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Biology and Fishery of Southeastern Bering Sea Red King Crab (*Paralithodes camtschatica*, Tilesius)

May 1985

BIOLOGY AND FISHERY OF SOUTHEASTERN BERING SEA

RED KING CRAB (<u>PARALITHODES CAMTSCHATICA</u>, TILESIUS)

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BIOLOGY AND FISHERY OF SOUTHEASTERN BERING SEA RED KING CRAB (PARALITHODES CAMTSCHATICA, TILESIUS)

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1. IDENTIFICATION

1.1 Taxonomy

The red king crab, Paralithodes camtschatica (Tilesius) is one of 5 species of the genus, three of which inhabit the subarctic North Pacific Ocean and Bering Sea. The taxonomy of the species are as follows:

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Kingdom Animalia
  Subkingdom Metazoa
    Phylum Arthropoda
      Class Crustacea
        Subclass Malacostraca
          Series Eumalacostraca
            Superorder Eucarida
              Order Decapoda
                Suborder Reptantia
                  Section Anomura
                    Family Lithodidae
                      Genus Paralithodes
                         Species  P. camtschatica (Tilesius)
                                  P. platypus (Brandt)
                                  P. brevipes (Brandt)
                                  P. rathbuni (Benedict)*
                                  P. californiensis (Benedict)*
                      Genus Lithodes
                   Family Paguridae (Hermit crabs)
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* Taken infrequently in deep water off California

The Lithodids are not true crab such as the Tanner and Dungeness crab but are related to the hermits crabs (Fam. Paguridae). They have lost their habit of living in abandoned snail shells and have taken on the traits of true crabs. Their ancestry is revealed by the asymmetry of the abdomen and first walking legs, the degenerated fifth walking legs, and several other minor structural traits (Marukawa, 1933; Borradaile and Potts, 1961. also see Fig 1). Unlike true crabs which have legs which are jointed in a manner such that they are oriented forward, the legs of king crab are jointed so that the legs are extended backward.

1.2 Morphology

The red king crab has an exoskeleton with a coalesced head and thorax (cephalothorax), abdominal flap, one pair of chelipeds (legs with claws or pincers), three pairs of walking legs and an array of antennae and mouth parts (mandibles, maxillae and maxillipeds). Metamorphosis through five larval stages and growth from the first instar form through adulthood is achieved by molting.

The external morphology of adult king crab has been described in detail by Marukawa (1933). The morphological characteristics of red king crab, *P. camtschatica* are shown in column 2 of Table 1. Characteristics of *P. platypus* and *P. brevipes* are presented for comparison. The red king crab is readily identifiable by the shape and color and number of spines on the posterior and postero-lateral margins and cardiac and branchial regions of the carapace (Fig. 2).

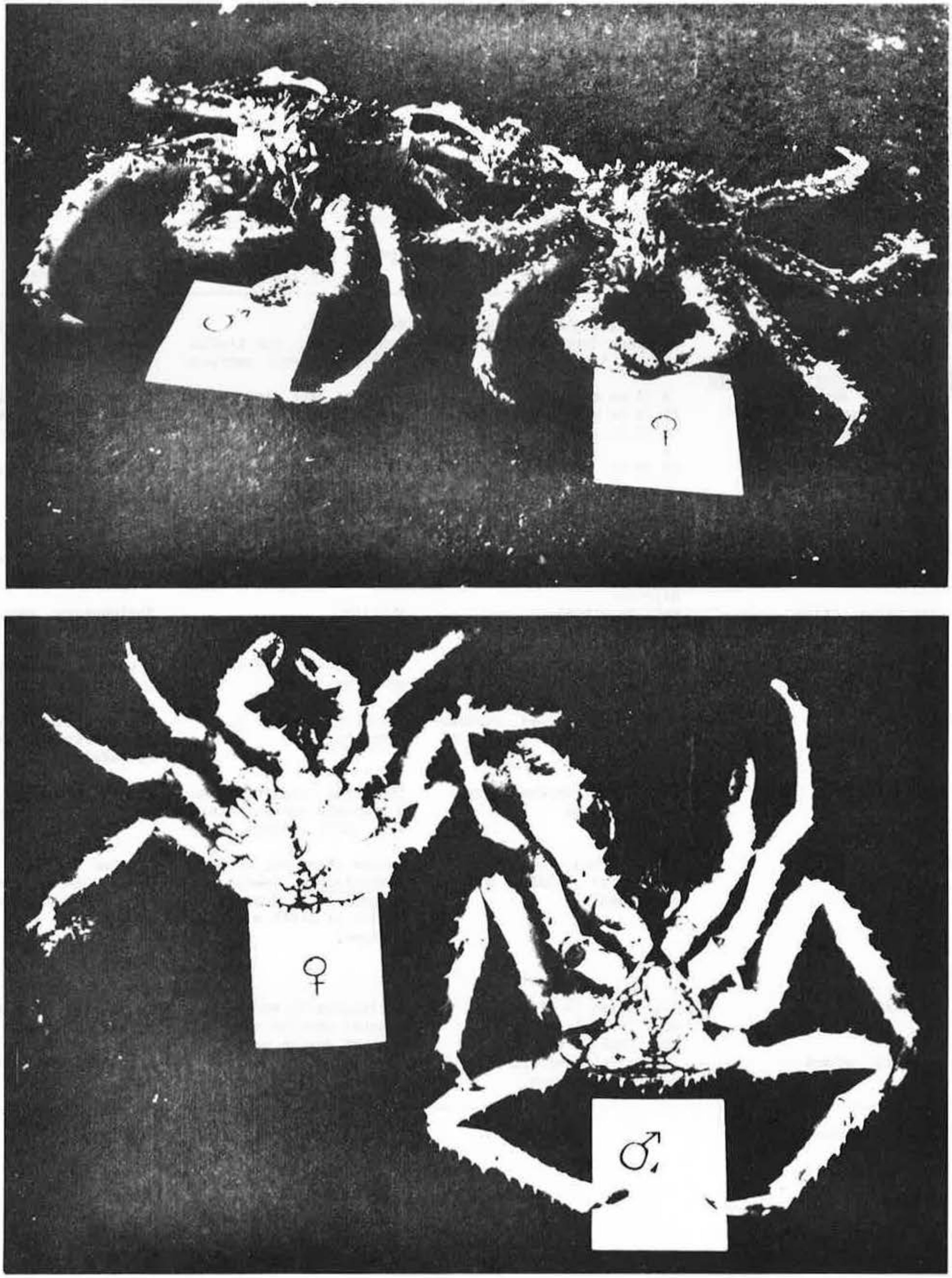

Figure 1. Dorsal and ventral views of adult male and female P. camtschatica.

Table 1.--Morphological characters of P. camtschatica, P. platypus and P. brevipes.

	Species		
	P. camtschatica	P. platypus	P. brevipes
Color of body	Dorsal surface of carapace and legs dark brown, ventral light yellow.	Resembles P. camtschatica, but bluish purple on dorsal surface.	Dorsal red, when dried appears blue
Number of spines on carapace			
Posterior margin	8 (4 on each side)	14 (7 on each side)	12 (6 on each side)
Postero-lateral margin	10 (5 on each side)	12 (6 on each side)	12 (6 on each side)
Antero-lateral margin	8 (4 on each side)	8 (4 on each side)	8 (4 on each side)
Anterior margin	4	4	6
Branchial region	18 (9 on each side)	12 (6 on each side)	14 (7 on each side)
Cardiac region	6	4	4
Gastric region	9	9	11
Spines on rostrum			
Central spines	Long, slightly curved for dorsal, terminal portion pointed.	Short, stout, and not curved.	Short, terminal portion slightly rounded.
1st dorsal spine	Well developed.	Wanting	Rudimentary, very small
2nd dorsal spine	One pair, much smaller than 1st dorsal spine	One pair, close to each other	One pair, larger than 1st dorsal spine
3rd dorsal spine	One pair, rarely 3 spines	3 spines arranged in straight line	3 spines, not arranged in straight line
Eye	Slightly protruded, diameter about equal to that of eye-stalk	Resembles that of P. camtschatica	Not protruded; diameter is shorter than that of eye-stalk
Antenna	Exopodite transformed to a small spine	Exopodite transformed to 2 branched spines with a very small lateral spine	Exopodite large with complicated spines
Legs	3rd leg long, length of meropodite 70-80% of width of carapace	Longer than that of P. camtschatica, length of meropodite of 3rd leg 85-90% of width of carapace	Shorter than that of 2 other species, chelipeds long and developed remarkably
Digit			
Dorsal spine	1	1	1
Ventral spine	1 situated in slightly more frontal position than that of dorsal spine	1 situated in more frontal portion than that of dorsal spine	1 situated in same position compared with that of dorsal spine
Internal spines	In general wanting, rarely retained as trace	5, situated on ventral side	7, sharp, needle-like form

Source: Marukawa (1933).

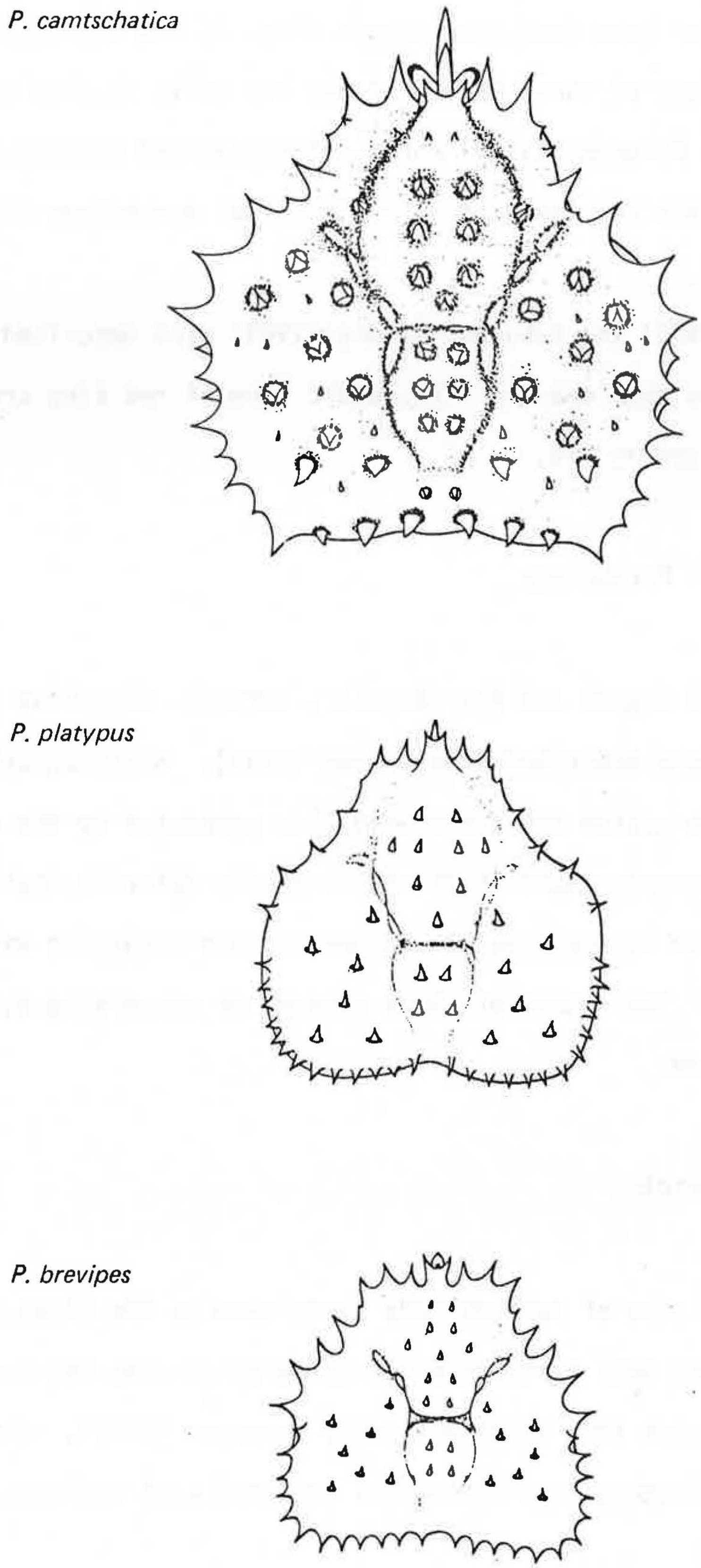

Figure 2. Arrangement of carapace spines on Paralithodes camtschatica, P. platypus and P. brevipes.

Red king crab have four zoea stages (Fig. 3) and one megalops stage. The external morphology of these larval stages for three species of Paralithodes was described by Marukawa (1933) and supplemented and corrected for red king crab larvae by Sato and Tanaka (1949). External morphology of zoea larvae is shown in Table 2.

Marukawa (1933) and Sato and Tanaka (1949) also described the external morphology of the megalops and first adult form of red king crab. These stages are depicted in Fig. 4.

1.3 Internal Morphology

The internal organs and the vascular, nervous, digestive systems of red king crab have been described by Marukawa (1933). Histological studies of the male reproductive system and sperm were also presented by the same author. Based upon microscopic examination of the ductus deferens, Wallace et al. (1949) reported on indications of changes in this structure with the onset of sexual maturity. The nature of these changes or supporting evidence for them were not presented.

1.4 Morphometrics

Data on the size of various body parts such as the claws, certain leg segments and other body parts relative to carapace size has been recorded from mature red king crab from Asian waters by Marukawa (1933). Similar information for southeastern Bering Sea red king crab has been given by Wallace (1949).

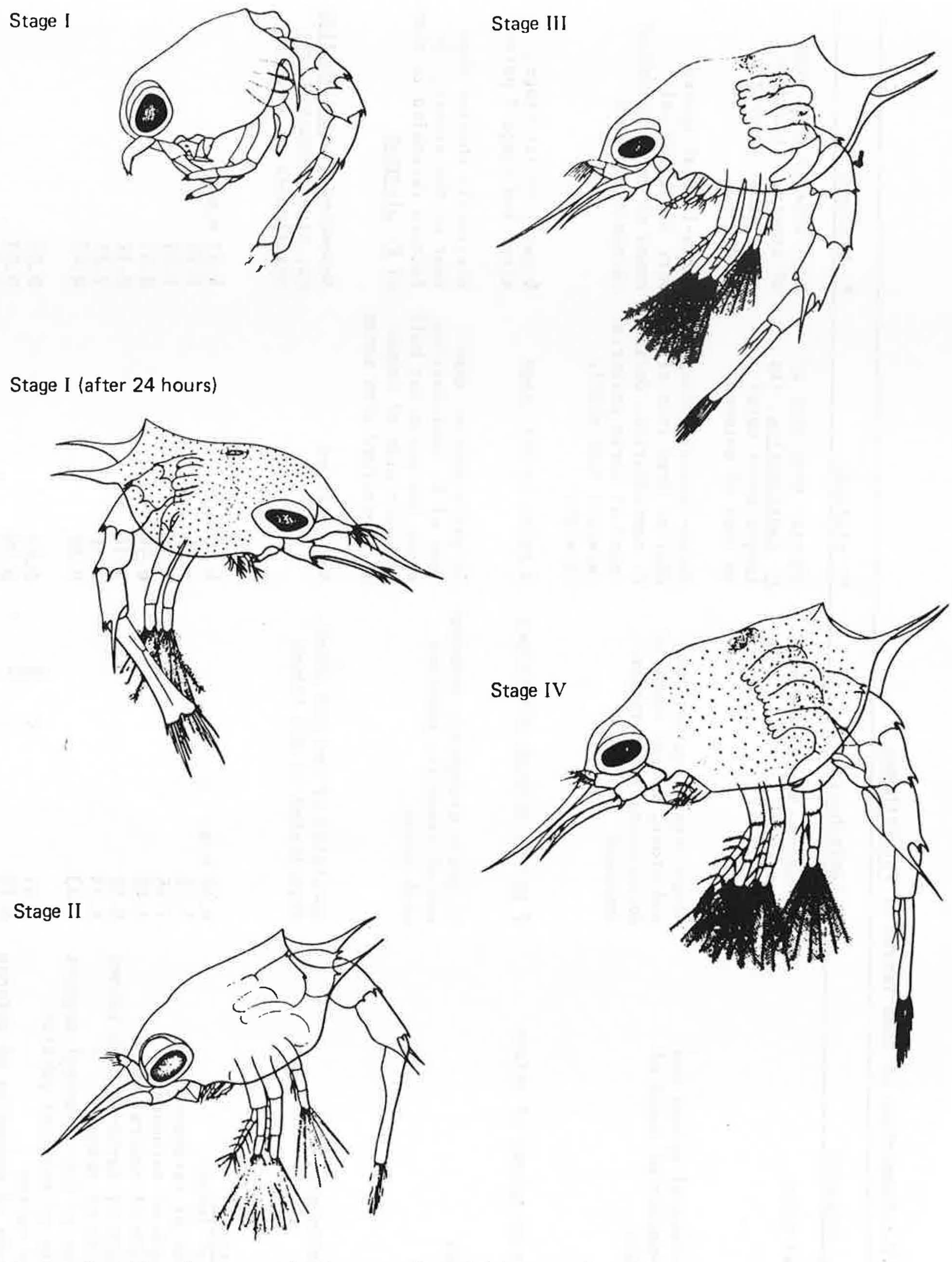

Figure 3. The four zoeal stages of red king crab.

