment to populations. The time and the events which cause cycles are usually modeled in stocastic terms, simply because we're ignorant of the facts causing the noise. The reason we're ignorant of these facts is that important phenomena occur sporadically in the long-term, and we may see only one event of this kind in a lifetime of working on a species. For example, why were the 1971 or the 1971 and 1972 year classes successful in the eastern Bering Sea? The 1978 year class is pretty easy to understand because of the size of the female population that produced it. But really, there's been only one extremely successful period during the time we have monitored red king crabs closely.

What I'm saying is that it's hard to anticipate, and to do what the fishery management people seem to want us to do, and I think that it all boils down to relatively short-term predictions over a period of one to three years. We can study the nature of variability of stocks through phenomena that occur over longer periods of time. If you look at nature, fisheries, oceanography, and long-term weather, you will find quasi-cyclical patterns. There are sun spot cycles which are approximately 10 years and 33 years in duration. In the field of oceanography, scientists have been able to predict and demonstrate a cyclic pattern in the eastern North Pacific of around seven or eight years duration for many, many years. We look at fish populations, and we see the sporadic recruitment among year classes. Why was 1977 in particular such a phenomenal year for various fish populations? Somehow, you need to think seriously about how we structure our total research pattern and how we allocate our dollar resources between research that addresses short-term phenomena and research that addresses long-term phenomena. Perhaps the most valuable thing we do is to maintain the integrity of our long-term data base. On the other hand, you might recognize that the costs of doing that have to be calculated. As a research administrator working in this field, I try to do that as long as it's within my program's needs, but we need to look at the projects as a group. If we could move the schedule back to where we're getting reliable recruitment estimates of two- or three-year-old crabs rather than four- or five-year-olds, that would be the most important step we could take for the short-term.

Just one more point here, and I'll stop. If you hypothesize transport as the critical factor affecting the ability of the larvae to settle in appropriate areas, there are relatively short-term events or series of events during the larval period that could be exceedingly important. You may have a six-day period when it's critical whether or not you have wind. Simply doing a persistent series of offshore weather observations for a period of some days would become truly important. Please think very seriously before you make a change in the direction of research. Anything we do may take 20 or 30 years to come to fruition.

OTTO: One comment for those of you who are perhaps not quite as familiar with this as Murray Hayes is. As Forrest Blau demonstrated, the 1971 class of red king crab looked good at a lot of places around the state. For 1972, the Bering Sea seems more or less unique. Pandalid shrimp also had an excellent recruitment year in 1971. In Pavlof Bay, that year class alone provided more than 50 percent of the shrimp fishery over the succeeding seven years. In 1977, the year classes he is talking about are not just cod; 1977 was also a strong year class for pollock, halibut, and sablefish. So there's circumstantial evidence, tied at least to this most recent cycle, suggesting that whatever is happening is in some way very good for fin fish at times when it's very poor for shellfish.

KOENEMAN: Stability of catch, as a first objective, fits man's needs. And in some ways, it fits man's egos quite well, but it doesn't quite work in with the biological system. What Murray Hayes is saying, from a management point of view, is what I also find perturbing about the system; there's very little information at any level on the effect of fishing on the population. We can imagine all these outside forces that are being exerted on a population that which we ultimately want to fish, but, as managers, we usually can't even see the results of our decisions. Going along with what Dr. Hayes said, I think that once we take a path, we need to stay on it for a period of time so that we can see the potential effects, rather than letting other things interfere and change our path along the way. Another point is that in face of all these factors we don't know anything about, we have to allow the population to maintain itself in as much of its natural state as we can, so that it has a resiliency against outside forces. That's where we fail as managers, because this stability, maximum sustained yield everyone calls it, doesn't really fit in with the biological entity. I guess it's kind of naive to think that we may be able to get there without considering the biology of the animal rather than our own needs, but then we need to throw ourselves in the system, too. A lot of the things you see over time, whether diseases like Al Sparks says, or predators or year classes in certain species, like Bob Otto's talking about, in my mind are things that have all occurred in some type of natural setting that we can't define. Our own interjections through fishing, and what eventually happens in the population, have a tendency to be pointed toward one thing; namely, exploitation at a higher and higher rate. You have to have real fine numbers to do that successfully.