Table 2.--Comparison of zoea larvae of Paralithodes.

Parts, compared	P. camtschatica	P. platypus	P. brevipes
Rostral spine	Elongates, beyond the end of antenna	Shorter than that of P. camtschatica, its length about equal to that of antenna	Much shorter than that of others, its length about equal to that of antenna
Dorso-lateral spines and dorso-posterial round of carapace	Dorso-lateral spines long and stout, dorsal round of dorso-posterial carapace concaved	Dorso-lateral spines shorter than that of P. camtschatica, dorsal round of dorso-posterial carapace runs nearly straight	Dorso-lateral spines very short, dorsal round of dorso-posterial carapace convexed
Number of spines of telson	7 pairs, through all stages	8 pairs in 1st stage	6 pairs in 1st stage, after 2nd stage 7 pairs
Antenna	Slightly elongated, terminal end of exopodite provided with setae	Slightly shorter than than of P. camtschatica, about the posterior half of inner side of exopodite provided with setae	Distinctly shorter than that of the others, its feature resembled to that of P. platypus
Chromatophores	Consisted of red and green, distributed in all stages	Not observed	Resembled P. camtschatica, but blue chromatophores distributed on antenna
(1st stage)			
Total length	4.56 m.m.	4.98 m.m.	4.31 m.m.
Width of carapace	1.12	1.16	1.25
Length of carapace	1.45	1.66	1.49
Length of rostral spine	1.08	0.99	0.61
Length of dorso-lateral spines	0.45	0.32	0.12
Length of abdomen	2.14	2.32	2.24
Width of 5th abdominal segment	0.23	0.29	0.27
Width of terminal portion of telson	0.51	0.65	0.50
Length of exopodite of antenna	0.83	0.79	0.53

Source: Marukawa (1933).

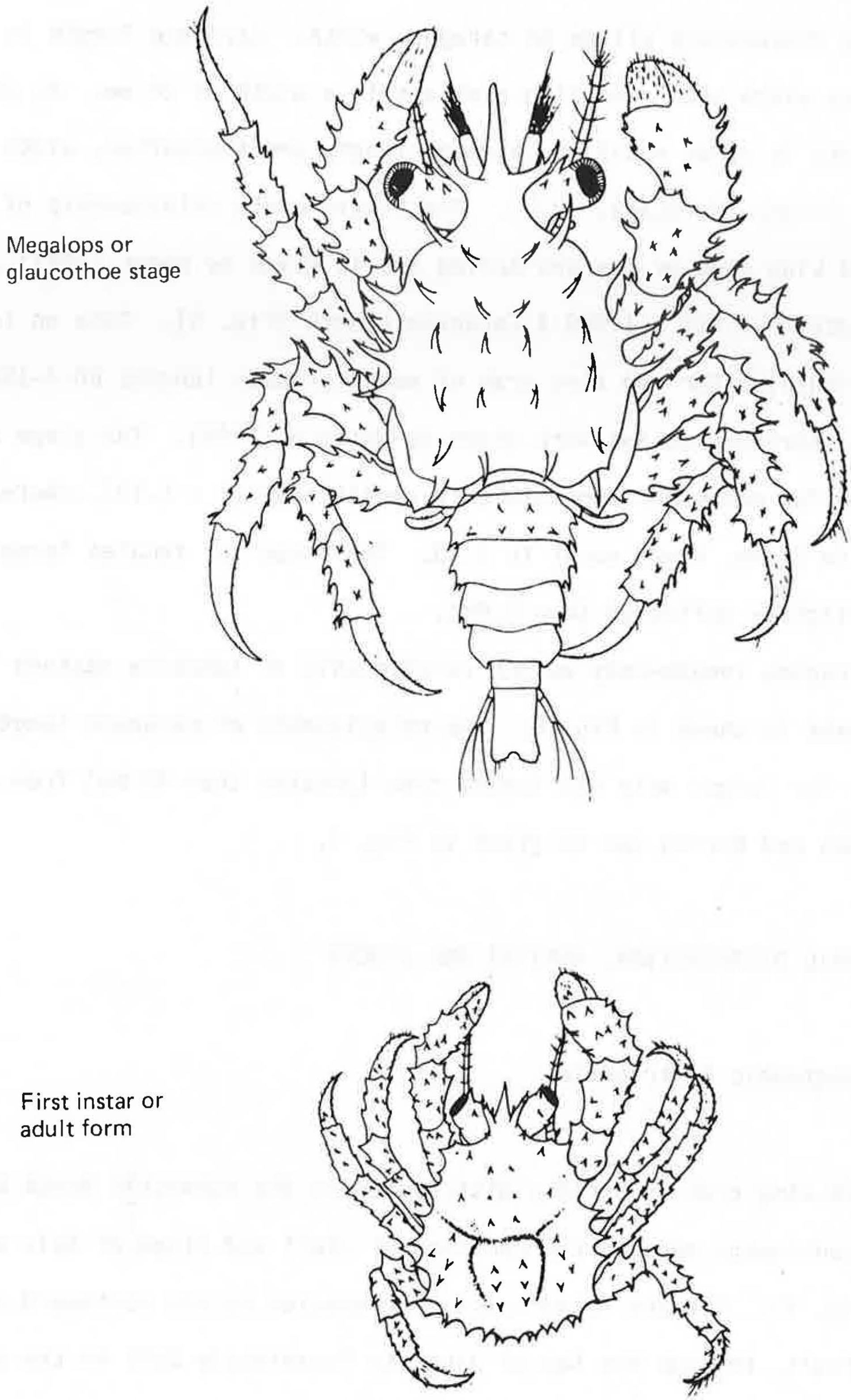

Figure 4. The megalops or glaucothoe stage and first instar or adult form of red king crab.

Although, conventionally, the size of king crab is given in carapace length, some discussions allude to carapace width. Carapace length is longer than carapace width until red king crab attain a width of 20 mm. At 20-25 mm, carapace width is about equal to carapace length and thereafter, width remains longer than length (Marukawa, 1933). The length-width relationship of immature red king crab of eastern Bering Sea is given by Weber (1967) as: Carapace Width = -1.449 + 1.080 X Carapace Length (Fig. 5). Data on length-width relationships for red king crab of mean carapace lengths 60.4-196.9 mm from southeastern Bering Sea were given by Wallace (1949). The slope of the relationship for males was approximately rectilinear (k = 1.10), whereas for females up to 87 mm, k was equal to 1.13. The slope for females larger than 87 mm was slightly deflected (k = 0.96).

The carapace length-body weight relationship of immature eastern Bering Sea king crabs is shown in Fig. 6. The relationship of carapace length to body weight for larger male and female crab (greater than 40 mm) from the Pacific Ocean and Bering Sea is given in Fig. 7.

2. GEOGRAPHIC DISTRIBUTION, HABITAT AND STOCKS

2.1 Geographic Distribution

The red king crab is broadly distributed in the subarctic North Pacific Ocean and contiguous seas on the continental shelf and slope of Asia and North America (Fig. 8). Off the Asian coast, the species occurs northward of Tsushima Strait, through the Sea of Japan to Penzhinskiy Gulf in the northern Okhotsk Sea. In Pacific Asian waters, red king crab occur from Cape

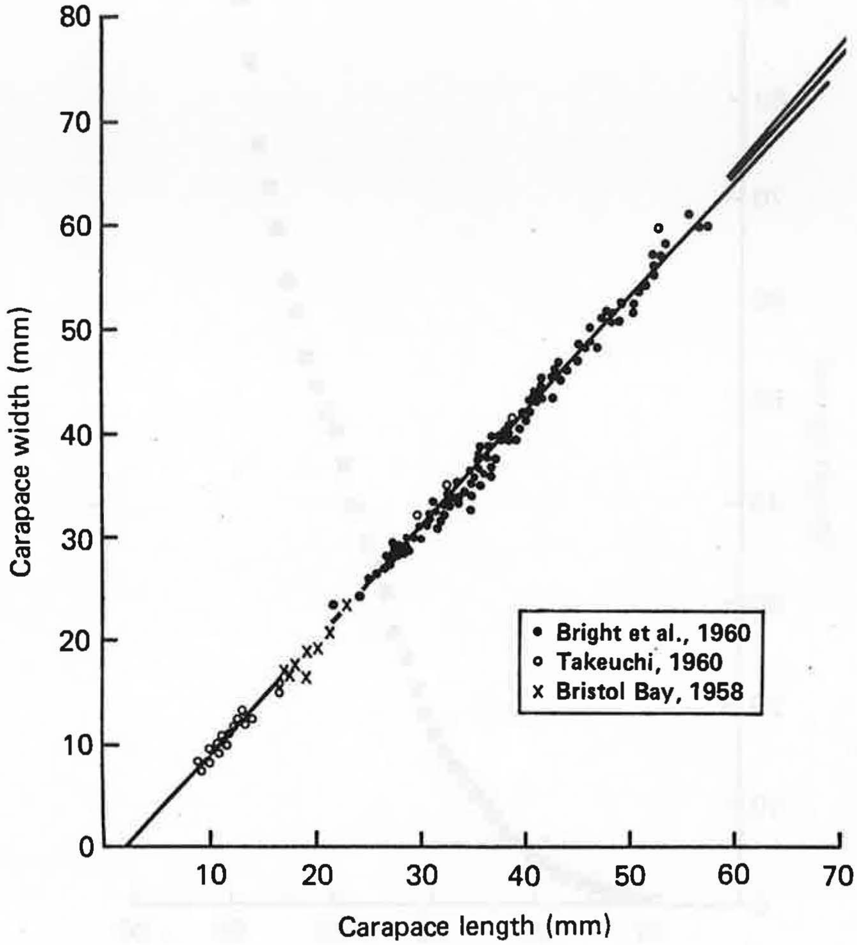

Figure 5. The relationship of carapace width to carapace length in juvenile king crab.

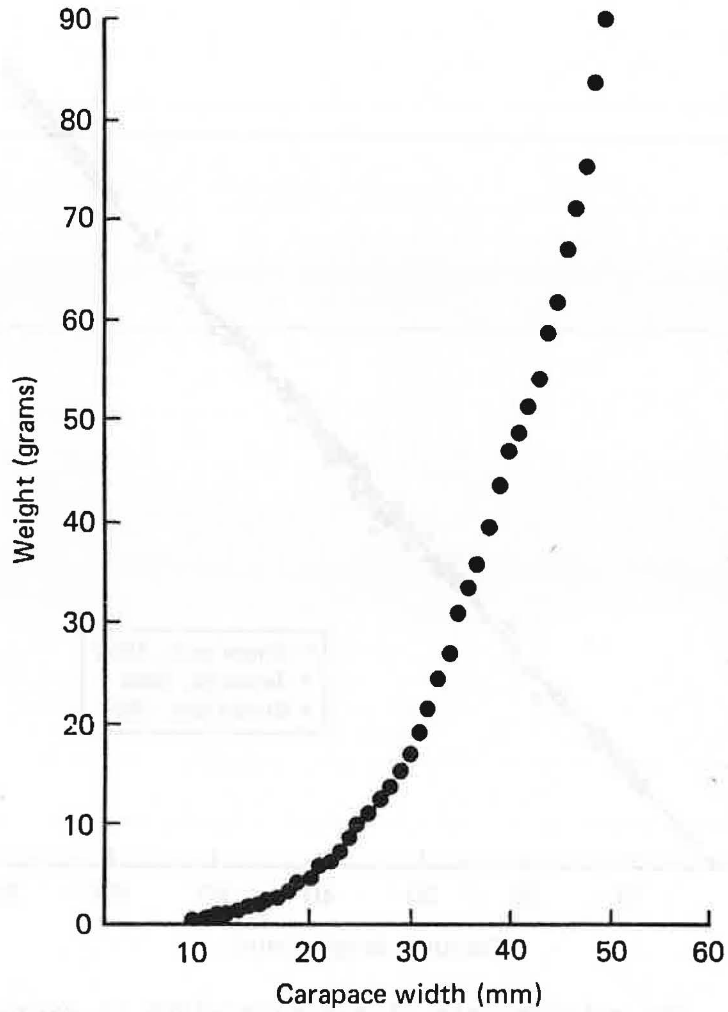

Figure 6. Relationship of carapace length to body weight for immature king crab.

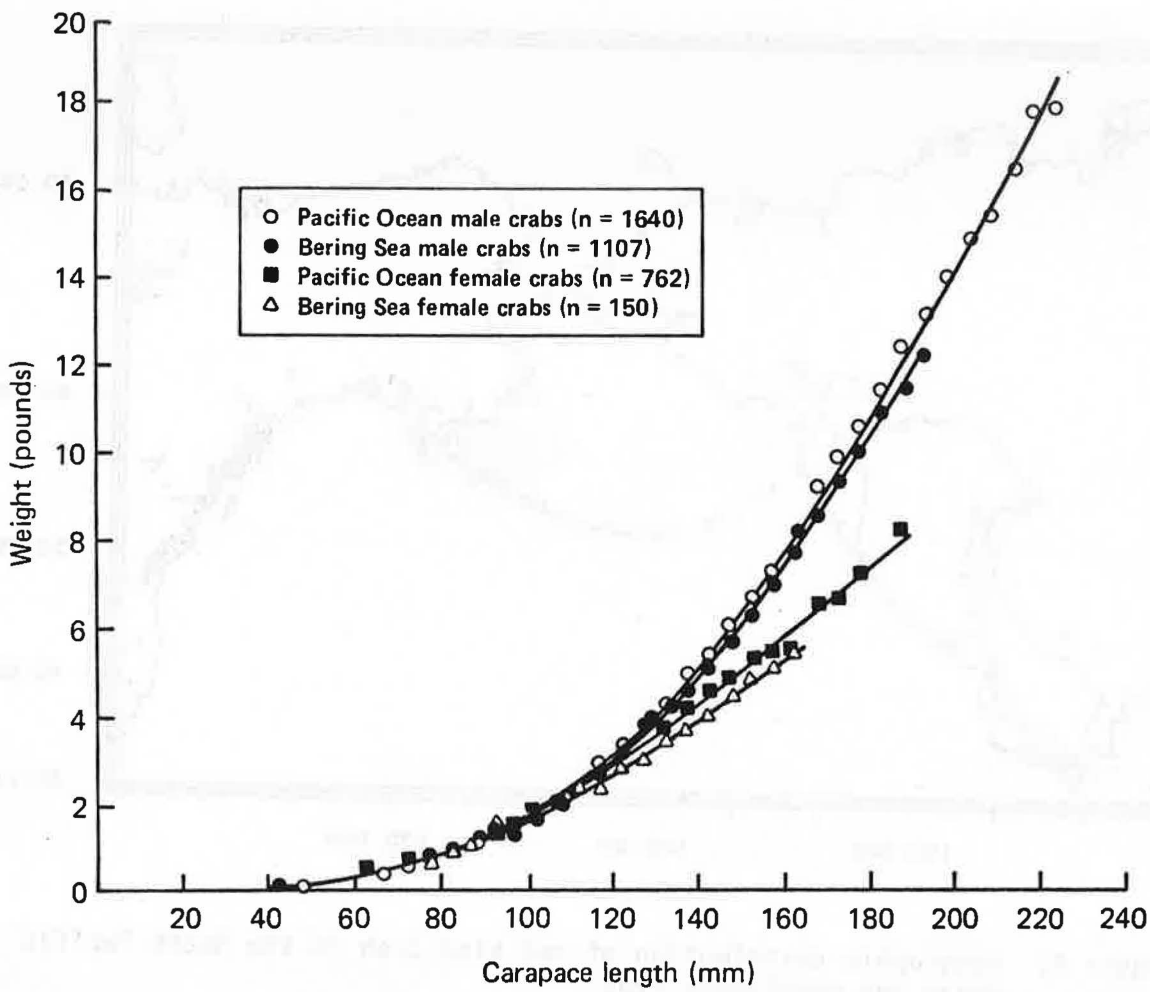

Figure 7. Relation of carapace length to body weight for king crab longer than 40 mm.

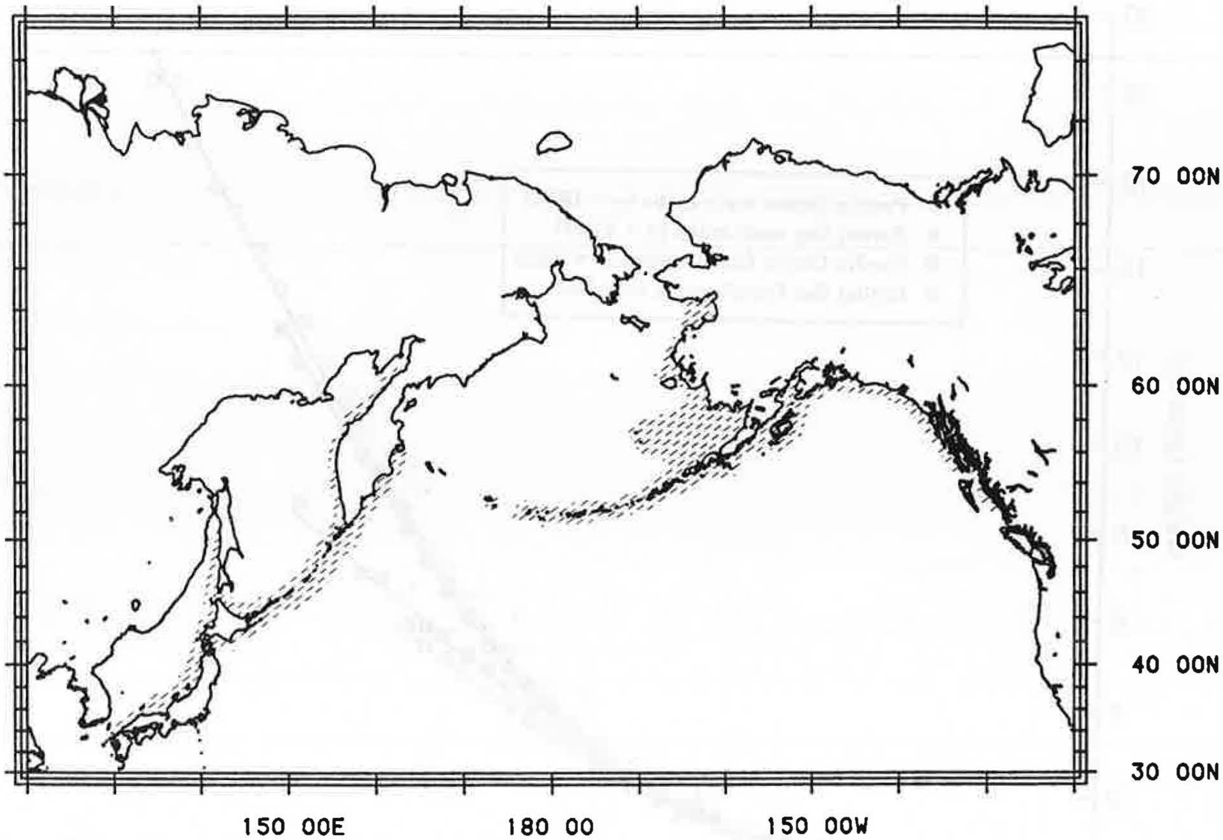

Figure 8. Geographic distribution of red king crab in the North Pacific Ocean and contiguous seas.

Olyutorksi southward to at least Cape Erimo (Vinogradov, 1946). Nakazawa (1912) reported small commercial catches in northern Honshu, Japan.

In the eastern North Pacific Ocean and Bering Sea the northern limit of distribution is Norton Sound. The species occurs in the southeastern Bering Sea (Bristol Bay), along the Aleutian Islands and in the Gulf of Alaska from Unimak Pass eastward and southward to Vancouver Island, British Columbia (North Pacific Fisheries Management Council, King Crab, Draft Fishery Management Plan-1981, hereafter referred to as NPFMC, KC, DFMP-1981).

In Asia, the principal stocks of red king crab occur off West Kamchatka, West Sakhalin, and in the Nemuro and Wakkanai districts of Hokkaido. There is no evidence to indicate that there is intermingling of crabs between these populations. From tagging experiments, Sato (1958) concluded that crabs breed along the entire western Kamchatkan shelf and migrate from south to north. On the the basis of areal variations in sex and size composition and the temporal-spatial distribution of the larval stages of king crab, Vinogradov (1969) concluded that 5 groups constituted the West Kamchatkan red king crab population of which the northernmost group provides the reproduction for virtually the entire West Kamchatkan population.

In North America, red king crab are most abundant in the Bering Sea and Gulf of Alaska. Major fisheries for red king crab are in Prince William Sound, Cook Inlet, Kodiak Island, south Alaskan Peninsula, Aleutian Islands, Norton Sound and southeastern Bering Sea (Fig. 9). There is no direct evidence (such as from tagging) that crab of one stock internmingle with those of another stock (Hayes and Montgomery, 1963; Powell and Reynolds, 1965; Simpson and Shippen, 1968). Due to passive drifting and the rather protracted early life history of king crab, larvae hatched in one locality may settle on

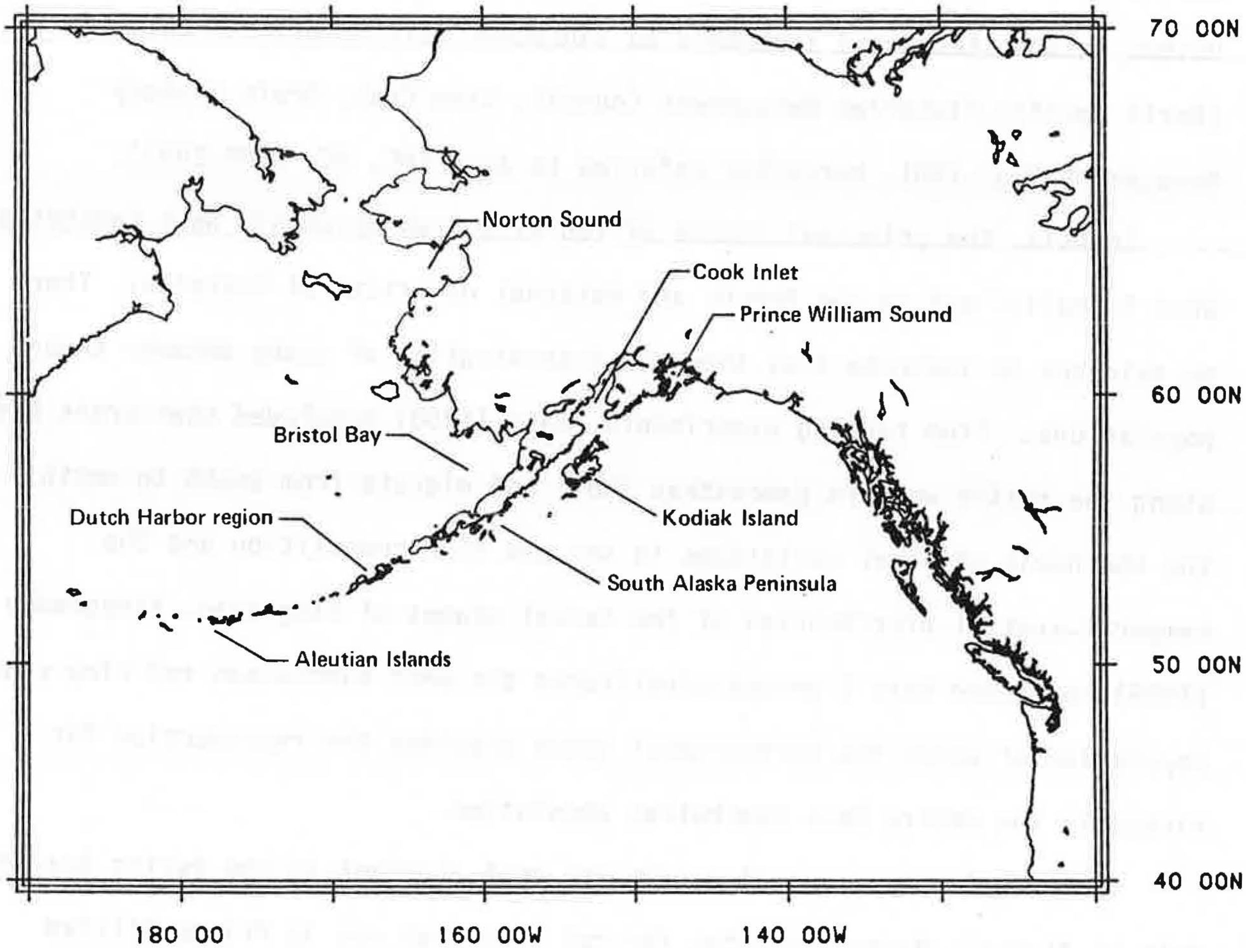

Figure 9. Principal red king crab stocks off North America.

the bottom as megalops or first instars a considerable distance away (Hebard, 1959; Haynes, 1974; Armstrong et al., 1983) and may even contribute to the productivity of another population (Vinogradov, 1969).

2.2 Habitat

2.2.1. Larvae

Zoea are positively phototactic for about 5 days after hatching (Marukawa, 1933). The first zoea stage occupies the upper and middle layers of the water column. Zoeal stages II through IV occupy the middle or lower layers. Zoea occur in water depths of 9-40 fathoms in water temperatures of 0.8° to 4.0°C. Marukawa hypothesized that the zoea must be most numerous in vortices or gyres since the perpetuation of the population must depend upon the ultimate settling of the first instar in environments suitable for survival.

Megalops larvae inhabit the bottom and walk on the 2nd to 4th walking legs and catch prey with their chela. They can, however, swim short distances by moving the pleopods and are frequently attached to sponges, bryozoa and fragments of seaweed. The depth and temperatures of their environment are the same as that for zoea (Marukawa, 1933).

2.2.2 Juveniles

Megalopae and juvenile crab smaller than 30 mm in carapace width inhabit depths of 10-30 fathoms. Relatively little information is available on the distribution and habitat of these early life history groups. Apparently, juvenile king crab less that 2 years old (less than 35 mm carapace length) are mainly solitary, living under rocks and debris (NPFMC DF,-1981). Small crab (carapace length less than or equal to 10 mm) were found in great numbers among sea weed and ascidians (sea squirts) taken in king crab tangle nets off Hokkaido (Nakazawa, 1912). After a thorough search, very young juvenile crabs were found in the region from Ptich'ii Island (57°10'N) to the central area of Penzinskiy Bay. The greatest numbers were taken at depths of 5 to 15 m among stones or boulders (Vinogradov, 1969). Megalopae and juvenile king crab in eastern Bering Sea were also reported to be associated with marine algae, hydroids and sponges (FAJ, 1963a).

According to Weber (1967), juvenile crab inhabit the eulittoral zone until they attain carapace lengths of 40-50 mm. Thereafter, they migrate toward deeper waters but do not occur in quantity on the fishing grounds until after they have grown to sizes of 70-80 mm carapace length. Beginning in their second and third years, crab in the Kodiak area have been observed to congregate in large, tightly packed groups called pods. These pods contain as many as 6000 crab with up to 50 crabs stacked on top of each other (Powell and Nickerson, 1965; Powell, 1974). Weber (1967) also reported that most immatures are gregarious and found in pods although no evidence of such aggregating behavior was presented for Bering Sea red king crab. Weber's search (1967) for immature king crab in the eastern Bering Sea eulittoral zone was not particularly successful. A total of 85 juvenile crab were taken of which 77 were captured in one beam trawl haul. By contrast, a single beach seine haul in Akutan Bay took over 200 immature crab.

2.2.3 Adults

Unlike megalopae and juveniles which on the basis of available evidence appear to inhabit rocky or coarse substrate, adult king crab are known to occur on sand and mud bottoms (Nakazawa, 1912; Marukawa, 1933; Vinogradov, 1946; Wallace et al., 1949; Vinogradov, 1969).

King crab tend to be aggregated by size or life history group or sex (Marukawa, 1933; Vinogradov, 1946; Wallace, et al., 1949; Weber and Miyahara, 1962). Adult crab are not uniformly distributed in area or time but tend to be more concentrated at certain times and places. Very pronounced aggregations of both sexes occur during the spring spawning season. After the mating season, the sexes form separate aggregations throughout the remainder of the year.

In the southeastern Bering Sea where uniform beaches and substrate extend for relatively great distances, crabs tend to be concentrated in particular places (Wallace et al., 1949; Korolev, 1964; Rodin, 1970). Aside from mating, an important determinant of aggregation is the availability of food and perhaps as pointed out by Chebanov (1965), the availability of prey which satisfies some specific, transitory physiological requirement such as the replacement of calcium after molting.

3. LIFE HISTORY

3.1 Embryological Development

After mating in April and May, the eggs are retained on the pleopods under the abdominal flap of the mother crabs for almost a year (Marukawa, 1933; Wallace et al., 1949). The eggs hatch during the inshore spawning migration which begins in late February or March, peaks in April and is completed in May. The time of hatching for southeastern Bering Sea king crab can vary by as much as a month (Weber, 1967; Armstrong, 1983) and may occur from early April to June. Mature females are without eggs for only a brief period. Females molt, mate and ovulate usually within a 1-2 day interval. Studies indicate that a female crab must mate within one week after molting for successful ovulation and fertilization (FAJ, 1963a).

The embryology of king crab has been described in detail by Kajita and Nakagawa (1932) and Marukawa (1933). The following summarization of embryonic development was obtained from Marukawa (1933).

Approx. time after Fertilization	Stage of Development
1- 4 days	Internal Cleavage
5- 20 days	External or superficial cleavage
20- 25 days	Gastrula
35- 38 days	Rudimentary embryo
50- 75 days	Nauplius embryo
100-110 days	Prozoea
150 + days	Postzoea

Seven months after hatching (December) Marukawa noted that the heart was well developed and pulsating at 168-170 times per minute and the embryo was hard to distinguish from the zoea larva which would hatch from the eggs four months hence in April.

3.2 Larval Stages

King crab metamorphose through four zoea stages and one megalops stage. Weber (1967) reports that upon hatching, the prezoeal larvae molt, usually within minutes, into the zoeal form. Although Marukawa (1933) illustrates a newly hatched zoea and a 24 hour old zoea (see Fig. 3) neither Marukawa or any other authors indicate that a molt occurs between these two forms.

From the results of rearing experiments, Marukawa (1933) determined that 5 molts were required to develop from the Zoea I stage, through the Zoea II through Zoea IV and megalops stage to the first adult form. The first molting (Zoea I to Zoea II) occurred 21 days after hatching and the interval between molts for the second through last zoeal stages and from Zoea IV to megalops was 14-16 days. The time required for megalops to metamorphose to the first adult form was also estimated to be about two weeks.

Subsequent experiments and observations have shown that the molting schedule is dependent upon certain environmental variables (Table 3). From the results of temperature controlled rearing experiments, Kurata (1960 & 1961) concluded that first stage zoeal larvae can be reared at temperatures of 2°-15°C with the highest survival within the range of 5°-10°C. Within this range of optimum temperature, larval growth rate increased with higher temperature. The length of time between hatching and molting was estimated to be in excess of 20 days at 2°C, 12 days at 5°C, 7 days at 10°C and about 5 days at 15°C. Kurata calculated that about 465 day-degrees (days X C°) were required to develop from hatching through megalops stage, 291 day degrees of which were required to complete the four zoeal stages.

Table 3.--Days required to finish the molting process.

[Average temperature of the water in parentheses]

Stage	Marukawa's experiment (1933)	Shimizu's experiment (1936)	Sato and Tanaka (1941)
First zoea	21 days (3.8°-6.1°C.)	24 days (2.0°C.)	7 days (9.0°C.)
Second zoea	14 days (6.8°C.)	12 days (5.0°C.)	10 days (8.9°C.)
Third zoea	15 days (7.3°-7.5°C.)	14 days (6.9°C.)	9 days (9.2°C.)
Fourth zoea	14 days (7.8°C.)	14 days (5.5°C.)	9 days (11.3°C.)
Glaucothoe[1/]	20 days	--	12 days (14.9°C.)
Total to the glaucothoe[1/]	64 days	64 days	35 days
Total to the youngest adult form	84 days	--	47 days

1/ Glaucothoe = megalops

Salinity less than about 21.7/1000 is detrimental to survival of zoea. The growth rate of zoea is not affected by salinities within the range of 21.7-39.7/1000 (Kurata, 1960).

3.3 Juveniles

The first instar or adult form is about 2 mm in carapace length. Growth rate and size at maturity appears to vary somewhat with area (Marukawa, 1933; Powell, 1960). On the evidence of the percentage of ovigerous crabs, Wallace (1949) concluded that female crab in eastern Bering Sea were mature at 86 to 102 mm carapace length. Males were considered to become mature at minimum lengths of 85 to 90 mm. Weber (1967) estimated that both male and female king crab in southeastern Bering Sea matured at about 95 mm. This size is equivalent to five years in age for males and five and a half years for females.

3.4 Adults

Crabs larger than 95 mm constitute the adult population. The sexes are generally segregated except for spawning. After attaining sexual maturity, growth increment per molt remains about the same for males but is drastically reduced in females (Weber, 1967). Sexual dimorphism is also evident in allometric growth which occurs in certain body parts (e.g., size of chela) with the onset maturity (Marukawa, 1933; Wallace et al., 1949).

4. SPAWNING AREAS AND SEASONS

Knowledge relating to the area and season of red king crab spawning in eastern Bering Sea has been obtained from such evidence as the reproductive state of the female or the stage of egg development, the timing and distribution of first stage zoea larvae and the capture of crabs in copulatory embrace.