REEVES: I would like to add a little bit to that. Management is made up of many components. I'm a biologist, and I tend to look at the work just from that perspective. I divide it into two areas: "How much can be caught in any year?" and "How much is coming down the road?" I think these are key questions from the biological/conservation/management point of view. Murray Hayes has touched on the problem of forecasting. Obviously this is something we need to work on, but it is also obvious to me that there hasn't been any discussion at this symposium on what is the proper or optimum exploitation rate for king crab stocks. I suspect this is because, in many areas, we were using somewhat subjective, even arbitrary, methods of determining the quotas or exploitation rates. This is a key area that needs a substantial amount of work, and if we're establishing priorities, I think it should be at the top of the list.

ARMSTRONG: But how would you go about determining or modifying current levels of exploitation?

REEVES: Well, I think we need to determine the right exploitation rate let's say just from a biological point of view: How many king crab can be removed in any given year without doing damage to the stock? I don't think anybody here really knows the answer to that question.

ARMSTRONG: Are there missing points of information?

REEVES: We need to look at things like the relationship, if any, between female reproductive capacity and exploitation rate; or between that and the sex ratios we observe; or between that and size ratio. How big a male does there really have to be to mate any given female? These types of questions have been raised for 20 or 30 years.

ARMSTRONG: And not resolved?

REEVES: Right.

OTTO: This idea of protection of the female stock goes back to a British act of Parliament in the management of Cancer productus, the European edible crab. I believe 1891 was the first formal adoption of this sort of a regulation for the protection of reproductive potential in a crab stock. In all the time since, I have yet to see a demonstration of a good, solid feedback mechanism. Yet, when we had to decide what we were going to do when stocks were going down, we set up an exploitation schedule that drastically reduced exploitation rates and was, in part, intended to deal with the possibility of reduced reproductive potential.

Now, one other comment. You can't exploit a population and talk at the same time about maintaining it in its natural state. If we don't want to change the natural character of a population through biological management, we have no business managing at all. As near as I can tell, it's perfectly natural for king crab populations to go through drastic fluctuations. If we don't want to handle that problem, we have to learn to live socioeconomically with the fact that king crab populations undergo large fluctuations. Our institutions do not, and cannot, go through cycles that rapidly without fantastic human costs in terms of lost livelihoods, people bankrupt, companies bankrupt, and other social consequences. We have to do something about variation or try to modulate it in some way, if we're going to be talking about managing at all.

HAYES: When I came into this business about 25 years ago, I had the idea that somehow, as managers, we could manipulate populations for the good of everyone. But after studying these problems for 25 years, when people now ask, "Whatever happened to king crab?" my first answer is, "nothing." When I say "nothing," what I'm really saying is that variations are a natural phenomenon in nature. Stocks go up and stocks go down. So I think the focus of management has to be on the variability and the fluctuations in abundance and on managing those changes in the short term. That doesn't mean for a minute that you shouldn't use all the knowledge available to make predictions and accommodate fluctuating stock abundance. But it does mean basing your management on a philosophy of stability, and trying to manipulate to obtain that stability.

OTTO: I think maybe we've gotten to where we're talking about things as they are, rather than about what we need to know. Does anybody have anything further in terms of data gaps? For the purposes of this kind of conference, I think it's important to talk about other aspects besides those that are directly pinpointed by management.

HANSON: I would just like to make a comment with respect to what Jerry Reeves said. He feels that it is important to study the optimum harvest and attrition rates. I am not a biologist, I'm an economist. Some of the managers I've talked with say that many of the management tools they use, such as limited entry, have no biological basis; they're economic. They're being imposed not necessarily for biological reasons, but because the industry has to be maintained outside the context of the biological objectives. It seems to me that an optimal exploitation rate is not simply one that the population will bear, but one that will maintain a stable economy and a stable industry, because the population is being managed for the purposes of that industry. If you have a collapse as we have had recently, that makes it questionable whether the industry itself can survive, it seems to me you have to begin looking not just at biological questions but at working with people who might be interested in looking from the other side, the industry side. How can we work together at managing this resource in a more stable way and according to management objectives?

ARMSTRONG: Sir, can you give us an example of how that might be applied to the king crab fishery, after the fact? In other words, it still seems to me that management would be translated at the level of harvest and rates of harvest. What does it mean, to consider the economics and incorporate that consideration into a goal of stability, in terms of the type of harvest rates and biological considerations?

HANSON: From the manager's standpoint, the rationale for most regulations is not biological. There is probably a biologically optimal harvest rate quite apart from an economically optimal or desirable harvest rate. For managers and biologists to ignore that reality is a mistake, because decision-makers, the ones who are ultimately making the regulations, are receiving input from industry. In other areas of resource management, I've seen situations in which biologists, working apart from economists or from the people involved with decision-making and policy-making, come up with recommendations that are totally unattainable and unacceptable in terms of social realities. I think it's great to study all these specific aspects of biology in order to determine optimal runs and so forth, but there has been very little presented here about management implications of, for instance, parasites. To really contribute to the stability of the industry, which is important, I think that scientists have to begin including these implications in their analyses and not look simply at the biological details.