4.1 Reproduction

Marukawa (1933), Wallace et al. (1949) and Powell & Nickerson (1965) as well as others have described the mating process in king crab. Essential aspects of the reproductive process are as follows:

1. The spring or spawning migration begins in February and March, peaks in April and is completed in May. During this migration, eggs which have been carried for about 11 months hatch into first stage zoea larvae.
2. Upon reaching the spawning grounds the female crab form large aggregations. Through some communication mechanisms, the sexes are attracted to each other. Although experimental evidence is lacking for Paralithodes, the attraction is apparently based on a mating pheromone (Rebach and Dunham, 1983).
3. Males select females for their behavior and relative size. In nature, males almost always select females of equal or smaller size (NPFMC, KC, DFMP-1981).

4. Male grasps female by the meropodite of the chelipeds while the female molts.
5. After assisting the female to molt, the male regrasps the female, inverts her beneath his body and spreads spermatophore bands over her gonopores. Only then does the female extrude eggs which are fertilized and attached to the pleopods where they remain protected by the abdominal flap to develop for about 11 months.
6. Male red king crab are polygamous and are capable of fertilizing as many as 7 females (Marukawa, 1933; Wallace, 1949; Powell et al., 1972).

Successful mating requires that fertilization occur within 7 days of molting in the Bering Sea (Weber, 1965; FAJ, 1963a) and 5 days in the Gulf of Alaska according to Powell et al. (1974). Fertilization usually takes place within two hours of molting. In shipboard experiments during the 1961 fishing season scientists of the Fishery Agency of Japan (1963b) observed that when females were placed with males prior to or within 24 hours after molting, mating and ovulation proceeded normally. When females were placed with males 2 to 7 days after molting, mating occurred immediately, however, ovulation was incomplete and unfertilized eggs were dispersed in the water. In all cases where females were separated from males after molting, no ovulation occurred.

There is evidence that it is the old shelled males and not those which have recently molted which participate in mating. Also, small adult males do not participate in mating until 2 years after attaining sexual maturity (NPFMC, KC, DFMP, 1981).

4.2 Spawning Areas

Spawning of Bristol Bay red king crab occurs off the Alaskan Peninsula from near Amak Island and the Black Hill to Port Moller area (Fig. 10).

4.3 Spawning Season

Figure 11 from Weber (1967) shows the percentage occurrence of the stages of egg development with time as observed by several authors during the spring and summer in eastern Bering Sea. The trends in occurrence of females with empty egg cases and new eggs indicates that spawning probably occurred in the first and second deciles of June in 1960 and 1961 and perhaps in the third decile of June and first 10 days of July in 1962. Although the period of spawning may vary according to temperature or other environmental conditions, from these data it appears that it can occur between the beginning of June and the middle of July.

4.4 Fecundity

Fecundity of king crab as estimated by various authors is shown in Table 4.

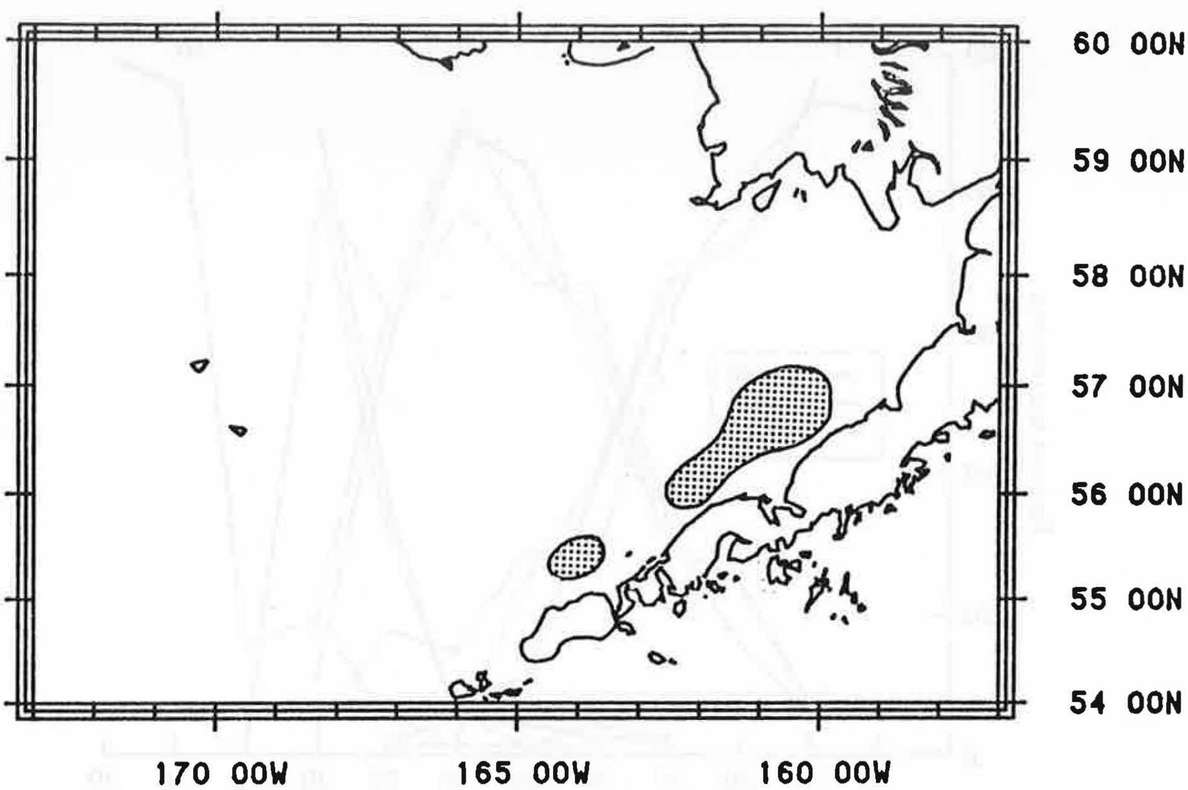

Figure 10. Spawning areas of Bristol Bay red king crab.

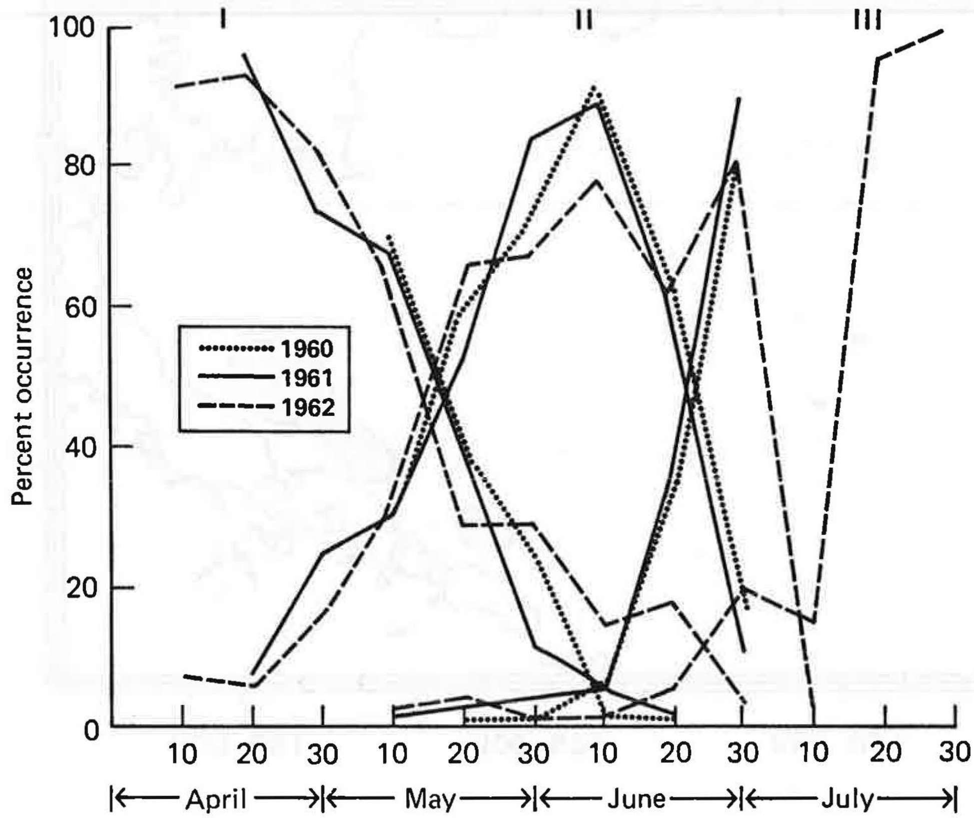

Figure 11. Occurrence of females with eyed eggs, empty egg cases and new eggs.

Table 4. The fecundity of king crab.

Source	Carapace width	No. of eggs	Area
Nakazawa (1912)	127-169 mm	62,550-345,900	Hokkaido
Marukawa (1933)	115-168 mm	69,598-270,204	"
Wallace et al. (1949)	128-145 mm	148,349-446,639	Canoe Bay
Rodin (1970)	94-171 mm	55,408-444,651	Bristol Bay

Nakazwa (1912) and Wallace (1949) held the view that the number of eggs carried by female king crab varies considerably not only between crabs of different size but among females of the same size. Rodin's (1970) studies on the fecundity of eastern Bering Sea king crab, however, indicate comparatively little variation in egg numbers within size groups and a direct relationship between fecundity and size of females (Fig. 12).

In all of these studies the number of crabs examined was very small, therefore, neither the accuracy nor the precision of the estimated fecundity can be evaluated. It is clear, however, that potential egg production in female king crab is very high and each year, all fertilized females characteristically produce a very large number of eggs with larger females tending to have larger egg clutches.

The high fecundity of king crab implies that the species is typically subjected to extremely high natural mortality. Inasmuch as the eggs are protected for almost a year to hatching and natural mortality of older juveniles and adults has been estimated to be relatively low (see later section), most of these very large mortalities occur between hatching and the early juvenile stages. Limited experimental evidence indicates that

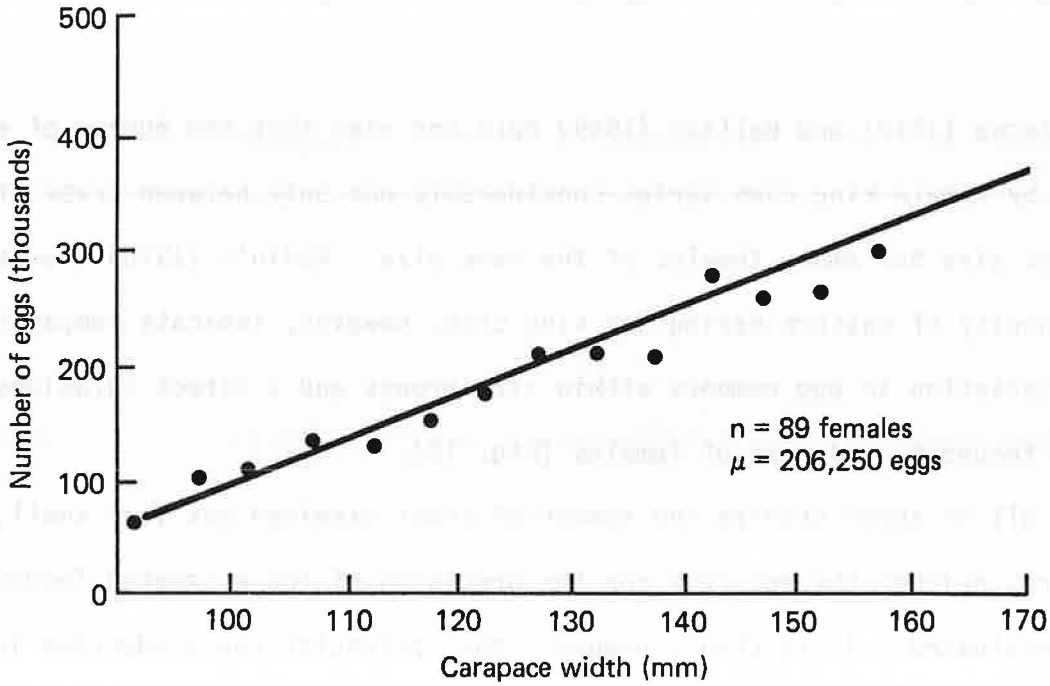

Figure 12. Fecundity of females as a function of size.

vulnerability is greatest at the first zoeal stage and diminishes through successive larval stages (Marukawa, 1933; Kurata, 1960).

5. FOOD AND PREDATORS OF RED KING CRAB

5.1 Food of Larval and Postlarval Crab

The stomach contents of larval and postlarval king crab reported by various authors is given in Table 5.

Marukawa (1933) and Shimizu (1936) considered diatoms to be the important part of the diet of larval king crab. Kurata (1960) in feeding experiments had zero survival of stage I zoea larvae fed exclusively on diatoms. Best survival was achieved with *Artemia nauplii* and Trochophores of *Chone teres*, a polychaete (Kurata, 1959) which indicates that a diet of animal origin must be the principal diet of larval king crab (Kurata, 1960).

5.2 Food of Adult King Crab

Stomach contents of adult king crab as reported by several authors is given in Table 6.

The food of king crab appears to be similar throughout its range. Polychaetes, molluscs, crustaceans and echinoderms have been observed to be the food items of principal importance.

King crab in the eastern Bering Sea must compete for food with a number of other bottom dwelling creatures. These include the Tanner crab (*Chionoecetes bairdi* and *C. opilio*), Pacific cod (*Gadus morhua macrocephalus*),

Table 5.--Stomach contents of king crab larvae and post larvae.

Author	Area	Contents
Marukawa (1933)	Hokkaido, W. Kamchatka	Zoea feed on pelagic diatoms, glaucothoe on bryozoa. Juveniles feed on Navicula, Synedra, Coscinodiscus, Nitzchia, Chaetocerus, Thalassiosira, Biddulphia, Fragilaria, Ceratium, Nereis, Zostera, Detritus
Shimizu (1936)	Hokkaido	Larvae on diatoms
Sato and Tanaka (1949)	Experimental	Zoea fed on Polydora sp., Zoea cannibalize other zoea
Kurata (1959, 1960)	Experimental	Zoea fed trochophores of Polydora, nauplii of Artemia salina and diatoms
Tsalkin (1969)	W. Kamchatka	Hydroids preferred by postlarval king crab
Feder, et. al. (1980)	Cook Inlet	Detritus, diatoms, Bryozoa, Harpacticoid copepods, ostracods

Table 6.--Food of adult king crab.

Author	Area	Contents
Marukawa (1933)	Hokkaido; W. Kamchatka	Cucumaria japonica, Cardium californiens, Astarte borealis, Chrysodomus sp. Spisula sp., Yoldia sp., Schizothaerus sp., Venus sp., Chlamys sp., Fusirius sp., Tellina sp., Pecten yessoensis, Strongylocentrus sp., Cynthia superba, Bryozoa, Zostera, Diatom
Nakazawa (1912)		Clams (Mactra sacchalinensis and Pecten yessoensis), Echinoderm (sea urchins), Sea cucumber (Cucumaria japonica), isopods
Takeuchi (1959)	W. Kamchatka	Clams - Nucula, Acila Yoldia, Musculus, Liocyma Macoma; Snails - Margarites, Pupinaria, Euspira, Tectonatica; Crab - hermit crab and other crab; Amphipods, Barnacles, Echinoidea, Ophiuroidea, Hydroidea, Polychaste worms and fish
Feniuk (1945)	W. Kamchatka	Molluscs, crustaceans and polychaetes
Mikulich (1954) and Kulichkova (1955)	W. Bering Sea	Clams - Yoldia, Serripes, Siliqua, Tellina; Snails - Polinices, Margarites; Crusdacea - amphipods, Cumacea; Echinodermata - Strongylocentrotus, Asterias, Ophiuroidea; sea squirts - Pelonia, Boltenia
McLaughlin and Hebard (1961)	E. Bering Sea	Molluscs, Asteroids, Ophiuroids, Echinoids, Shrimp, Polychaetes, Crustacea
Neiman (1963)	E. Bering Sea	Ophiura sarsi
Chebanov (1965)	S.E. Bering Sea	Ophiura sarsi, Yoldia, spirorbis, polychaetes, isopods, young Chionoecetes. opilia, brown algae, unidentifiable, brown, gelatinous mass
Cunningham (1969)	Bering Sea	Brittlestar (Ophiura sarsi), basketstar (Gorgonocephalus), Sea urchin (strongylocentrus sp.), Sand dollar (Echinarachinius parma) most important by weight. Clams - Nuculana radiata. Clinocardium californiense. Chlamys sp. Snails - Solariella sp. and Buccinidae; crabs - Hyas coarctatus alutacens, Erimacrus isenbeckii, Pagurus sp.; sandfleas - amphipods
Tarverdizva (1976)	E. Bering Sea	Polychaetes, Sand dollars (Echinarachnia parma); gastopods - Trochidas and Nactidae; Clams - Yoldia, Nuculana, Nucula, Cyclocardia
Feder and Jewett (1980)	S. E. Bering Sea	Cockle (Clinocardium ciliatum), Snail (Solariella sp.), Clam (Nucula fossa), Brittlestar (Amphiuridae), Polychaete worm (Cistenides, sp.) and Snow Crab (Chionoecetes spp.)
Feder et. al. (1980)	Cook Inlet, Kamishak Bay, Kachemak Bay	Barnacles, Clams (Spisula polynyma)
Feder & Jewett (1981a)	Izhut Bay, Afognak Island	Fish (probably capelin)
	Kilinda Bay, Kodiak	Clams
	Kodiak and shallow bays of Kodiak	Cockles, crustaceans and fish, Clams (Protothaca staminea and Macoma spp.)
		Cockles (Clinocardium spp.), Acorn barnacles (Balanus crenatus)

yellowfin sole (Limanda aspera), Alaska plaice (Pleuronectes quadrituberculatus), rock sole (Lepidopsetta bilineata), flathead sole (Hippoglossoides elassodon) and rex sole (Glyptocephalus zachirus) (Feder and Jewett, 1981b; Takeuchi, 1959). Most of the fish species are swifter and much more mobile than the king crab. The abundance of these fish species can, therefore, have considerable impact on the growth of the eastern Bering Sea king crab stock.