OTTO: I think one of the most confusing things to someone who is not involved, day-to-day, with management--particularly in dealing with king crab--is that many of the regulations and considerations are economic in nature but are couched in biological terms for political reasons. If you can come up with a conservation or "wise use" argument for certain types of regulations, you can improve their political saleability. Now, those of us who are biologists involved in management are fully aware that we can get trapped by this process and it can come back to bite us. Where a regulation was designed for economic reasons, but its justification was written in terms of conservation, you can come right smack down to it and somebody will say, "Well, what are the conservation purposes?" Or you can get trapped into a regulation that works counter to what you are trying to accomplish, and when you try to change it, somebody says, "But this was for conservation."

MATULICH: I'd like to pick up a little bit where Jeff left off. I'm also an economist, and know little about biology. Let's get away from arguing whether we're going to have natural stocks or stocks managed for human purposes. Most everybody in this room, including myself, is asking for public money to do our research. There's science for the sake of science and there's science for the sake of man. They're two completely different things, although they can coincide. Unless scientists produce results that are useful to man, I doubt if the scientists in this room are going to have their funding maintained for very long. Who's paying the bills? We're in a political economy, and I'm going to emphasize politics, particularly with the Reagan Administration. Who will be the first group to go in the next budget cut? Probably the National Marine Fisheries Service and various academics. Why are they going to get cut? Because there's been a long-standing trend of failing to look at biology in the context of the economic situation.

SPARKS: As a former manager in Washington, I'd agree with most everything you say, but I submit that the quality of research programs that are in danger, and even their relationship to the real world, have absolutely nothing to do with budget cuts. It's purely a political process. It's based on the question of who you can hurt without real cuts. The biggest problem is that the fishing industry has virtually zero clout in Washington. We once had a couple of guys in California with a great deal of political influence, but since their death, our influence has dwindled; and our support at the federal level has consistently gone down.

ARMSTRONG: So while we're worried about whether larvae are being moved hundreds of miles, that question may be somewhat superfluous if we can't nurture research projects through politically savvy lobbying.

OTTO: I disagree with Al Sparks on this. I can't say that the fishing industry has no political clout, because sometimes it does. Many times, we survive by selling something politically, selling a "motherhood" program and putting enough slush in it to fund things that we know have to be done in the long term. We're darned poor biologists if we can't figure out a way to get something with some basic significance out of these programs. The fact is that there's a little bit of fat around all that meat, and that's what basic research has survived on.

SPARKS: Perhaps I was a little extreme. But as far as political clout goes, just compare fisheries clout with that of the agricultural community or the aerospace industry or the military industry.

MATULICH: But that's precisely my point. Let's take the agricultural community. Biology, say agronomy, serves a clientele group that has become very effective, and that supports the underlying financial base to do the research on basic agricultural biology. That doesn't seem to exist for fishing, probably because the biology of fishing is far more complex.

OTTO: The importance of fisheries, even when you're talking about something as magnificent as the boom of king crab fisheries, is miniscule on a national scale. I don't think there are ten people in Washington, D.C. that have any real background and knowledge of what happens to king crabs, or their relation to the fishing industry, or of the processing industry and its capitalization. I think we're getting way into the politics of fisheries and far away from things that we need to do; or is this simply an indication that we've run out of data gaps?

KARINEN: I have one more data gap that I'd like to point out. We all know that king crab occupy that one-tenth meter of water above the benthic substrate. Yet we know virtually nothing about the temporal or spacial dynamics of environmental characteristics in that water, which may have an impact on crab reproduction and on the survival of these species. Most oceanographic work stops a meter or two above the bottom, and we really haven't looked at what's happening right at that interphase, which is so important to crabs and their survival.

OTTO: Yes, I have to agree with you. There has been very little work done. We're "whole-animal" biologists; we give them a place to hide from predators, or we look at cryptic coloration, but there's a lot more to that environment.

KARINEN: I'm specifically thinking about oxygen, H_2S, ammonia, the development of anaerobic conditions, on small or large scales.

SOMERTON: There are other data needs. I think Al Sparks is right about the potential threat of disease to crab populations. One study that needs to be done is a determination of how long, from the time of infection, it takes for an animal to die. This would allow us to measure rates out in the field and turn them into mortality rates that the disease is imposing on the stock at the time we measured. That's something that could be done in the laboratory.