5.3 Predation on King Crab

Table 7 includes a list of animals which have been reported by several authors to be predators on king crab.

An estimate of the magnitude of predation on larval red king crab has only recently become available (Haflinger and McRoy, 1983). They estimated that 18 billion king crab megalops larvae were consumed in a one month period by yellowfin sole. The authors considered the estimate to be conservative even as a measure of the predation by yellowfin sole alone.

According to Bakkala and Wespestad (1984), the biomass of yellowfin sole in the eastern Bering Sea which was about a million tons in 1975 doubled to about 2 million tons in 1979-1981. In 1982, biomass apparently increased to over 3 million tons and to almost 4 million tons in 1983. Cohort analyses indicate that the eastern Bering Sea yellowfin sole population exceeded 20 billion fish in 1981. The female spawning population of eastern Bering Sea king crab declined rather steadily after 1979 from about 122 million crab to less than 10 million crab in 1983. Although yellowfin sole and king crab compete to some extent for similar food, there are no obvious explanations for

Table 7.--Predators on king crab.

Author	Area	Predators
Gray (1964)		Halibut (Hippoglossus stenolepis) prey on large, recently molted crab.
Powell & Nickerson (1965)	Kodiak	Korean Horsehair crab (Erimacrus isenbeckii) observed to prey on juvenile king crab.
Feder and Jewett (1981a)	Kodiak	Sculpin (Hemilepidotus hemilepidotus) predators on postlarval crab 10 mm in length.
	Bering Sea	Sea otters predators on adult king crab.
Shimada and June (1982)	Bering Sea	Pacific cod.
June (1984)	Bering Sea	Pacific cod.
Haflinger and McRoy (1983)	Bering Sea	Yellowfin sole predation on larval and juvenile king crab. Conservatively estimated that 18 billion king crab larvae are consumed by yellowfin in eastern Bering Sea in a 1 month period.
Pruter (1983)		In areas where king crab are abundant, they composed 2 to 78% of the total weight of stomach contents of Pacific cod in 1981.

the inverse relationship in the abundance of the two groups a seen in Fig. 13. Yellowfin sole cannot possibly prey upon sexually mature red king crab. As mentioned in the previous paragraph, however, zoea and megalops of king crab have been shown to be an important component of the stomach contents of yellowfin sole on the northern Aleutian shelf during the spring and summer seasons. The quantity of larvae can be expected to be directly related to the abundance of fertilized female king crab. It is reasonable to assume then, that the decrease in fertilized female king crab was accompanied by a corresponding decrease in the abundance of crab larvae. The biomass of yellowfin sole has increased substantially in spite of this expected decrease in larval crab abundance. Although larval king were observed by Haflinger and McRoy to constitute an important part of the diet of yellowfin sole at specific times and places, they are obviously a very minor component of the total food intake of eastern Bering Sea yellowfin sole. Although the predation of 18 billion crab larvae seems very substantial, when one considers that the eastern Bering Sea yellowfin sole stock exceeds 20 billion, the consumption rate on the average is slightly more than one king crab larvae per fish.

Even if they constitute only a very minor component of their diet, the predation of 18 billion crab larvae may have some impact on the productivity of the king crab stock. To evaluate whether this potentially large mortality has affected the productivity of the eastern Bering Sea king crab stock, the relationship of the number of king crabs recruited to age 5 and the biomass of yellowfin sole was examined (Fig. 14). Although the predation by yellowfin sole may have been one of many forces of mortality which may have contributed to the suppression of recruitment, there is no obvious evidence of a negative

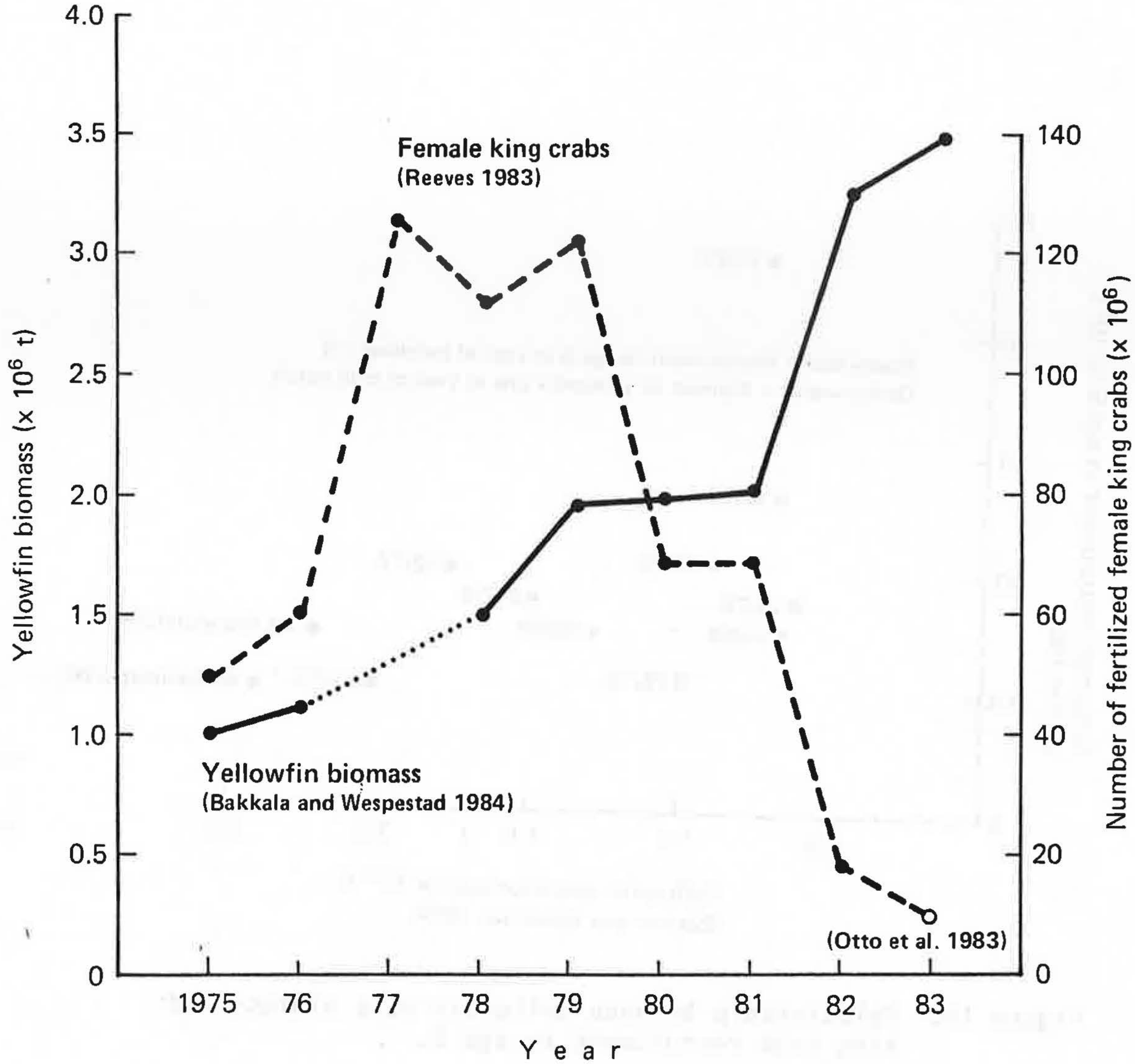

Figure 13. Yellowfin sole biomass and number of fertilized female king crab.

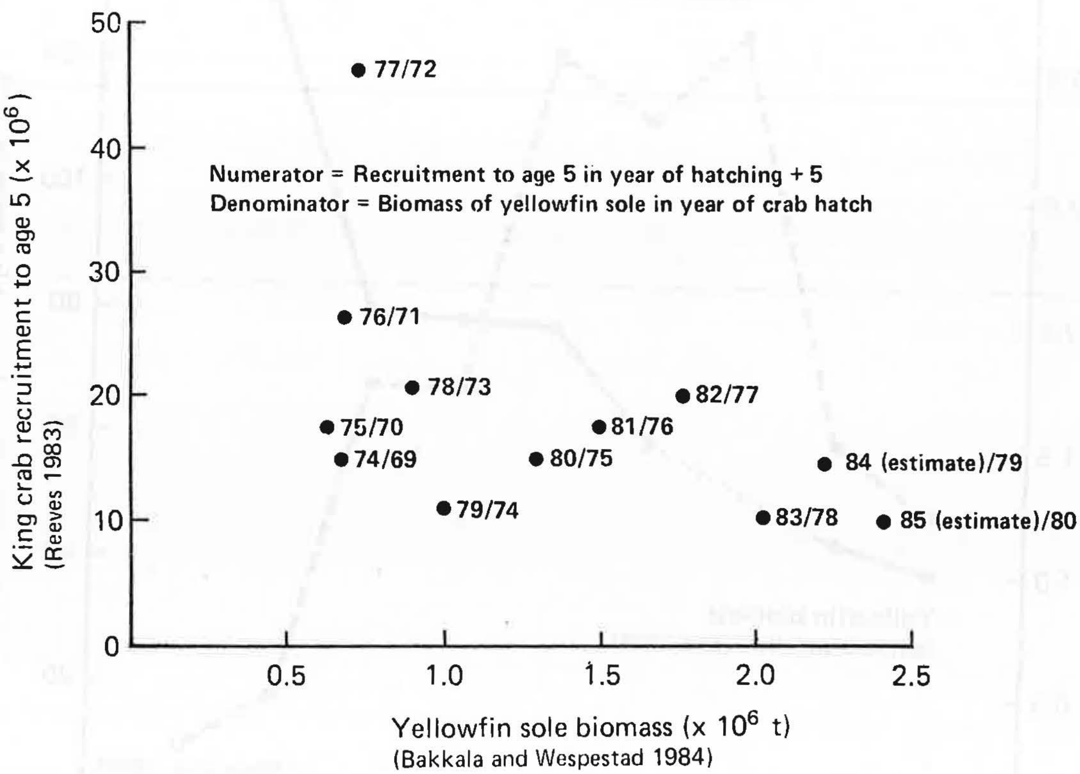

Figure 14. Relationship between yellowfin sole biomass and king crab recruitment to age 5.

trend in the recruitment of crab which might be attributable to the increasing biomass of yellowfin sole. The foregoing discussions have assumed an increasing trend in the biomass of the eastern Bering Sea yellowfin sole population as indicated by the NMFS trawl surveys. An increase of this magnitude in the biomass of yellowfin sole in a single year could not have occurred through recruitment, survival and growth of the exploitable stock. Bakkala and Wespestad (1983 & 1984) attribute some of the increase in biomass to an increase in the area surveyed and to the better bottom tending qualities of the trawl gear used in the 1982 survey (and thereafter).

Other flatfish (e.g., rock sole and flathead sole, which may have a combined biomass of about a million mt) sculpins (Myoxocephalus spp.) and elasmobranchs (Rajidae) which are resident to the area and transient species such as several species of Pacific salmon migrating through the northern Aleutian shelf waters may also prey upon larval and juvenile king crab. The food habits of the Walleye pollock (Theragra chalcogramma) are not very well known. It is conceivable that pollock also consume pelagic larvae of red king crab. If crab larvae constitute even a minor part of their diet, because of the substantial biomass of pollock (more than 6 million mt in 1983) the total consumption of larvae may be substantial.

Pacific halibut (Hippoglossus stenolepis) and Pacific cod (Gadus morhua macrocephalus) are the only fish species which have been reported to consume adult king crab. The deep water flounders such as the Greenland turbot (Reinhardtius hippoglossoides) and arrowtooth flounder (Atheresthes evermanni and A. stomias) and also the skates (Rajidae) appear to have the capability to prey upon adult crab.

June (pers. com.) examined the red king crab content in the stomachs of Pacific cod collected in eastern Bering Sea trawl surveys between May 5 and July 20, 1981. The remains of red king crab were in 10% of the total cod stomachs examined and 14% of the stomachs of cod 410-780 mm in length. The stomachs contained whole crabs as well as legs only. All of the crab in the stomachs of cod had new shells which were soft and flexible, indicating they were recently molted crabs. Determination of the sex of crabs was difficult due to partial digestion and the softshelled condition of the crabs. All crabs for which sex could be determined were females, which seems reasonable, considering the area and period of sampling. For the same reasons, measurements could be obtained from only 7 of the 34 whole crabs extracted from cod stomachs. These crabs were from 53.4 to 160.3 mm in carapace width. It was estimated that 58% of the crabs consumed were less than 100 mm carapace width, therefore, almost half the crab consumed were sexually mature females.

The biomass of Pacific cod in the area inhabited by king crab was estimated by the trawl survey to be about 240 thousand t. Assuming a minimum consumption of red king crab of 0.051% of cod body weight per day, Pacific cod were estimated to have eaten about 123 mt or about 110,000 king crab, daily. Using the maximum estimated ration of 0.551% of body weight per day, 1,300 mt or 1,163,500 king crab would be consumed each day. Applying these minimum and maximum daily consumption rates to the 30 days or so during which females might be expected to be in softshelled condition, the potential mortality to female crab from cod predation during the spawning and postspawning period may range from 3.3 million to 34.9 million crabs (June, pers. com.).

Evidence supporting June's observations concerning cod predation upon female king crab is shown in Fig. 15. The biomass of Pacific cod of eastern

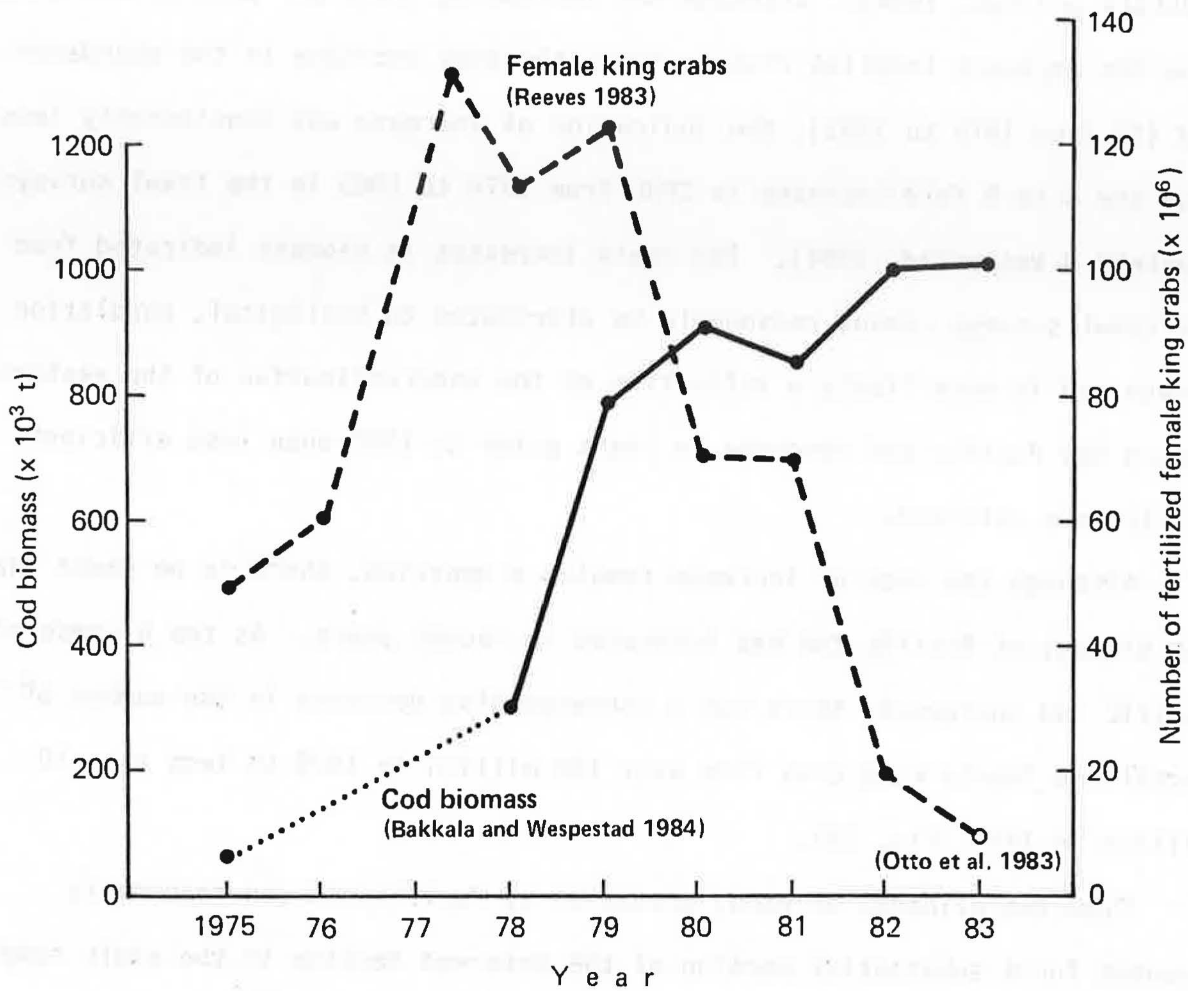

Figure 15. Number of fertilized female king crab and biomass of Pacific cod in eastern Bering Sea.

Bering Sea as estimated by the NMFS trawl surveys increased from about 300,000 tons in 1978 to almost 800,000 tons in 1979 and over 1 million tons in 1983 (Bakkala and Low, 1984). Although the increasing catch per unit effort (CPUE) from the Japanese longline fishery indicates some increase in the abundance of cod (2X from 1979 to 1981), the indication of increase was considerably less than the 4 to 5 fold increase in CPUE from 1976 to 1983 in the trawl surveys (Bakkala & Wespestad, 1984). The rapid increases in biomass indicated from the trawl surveys cannot reasonably be attributed to biological, population growth and is more likely a reflection of the underestimation of the eastern Bering Sea Pacific cod resource in years prior to 1982 when less efficient trawls were utilized.

Although the rate of increase remains a question, there is no doubt that the biomass of Pacific cod has increased in recent years. As the biomass of Pacific cod increased, there was a corresponding decrease in the number of fertilized female king crab from over 120 million in 1979 to less than 10 million in 1983 (Fig. 15).

From the evidence at hand, predation by Pacific cod can reasonably account for a substantial portion of the observed decline in the adult female king crab of eastern Bering Sea. In combination perhaps with mortalities which might occur in discarding female crabs in the king crab fishery, predation by Pacific cod appears to be the most reasonable explanation for the decline of the female spawning stock. One can only speculate on the mortality from cod predation (and other fish predators) which might accrue to other components of the eastern Bering Sea stock during their respective molting periods.

The sea otter (Enhydra lutris) is the only mammal which has been reported to consume adult king crab. Although there is no substantiating evidence, the harbor seal (Phoca vitulina) and the deeper diving ice seals (ringed seal, Phoca hispida; ribbon seal, P. fasciata; and bearded seal, Erignathus barbatus) may also include adult king crab in their diets.

6. GROWTH, AGE AND NATURAL MORTALITY

6.1 Growth

King crab grow by shedding their exoskeleton in a process called molting. The growth rate of crabs then is determined by the frequency of molting and the amount of growth added with each molt.

6.1.1 Molting Process

The molting process in king crab has been described by Marukawa (1933), Weber (1967), Sakuda (1958) and others. One or two weeks prior to molting, coloration of the shell changes and spaces between the abdominal plates begin to widen slightly. About three days before molting the crab becomes very inactive and ceases to feed (Marukawa, 1933) and the abdomen begins to swell. Within a day of molting (12-18 hours according to Weber, 1967 and 1-6 hours before according to Takeuchi, 1960; Powell, 1960 and JFA, 1963) the abdomen swells very rapidly, rupturing the abdominal covering and subsequent sloughing off of the abdominal plates. Simultaneously, pressure is exerted under the carapace leading to breaks in the sides and posterior margins of the old shell. The muscles become flabby and shrink sufficiently to be withdrawn past the strictures of the leg joints. A colorless mucuslike substance is deposited between the old and newly developing shells. Ultimately, the crab backs out through an opening between the hind margin of the carapace and the upper abdominal plates. In molting, all structures of ectodermal origin are discarded. These include not only the carapace and integument of the legs but also the mouth parts, esophagus, stomach, chitinous plates around the stomach, the hindgut, tendons and certain gill tissues (Marukawa, 1933).

The observed time required for molting ranges from 4 minutes (Sakuda, 1958) to 40 minutes (Takeuchi, 1960). Marukawa (1933), the Japan Fishery Agency (1963) and Weber (1967) generally agree that the actual molting requires ten minutes or less. Mihara (1932) estimated that adult females require 13 minutes to molt and that adult crabs in general required 13-15 minutes. He estimated that juvenile crab required about 9 minutes.

Although the actual process of molting is relatively brief, there is a period of three or four days after molting when the crab remains relatively inactive and not feeding and an additional week or so (about ten days after molting) before the new carapace is as hard as the old (Marukawa, 1933). Crabs are particularly vulnerable to mortality during molting. Results of larval rearing experiments show that large mortalities of Zoea I larvae (which was sometimes 100% in experiments) occur with the onset of molting. Marukawa (1933) observed that such mortalities occurred at about the time of the transition from yolk absorption to the feeding stage. Sato and Tanaka (1949) and Kurata (1960) observed large mortality to Zoea I larvae at the time of molting indicating that some extraordinary stress may be associated with ecdysis, at least, in the first zoeal stage. Similar physiological stress, although perhaps to a lesser degree, may also contribute to debilitation and mortality in later moltings as well. In all postlarval size groups, premolting lethargy and the temporary loss of the hard, spiny, protective exoskeleton for as long as ten days, increases greatly the susceptibility of crabs to predation.

6.1.2 Molting Frequency

Molting does not occur with uniform frequency but varies with age and sex of crab.

The initial molts although resulting in growth are essentially for metamorphic transitions through the four zoeal stages and the single megalops stage to the first adult form. Table 8 from Kurata (1961) records the molting history of a single crab which was reared under experimental conditions through 13 molts. Kurata as well as Marukawa (1933) identify five molts from hatching to the first instar or adult form. Weber (1967) describes an additional molt which occurs usually within minutes of hatching between the prezoeal form and the Zoea I larvae. Although Marukawa (1933) illustrates a newly hatched larva it was not described as a prezoea nor was there mention of a molt from this form to the first zoeal stage. The intermolt intervals of the single crab described in Table 8 are considerably shorter than those estimated by other authors, particularly for the duration of each of the five larval stages. Marukawa (1933) calculated the first molt to occur about 21 days after hatching. Subsequent molts from Zoea II to Zoea III, Zoea III to Zoea IV were estimated to occur at about two week intervals. He presumed molting from Zoea IV to the megalops stage required an additional two weeks.

Table 8.--The hatching and molting history of a single king crab reared in captivity.

Hatched:	14 April	Zoea I
1st molting:	22 April	Zoea II
2nd molting:	30 April	Zoea III
3rd molting:	9 May	Zoea IV
4th molting:	19 May	Glaucothoe
5th molting:	1 June	Small crab 1st instar
6th molting:	22 June	Small crab 2nd instar
7th molting:	14 July	Small crab 3rd instar
8th molting:	2 August	Small crab 4th instar
9th molting:	19 August	Small crab 5th instar
10th molting:	2 September	Small crab 6th instar
11th molting:	19 September	Small crab 7th instar
12th molting:	9 October	Small crab 8th instar
13th molting:	9 November	Small crab 9th instar

This schedule of larval development can, however, be modified by environmental circumstances. Kurata (1960) has shown that temperature is the most important factor governing rate of development of larval crab, assuming the availability of sufficient food. Within the limit of temperatures in which zoea larvae can survive (2° to 15°C), Kurata (1960 & 1961) found a linear relationship (i.e., development proceeded more rapidly at higher temperatures) which was expressed in terms of degree-days (Temperature in Degrees Centigrade X No. of Days). He calculated that 460 degree days were required for development from hatching to the first adult form. Considering this heat budget requirement, in eastern Bering Sea surface and subsurface temperatures, Weber (1967) estimated that a prezoea hatched in May would attain the first adult stage by mid-August. Empirical verfication of this calculated schedule was obtained in studies of larvae distribution in eastern Bering Sea by Takeuchi (1962), Rodin (1970), Haynes, (1974) and Armstrong et al. (1983).

In summary: After hatching in April and May, larval king crab undergo 5 molts, metamorphosing through 4 zoeal stages and a megalops stage before attaining the first adult form. This process requires slightly less than three months, with the first adult forms which are about 2mm in carapace length settling on the bottom in July and August.

From hatching to the end of the first year, king crab molt a total of from 11-13 times, including the 5 larval molts (Marukawa, 1933; Kurata, 1961; Weber, 1967). The size of crab at the end of the first year was given by Marukawa as 6.5 mm carapace length. For crab at Unalaska, Weber (1967) found crab of this age to range from 9-14 mm with an average carapace length of 11 mm.

Between the ages of 1 and 3, juvenile king crab undergo eight molts. At the end of the third year, the carapace lengths range from 50-67 mm with an average of 60 mm (Weber, 1967).

From the ages of 3 to 7 years, both male and female king crab molt once a year. For the female the annual molt is a necessary precursor to ovulation although females can molt without necessarily ovulating. For males the annual molt appears to occur in late fall or winter in Bering Sea (Wallace, 1949) and is unrelated to spawning.

After 7 years of age, females continue to molt annually, however, there is an increasing frequency of males which skip molting for one or two years (very few molt less frequently than biennially).

6.1.3 Age and Growth

The maximum size of crab reported from Asian waters is 226 mm carapace width or 181 mm carapace length (Kajita & Nakagawa, 1932). The largest crab of record which I was able to find in the literature was a male crab measuring 224 mm in carapace length taken in the Pacific Ocean (Wallace et al., 1949). The largest female taken in the Pacific was 189 mm. The largest male taken in 1941 in the Bering Sea was 197 mm in carapace length and the largest female, 170 mm (Wallace et al, 1949).

The maximum age of king crab is difficult to accurately ascertain. An approximation of the longevity of king crab has been obtained through tagging experiments by Powell (1965) and Hoopes and Karinen (1972). From the estimated age at tagging and the years intervening before recovery, Hoopes and Karinen estimated the age of one male and one female to be 17 (carapace length

= 170 mm and 157 mm, respectively) and one female with carapace length of 162 mm to be 18 years of age. Based upon the size-age relationship of these tagged crabs, it is conceivable that the 197 mm carapace length crab captured by Wallace et al. (1949) may have been almost 20 years old, the maximum age of Bering Sea king crab conjectured by Kurata (1961).

6.1.3.1 Larval Growth

Table 9 shows the size of the body and various body parts of the four zoeal stages. Total body length increases by about 10% in the first two molts and by 22% in the last molt from Zoea III to Zoea IV. Armstrong et al. (1983) calculated the dry weight of king crab from the mature egg through the megalops stage (Fig. 16).

6.1.3.2 Juvenile Growth

The growth of immature king crab has been described by a number of authors (Nakazawa, 1912; Kajita & Nakagawa, 1932; Wang, 1936; Kurata, 1961a & 1961b; Powell, 1960; Bright et al., 1960; Weber, 1967; Takeuchi, 1960). As mentioned by Weber (1967) the various sources present an array of growth curves which differ far more than can be simply explained by racial and environmental variability. Weber's (1967) study of the growth of juvenile king crab in eastern Bering Sea is not only directly relevant to our specific geographic area of concern but was the most thorough. Information relevant to the age and growth of juvenile king crab are summarized in Figs. 17 & 18. Among other things, Weber concluded the following:

Table 9.--Rate of growth of zoea larvae in each stage after molting.

Parts, measured	Size of 1st stage	(2nd stage) Size	(2nd stage) Rate of growth by 1st. moulting	(3rd stage) Size	(3rd stage) Rate of growth by 2nd moulting	(Last stage) Size	(Last stage) Rate of growth by 3rd moulting
Total length	4.56 mm.	5.02 mm.	10%	5.58 mm.	16.5%	6.85 mm.	17%
Length of rostral spine	1.08	1.25	16	1.58	26	1.62	2.5
Length of carapace	1.45	1.70	17	2.08	22	2.41	21
Width of carapace	1.12	1.29	15	1.41	15	1.78	26
Length of abdomen	2.14	2.16	1	2.24	4	2.78	24
Width of 2nd abdominal segment	0.30	0.37	23	0.45	22	0.51	12
Width of 5th abdominal segment	0.23	0.27	17	0.32	15	0.43	34
Length of the longest spine of telson	0.51	0.57	12	0.60	5	0.66	10
Length of dorso-lateral spine of carapace	0.45	0.56	25	0.91	62	1.00	10
Length of exopodite of 1st maxilliped	0.49	0.51	4	0.59	14	0.60	2
Length of exopodite of 2nd maxilliped	0.51	0.53	4	0.60	13	0.64	7
Length of exopodite of 3rd maxilliped	0.34	0.37	9	0.49	32	0.49	-
Length of exopodite of antenna	0.83	0.87	5	1.03	18	1.11	8
Longest diameter of eye	0.48	0.49	2	0.50	2	0.51	2
Shortest diameter of eye	0.28	0.28	-	0.28	-	0.30	8
Length of abdominal appendages	-	-	-	0.06	-	0.60	900
Length of uropods	-	-	-	0.26	-	0.37	50

Source: Marukawa (1933)

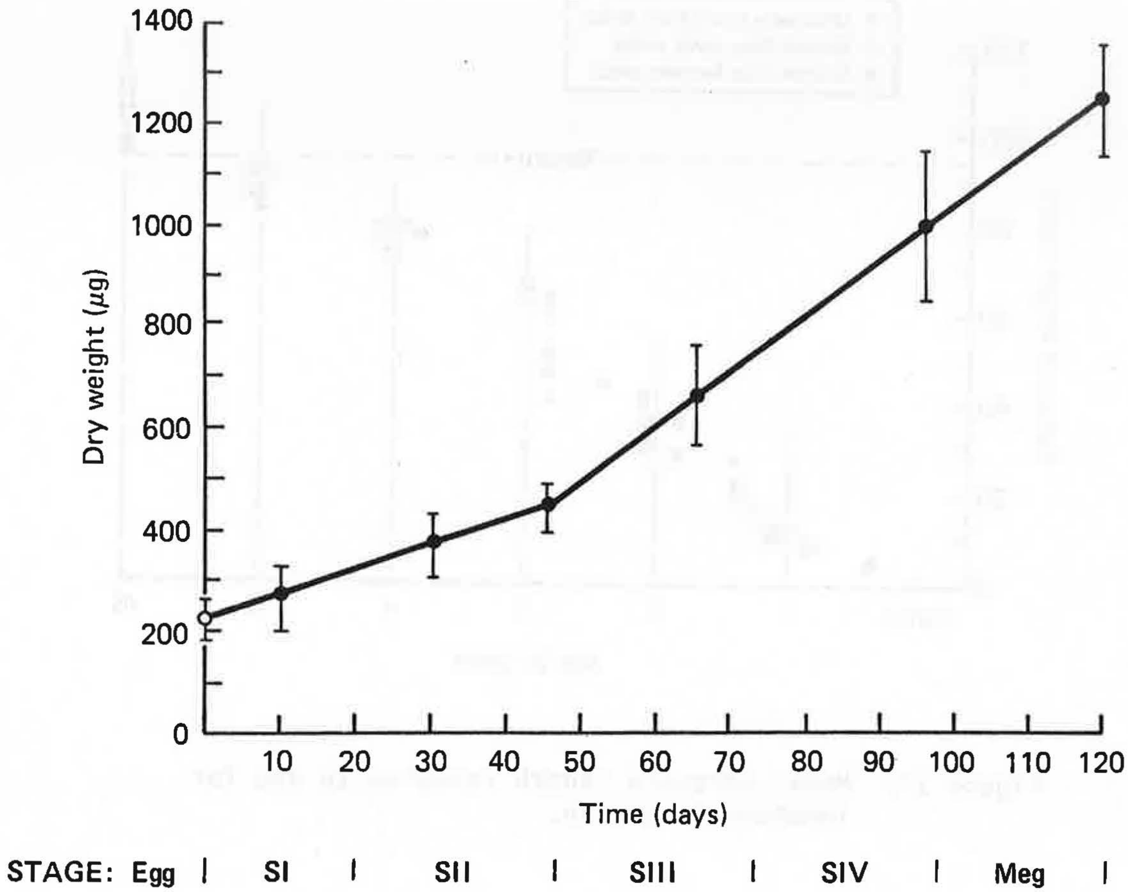

Figure 16. Increase of dry weight of king crab larvae from egg through megalops stage.