INCZE: I'm quite naive about the real management process and its goals, but many of the comments that have come up here sort of circulate back to a point that Dan Wickham brought up, and I have to ask the questions: "What is management really after when they say they're after the maintenance of the stocks?" Dan's point, if I interpreted it correctly, was that if you have a high population persisting for four or five years as it did in the late 1970s, you are inviting the type of epidemic situation that occurred.

WICKHAM: Right.

INCZE: If recruitment is very irregular--and we're dealing with slowly growing long-lived creatures--and you want to continue harvesting them year after year, you can't knock them off when you first see them coming up. If you do that, you're not going to have the resource that you need for stability, in order to continue harvesting. So what does management want? Does management want to stabilize harvest as we've heard said a couple of times? Or is it better to try to knock off a population if we really think that its size is a threat? This is biological management, not socioeconomical management.

OTTO: Can I summarize that as the problem of an optimum population as opposed to an optimum legal stock?

WICKHAM: There's a strong analogy with agriculture, where you automatically plant more than you need, but you do go out at a certain time and weed it, and usually you weed it very rapidly after you've gotten your initial set. We may not usually think of fisheries as providing agricultural commodities, but they really do. You're growing populations, you're trying to harvest them, and it's obviously much more difficult to control them, but there actually are ways of controlling them. We do it with fisheries all the time. And it's something that at least can be thought out. Sometimes, it's pretty risky to do these things, but it's also risky to do a lot of the agricultural things that work very well.

OTTO: Two things. First, because of the way we have our size and sex limits structured and the small proportion of the population that we're actually harvesting, it's very difficult to manipulate the population as a whole by fishing. For example, females are not harvested, and seafood processors have stated that they wouldn't be interested in processing them if their harvest were legal. Second, I'd have to side with the economists--whether it's worth having populations go up and down or not is a function of what your alternatives are. From a broader-based industrial perspective, one king crab stock going down isn't a real problem. We can go fish another one that's in Adak or someplace, and as long as we don't run out of places to go, the ups and downs of a single stock aren't so bad. Or if we can switch from crab to groundfish, in terms of long-term stability in industry, declines in king crab stocks are not a fantastic problem. In the situation we face, however, a fair segment of the industry didn't have many economic alternatives because the vessels involved were too new to have paid off their initial investment costs or lacked the wherewithal to enter other fisheries. Frankly, in terms of optimizing harvest trends, the only conclusion I've been able to come to is that you can't do it on a single stock or single species basis. You've got to look at the structure of all the stocks together and construct some sort of a model where you minimize change within constraints.

KURIS: I tend to resist this agricultural fisheries analogy. There are some very critical differences between the two fields. Fisheries operate with a common resource, while agriculture is held in private hands, and so, in fact, you really don't manage agriculture. There aren't departments of corn management in any state, whereas fisheries requires some sort of management because they are a common resource. Also, as far as the tie-ins between agriculture and research go, while it's true they do have a tremendous amount of money because of this privately held connection, it is actually USDA research, which was really blasted a couple of years ago by some review panels, and not fisheries research. So I don't see too much we could draw from agriculture.

SHIRLEY: I see a very strong dichotomy in what we're calling management, and both branches have real research needs. One is not management, it's forecasting, and that's what Murray Hayes was trying to do. That is probably within our capabilities--extending our forecasting capability ahead a few years and using some improved techniques. The other is optimizing population size, which is probably a pipe dream right now because we need much more biological knowledge to do it. We're not really managing stock size now. We're managing fishing pressure. We would like to eventually be able to manage the population size. Can we address the research needs for both of these goals?

OTTO: Since we've run out of time, I would like to thank you all very much for attending, and I'd like to thank the Alaska Sea Grant Program for an excellent job of coordinating and bringing us all together.

Topics requiring further research

Larval Stages

Interannual production and mortality rates
Mortality causes
Food sources
Effects of oceanographic conditions on survival
Optimal environmental conditions
Interannual settlement success
Habitats for post-larvae

Benthic Stages

Improved predictions for recruitment to the fishery
Identification of factors most influential in determining year class size
Interannual differences in mortality sources and rates
Reproductive biology--especially male sizes and sex ratios needed to maintain high levels of population fecundity
Observations of disease, parasitism and egg predation
Development of aging techniques
Longevity
Measurement of mortality rates of sublegal and female crab due to fishing and handling
Effect of female protection from harvest on recruitment; spawner recruit relationship
Identification of critical periods in the life history
Habitat types for the different sizes of crab
Distribution and abundance surveys

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