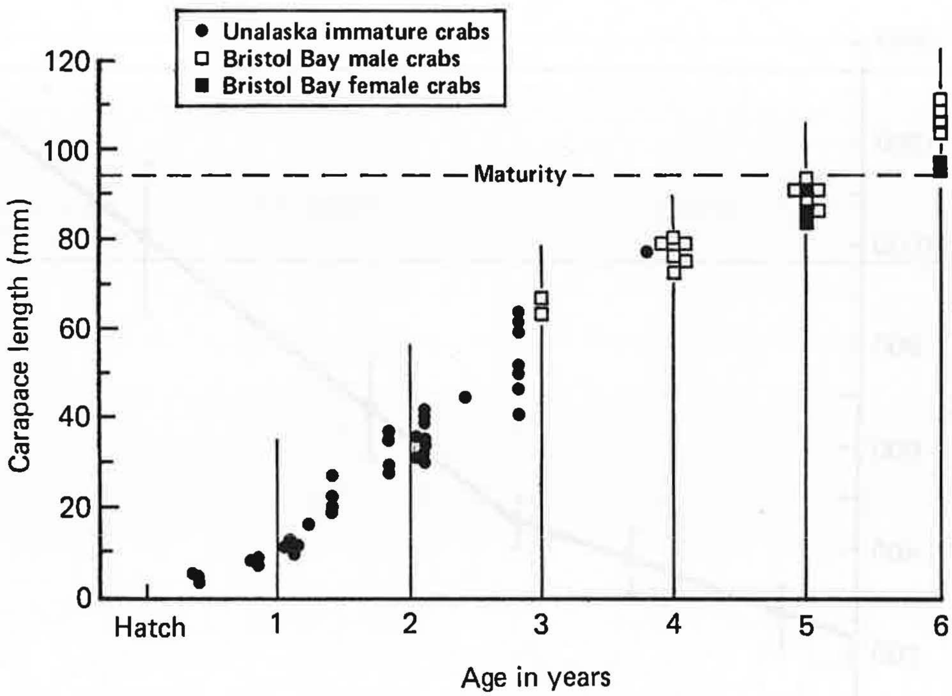

Figure 17. Modal carapace length relative to age for immature king crab.

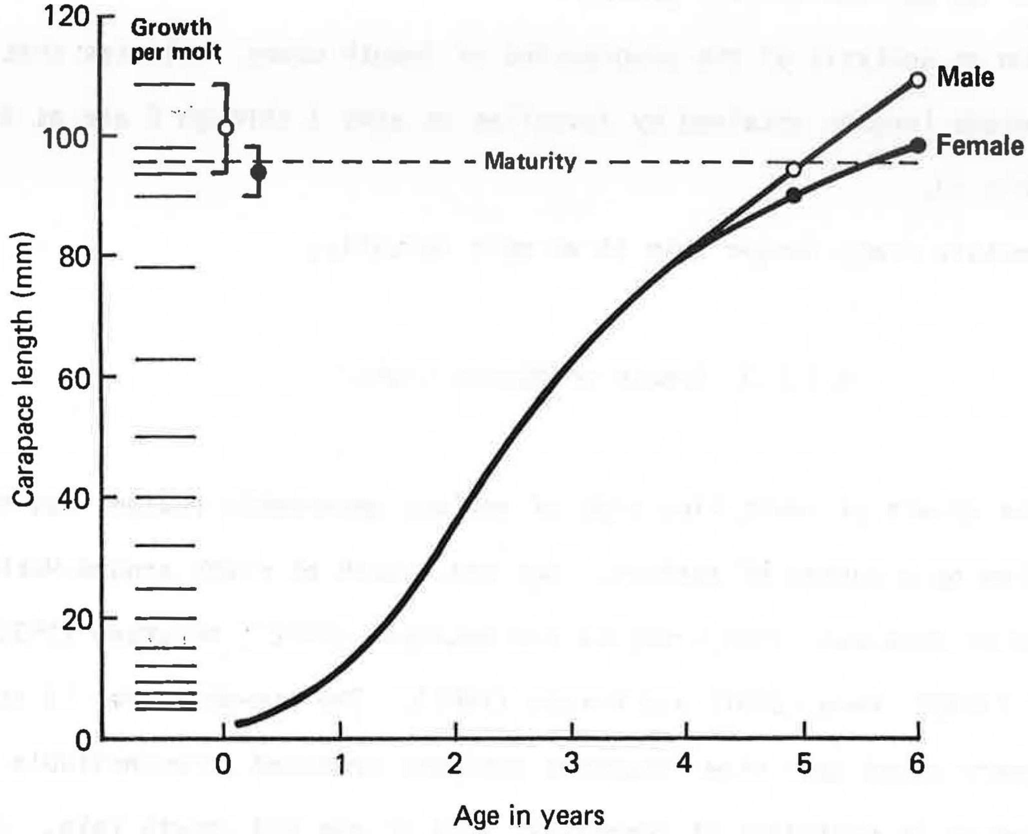

Figure 18. Growth curves of immature king crab of southeastern Bering Sea.

1. Both male and female king crab in eastern Bering Sea mature at about 95 mm carapace length (about 5 years for males and 5 1/2 years for females).
2. Growth per molt for confined crabs 4 mm to 60 mm in carapace length ranged from 23% at 10 mm to 27% at 50 mm. Growth rate of unconfined crabs 9-27 mm was one percent greater.
3. From an analysis of the progression of length modes indicates that the average lengths attained by juveniles at ages 1 through 6 are as shown in Table 10.
4. Immature crabs longer than 65 mm molt annually.

6.1.3.3 Growth of Mature Crabs

The growth of adult king crab of various geographic regions has been described by a number of authors. Age and growth of crabs around Hokkaido was studied by Nakazawa (1912), Kajita and Nakagawa (1932), Marukawa (1933), Mihara (1936), Wang (1937) and Kurata (1961). The pre-World War II studies which were based upon size frequency analyses produced irreconcilable differences in estimates of longevity, size at age and growth rate. A critique of these studies is given by Weber and Miyahara (1962) in which they concluded that due to differences in interpretation of modal values in length frequency analyses, the earlier studies tended to rather severely underestimate or overestimate growth rates and longevity of king crab.

The growth of king crab in the Gulf of Alaska has been discussed by Powell (1967), Eldridge (1975) and McCaughran and Powell (1977).

More recent studies on the age and growth of adult king crab have obtained more direct estimations of growth increments based upon tagged crab

Table 10.--Average length by age of immature king crabs of southeastern Bering Sea.

Age (years)	Average carapace length (mm) Male	Female
1	11	11
2	35	35
3	60	60
4	78	78
5	94	90
6	109	98

Source: Weber (1967)

as well as consideration of shell condition relative to the frequency and probability of molting. Studies of Gulf of Alaska king crab include those by Powell (1967), Eldridge (1975) and McCaughran and Powell (1977). Growth rate of mature king crab of the Kodiak area (or any area other than eastern Bering Sea) will not be discussed in any detail in this report. It is sufficient to note that king crab south of the Alaska Peninsula are larger and have a faster growth rate than king crab of eastern Bering Sea (Wallace et al., 1949; Powell, 1967).

Growth of Bering Sea king crab has been studied by Weber and Miyahara (1962), Weber (1965), Kurata (1961), Hoopes and Greenough (1970). Results of these studies were critically evaluated and incorporated into a growth model which took into account molting history and probabilities as well as size specific natural mortality (Balsiger, 1974).

Wallace et al. (1949) observed that female king crab taken in the eastern Bering Sea in 1941 were oviferous at 86-102 mm in carapace length. Weber (1967) examined the same relationship with the addition of data from the three years, 1956-1958 and concluded that the majority of females in eastern Bering Sea became mature at 90-100 mm carapace length. On the basis of changes occurring in the size of the merus and chela relative to carapace size and histological changes in the ductus deferens, Wallace et al. (1949) tentatively concluded that male king crab of eastern Bering Sea attained sexual maturity at approximately 100 mm carapace length. For eastern Bering Sea crab, the size at maturity for both sexes of king crab has been accepted as being about 95 mm carapace length. For males, this length corresponds to an age of about 5 years and for females 5 1/2 years.

An analysis of the progression of mean length frequency modes in successive years by Weber and Miyahara (1967) showed a rather consistent annual growth increment of 15 mm for adult male king crabs. The mean expected growth increment resulting from regression analysis (Expected Growth Increment = Y = 13.14 + 0.018X) varied from 15.1 mm for carapace length of 110 mm to 16.0 mm for carapace length 160 mm, a difference of less than 1 mm. On the strength of these analyses, growth increment per molt was considered by Weber and Miyahara to be 16 mm for male Bering Sea king crab 110 mm and larger.

Curves for the growth in length of mature (ages 5-14) male and female king crabs which have been used in most recent evaluations of the condition of the eastern Bering Sea king crab stock are given in Fig. 19. Comparable curves for the growth in weight are shown in Fig. 20.

6.2 Natural Mortality

6.2.1 Eggs

As previously mentioned, king crab eggs are retained by the female for about 11 months and develop entirely within the protected environment of the abdominal flap. Marukawa (1933) observed that very few eggs remain on the abdomen of the female as dead eggs after the completion of hatching. He, therefore, concluded that the percentage of eggs hatching or survival of eggs to hatching was extremely high.

Otto et al. (1982) and Reeves (1983) reported a high incidence of crab with incomplete egg clutches in the 1982 Bering Sea king crab surveys. Fertilized females in 1982 were dominated by larger and old shelled

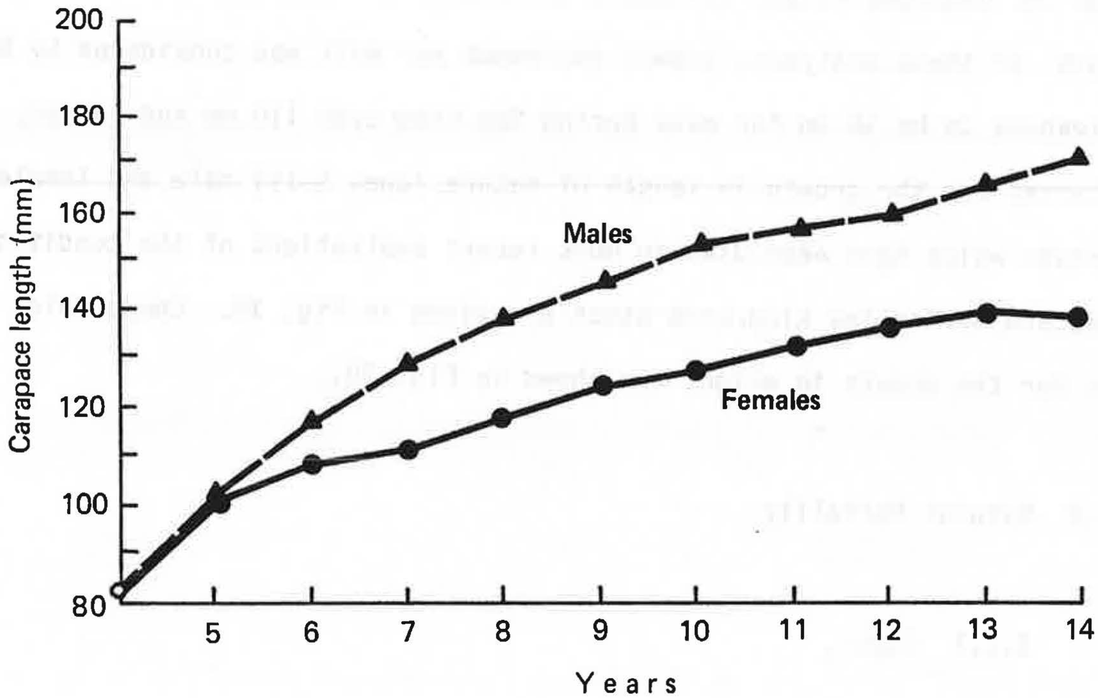

Figure 19. Average lengths of mature king crab at ages 5-14.

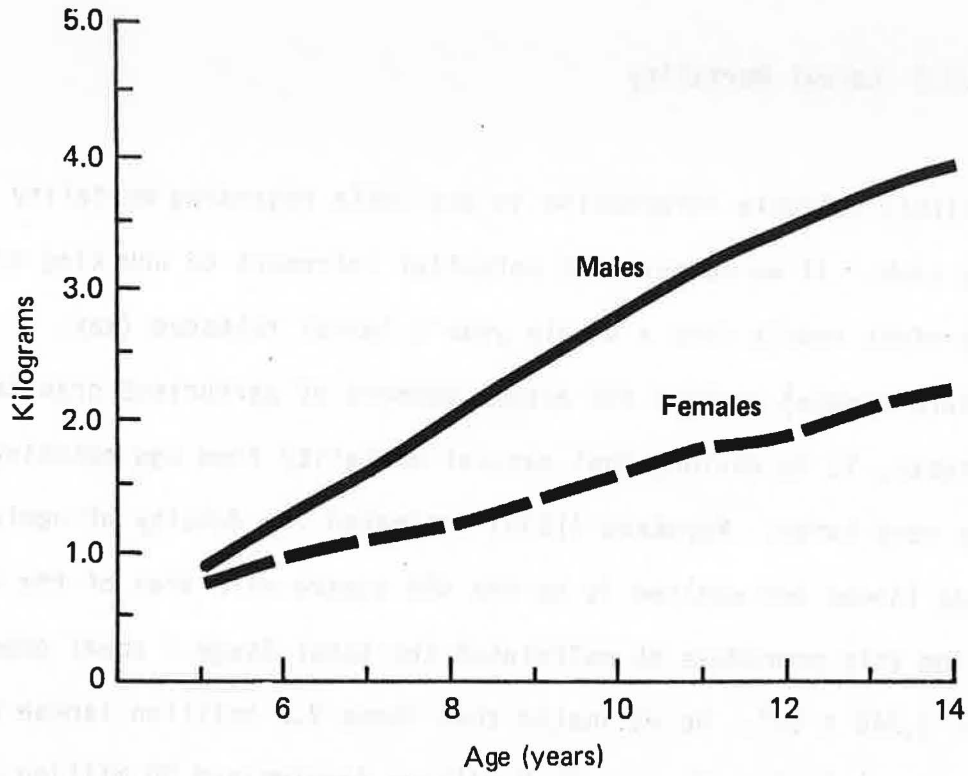

Figure 20. Growth in weight of male and female king crab.

individuals which were almost totally replaced by smaller, new shelled females having smaller but full egg clutches in 1983. One possible explanation for the prevalence of incomplete egg clutches may be that the older females in the 1982 survey did not undergo the annual molt as is typical for female crab (Reeves, pers. comm.).

6.2.2 Larval Mortality

Very little reliable information is available regarding mortality in larval king crab. If we compare the potential increment to any king crab stock which might result from a single year's larval releases (say, 200,000/mature female) against the actual numbers of parturient crab in the spawning stocks, it is obvious that natural mortality from egg hatching to maturity is very large. Marukawa (1933) estimated the density of newly hatched zoea larvae and applied it to the 458 square mile area of the Sea of Nemuro. From this procedure he calculated the total Stage I zoeal population to be about 2,248 X 10^9. He estimated that these 2.2 trillion larvae were released by a population of about 11.2 million females and 20 million males. Although Marukawa's estimate is based upon a number of unverified assumptions, it serves to illustrate that the total mortality to a cohort of king crab is very substantial. It is reasonable to assume that the most of this very large mortality occurs in the earlier life history stages.

From observations of larvae reared in laboratory experiments and from zoea collected periodically from the natural environment, Marukawa (1933) concluded that larval mortality was extremely high. Zoea I were found to have poorest survival (6.5%). Eighty percent of the surviving Zoea II lived to be

Zoea III and 86% of these survived to the last zoea stage. Survival from the last zoea to the megalops stage was also about 86%. From these observations, about 3.58% of the eggs hatched survive to become megalopae. This is a mortality of 96.4% up to the megalops stage all but about 3% of which occurs during the first zoeal stage. Marukawa attributed the large mortality during the first zoeal stage to the transition between yolk sac and free feeding. This implies either an inadequate quantity of appropriate food items at this critical transitional stage or perhaps developmental inadequacies and abnormalities which may prevent zoea from feeding in the presence of adequate food (Vladimirov, 1975).

On the basis of estimates of the quantity of zoea larvae, fecundity, observed larval mortality and intuitively reasonable survival rates of postmegalops crab, Marukawa estimated that only 14 crab out of 1,000,000 hatches survive to the desired commercial size of 160 mm carapace width.

6.2.3 Adult Mortality

Natural mortality in adult king crab occurs from spawning senescence, predation, fishery encounters (discards in target or nontarget fisheries), parasitism, and diseases.

The average annual natural mortality for male king crab in eastern Bering Sea for three year periods between 1968 and 1979 was estimated by Reeves and Marasco (1980) to be M = 0.26. Age specific (5-14 yrs) natural mortalities for males and females is given in Table 11 (Reeves, 1980). The estimated average annual instantaneous natural mortality for male (1968-79) and female

Table 11.--Age-specific population parameters used in king crab simulations.

Age	NATURAL MORTALITY (annual M)		AVERAGE LENGTH (mm)	
	Male	Female	Male	Female
5	.13	.58	105	100
6	.12	.58	117	107
7	.08	.58	128	112
8	.08	.58	137	117
9	.11	.58	145	122
10	.23	.58	152	127
11	.50	.58	157	132
12	.57	.58	162	136
13	.61	.58	166	139
14	.76	.58	170	142

*Ages 5-7 estimated by back-calculation using the natural mortality schedule

Source: Reeves 1980 (unpublished data)

(1970-79) king crab are shown in Tables 12 and 13, respectively. The adjusted natural mortality schedule for the exploitable males is given in Table 14.

7. DISTRIBUTION AND ABUNDANCE IN E. BERING SEA

7.1 Larval Distribution and Abundance

Information concerning the distribution of larval king crab in eastern Bering Sea can be found in Takeuchi (1962), Korolev (1964), Rodin (1970), Haynes (1974) and Armstrong et al., (1983). There is very little information concerning the distribution of megalopae and 1st year juveniles. Data on the zoeal stages is quantitative to the extent of ascertaining areas and timing of hatching from differences in relative abundance of the larval stages. There have been no estimates of the quantitative magnitude of the successive stages of larvae from which one can estimate the extent of natural mortality from the Zoea I stage through the first instar stage.

Time of hatching, the reference point from which age is calculated, for eastern Bering Sea king crab extends from mid-April to mid-June (Takeuchi, 1962; Niwa, 1962; Fishery Agency of Japan, 1963; Korolev, 1964). According to Weber (1967) 50% hatching falls in mid-May although this timing can vary by as much as a month (Fishery Agency of Japan, 1956 & 1963; Weber, 1967).

Figure 21 shows the distribution and abundance of male crabs during the inshore migration periods of 1960 through 1963 in southeastern Bering Sea. The migratory distribution of females was basically similar with concentrations observed off Amak Island, Black Hill and Port Moller areas (Fishery Agency of Japan, 1964). The Port Moller area was the most important with respect to

Table 12.--Estimate of average annual instantaneous natural mortality for exploited male red king crabs.

	MILLIONS OF MALE CRABS												
Age	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Mean
9	2.7	3.1	2.5	--	2.3	4.7	8.5	9.5	13.4	14.2	20.2	17.7	
10	1.2	1.0	0.6	--	1.0	1.3	2.1	2.5	4.5	4.7	6.2	7.1	
11	0.9	0.5	0.3	--	0.3	0.9	3.5	2.0	2.9	3.3	4.6	4.5	
12	0.6	0.3	0.1	--	0.3	0.5	0.7	1.3	1.5	2.0	2.1	3.5	
13	0.3	0.2	0.0	--	0.1	0.2	0.2	0.5	0.7	0.7	1.4	2.3	
14	0.5	0.3	0.1	--	0.2	0.1	0.1	0.3	0.3	1.5	0.5	1.3	
$\hat{Z}_p$	.37	.49	.65	--	.55	.73	.88	.64	.72	.50	.68	.48	
Period p	66-68	67-69	68-70	69-71	70-72	71-73	72-74	73-75	74-76	75-77	76-78	77-79	
$\bar{f}_p$	20,279	52,181	80,860	104,655	140,075	173,950	205,414	205,431	246,347	328,351	395,950	433,410	
$\hat{q}_p$ ($\times 10^{-5}$)	--	--	.326	.326	.331	.247	.239	.193	.155	.122	.084	.076	
$\hat{M}_p$			.39	--	.09	.25	.39	.24	.34	.10	.35	.15	.26

Source: Reeves & Marasco (1980)

Table 13.--Estimate of average annual instantaneous natural mortality for female red king crabs.

	MILLIONS OF FEMALE CRABS									
Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	MEAN
8	1.0	--	0.7	5.6	4.1	4.1	8.2	16.1	6.7	13.9	6.7
9	0.7	--	0.3	5.3	4.7	3.6	6.8	12.3	5.2	7.5	5.2
10	0.8	--	0.3	3.4	2.3	2.7	3.2	5.9	3.6	6.3	3.2
11	0.5	--	0.2	2.5	1.7	1.0	1.6	3.8	2.4	2.5	1.8
12	0.3	--	0.1	1.0	0.7	0.4	0.3	0.7	0.4	0.6	0.5
13	0.2	--	0.1	0.9	0.6	0.3	0.2	0.6	0.3	0.6	0.4
14	0.2	--	0.1	0.4	0.4	0.1	0.3	0.6	0.5	0.4	0.3
$\hat{Z}$											.58

Source: Reeves & Marasco (1980)

Table 14.--Adjusted natural mortality schedule for exploited male red king crabs 9-14 years.

AGE	BALSIGER M ESTIMATES	1970-1979 AVERAGE STOCK	ADJUSTED M ESTIMATES
9	.15	10.0	.11
10	.30	3.3	.23
11	.66	2.5	.50
12	.75	1.3	.57
13	.80	.7	.61
14	1.00	.5	.76
Weighted Average	.34		

Source: Reeves & Marasco (1980)

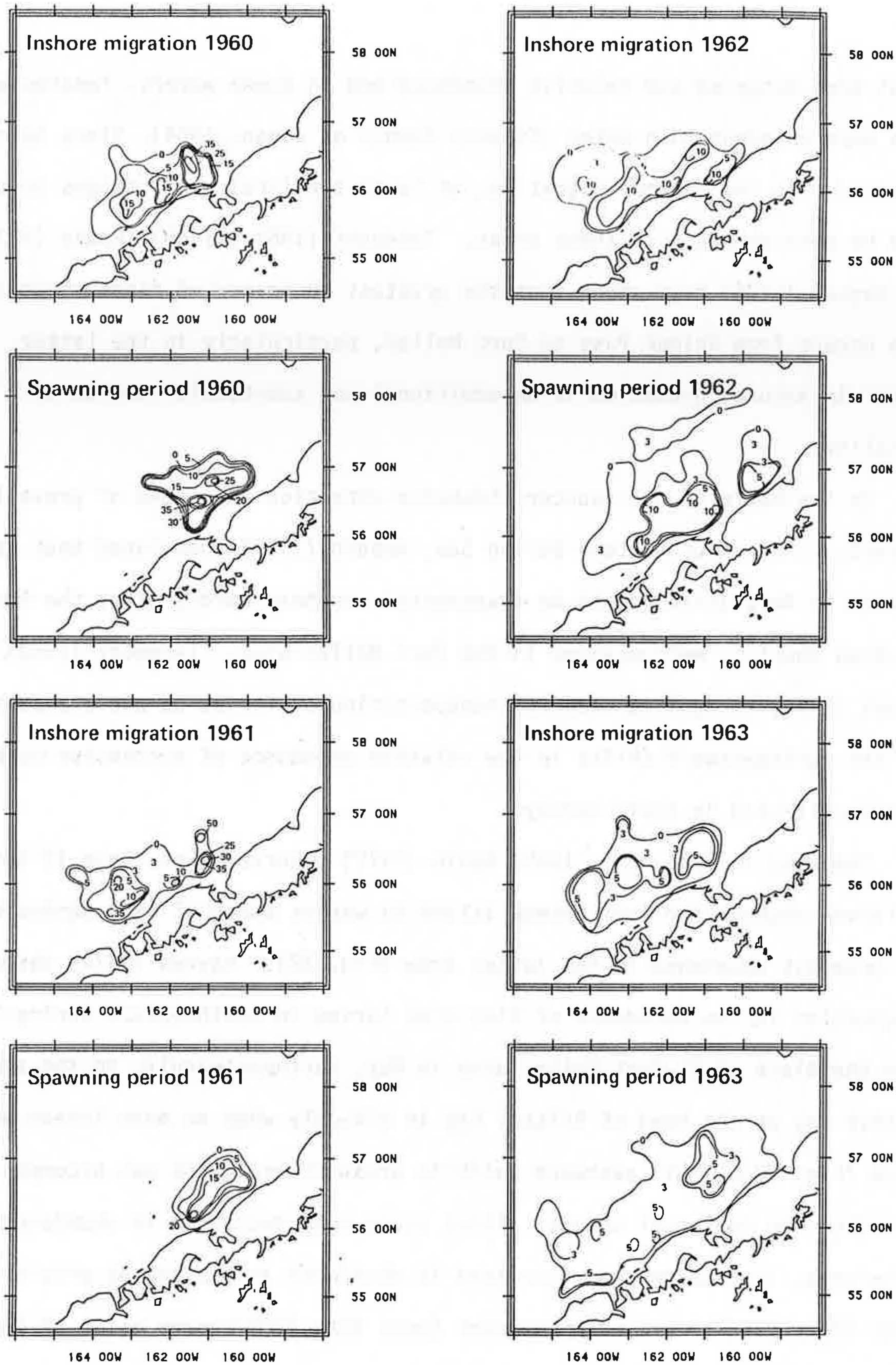

Figure 21. Distribution of male crab during inshore migrations and spawning period, 1960-63.

total area occupied and relative abundance and in these waters, females were even more abundant than males (Fishery Agency of Japan, 1964). Since hatching occurs during the inshore migration, at least the first zoeal stages should also be most abundant in these areas. Takeuchi (1962 & 1968), Rodin (1970), and Haynes (1974) have shown that the greatest abundance of first stage zoea also occurs from Unimak Pass to Port Moller, particularly in the latter area. In nature, predation is an additional and substantial source of mortality.

On the basis of the counter clockwise direction and speed of prevailing currents in the southeastern Bering Sea, Hebard (1959) speculated that larvae hatched at Amak Island could be transported northeastwardly along the North Aleutian Shelf to metamorphose in the Port Moller area. Takeuchi (1962) and Haynes (1974) recognized oceanic transportation of larvae as one explanation for the northeastward shifts in the relative abundance of successive zoeal stages collected in their surveys.

Sampling in June-July, 1965, Rodin (1970) observed Zoea Stage II through IV larvae distributed from Unimak Island to waters north of Cape Seniavin with the greatest abundance in the latter area (Fig. 22). Haynes (1974) observed a progression in the abundance of king crab larvae in southeastern Bering Sea from the Black Hill-Port Moller area in May, northeastwardly, to the area off Ugashik Bay at the head of Bristol Bay in mid-July when no more larvae were taken (Fig. 23). This eastward shift in areas of abundance was accompanied by a progression in larval stages. First stage zoea decreased in abundance and conversely, last stage zoea increased in abundance as the season progressed (Fig. 24). Larvae were most abundant (more than 1000/square meter of sea surface) near Unimak Pass and Port Moller and least abundant (less than

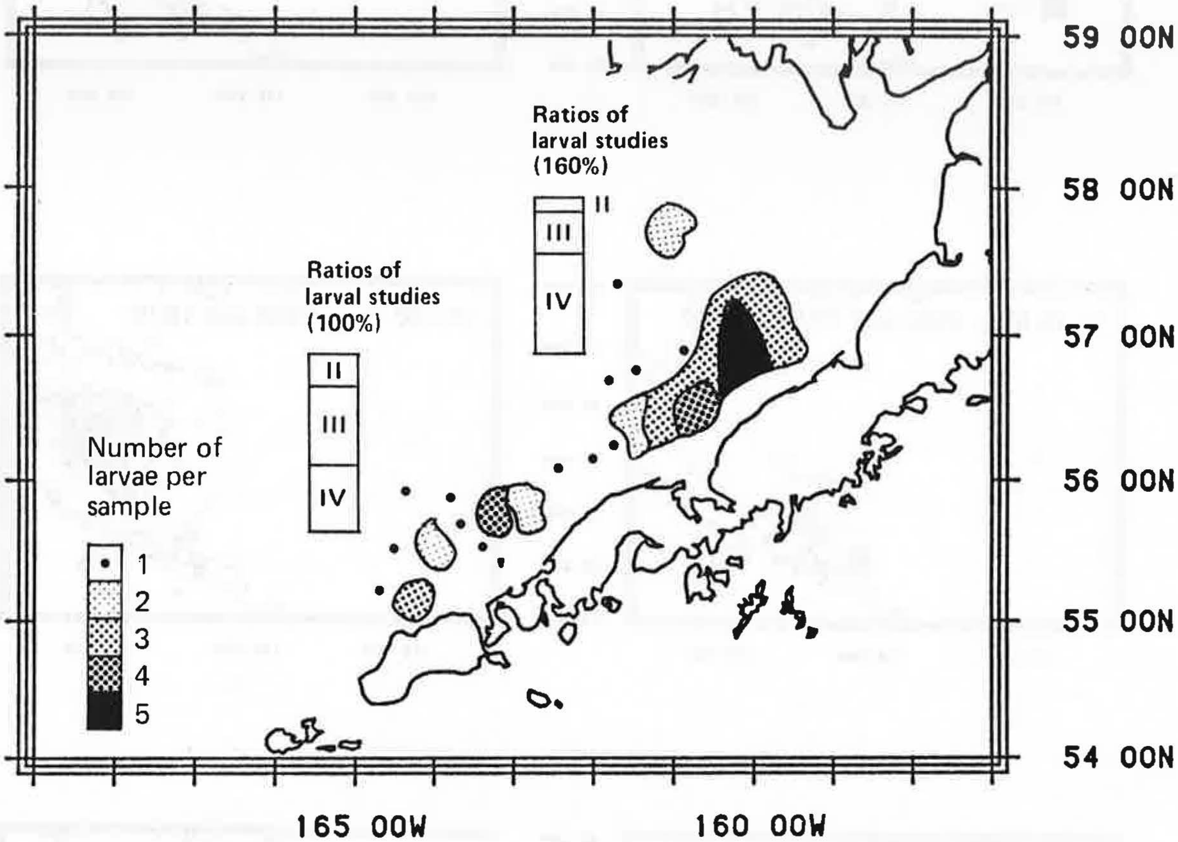

Figure 22. Distribution of king crab larvae (June-July 1965).

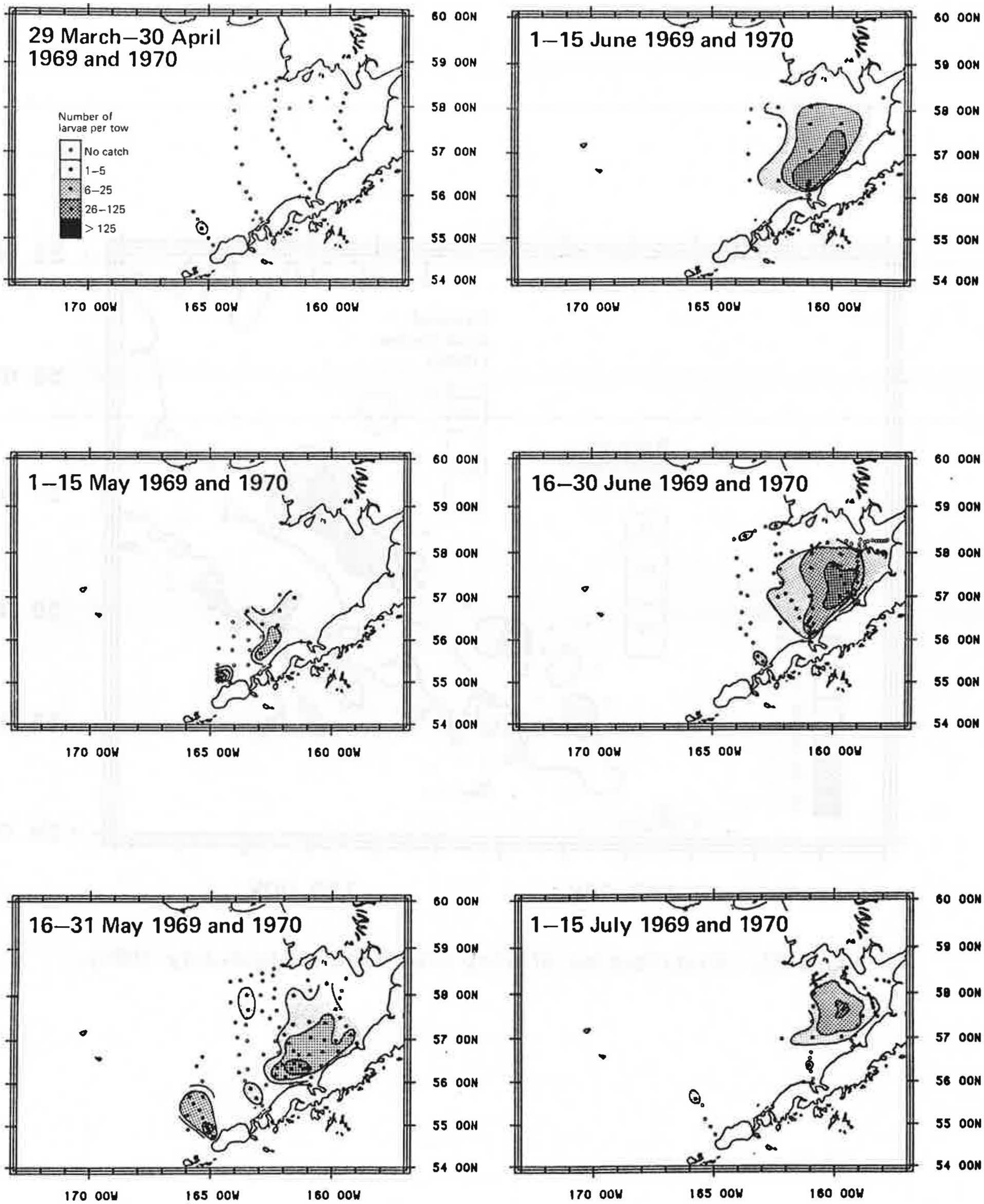

Figure 23. Distribution of king crab larvae in southeastern Bering Sea, May-July 1969-70.

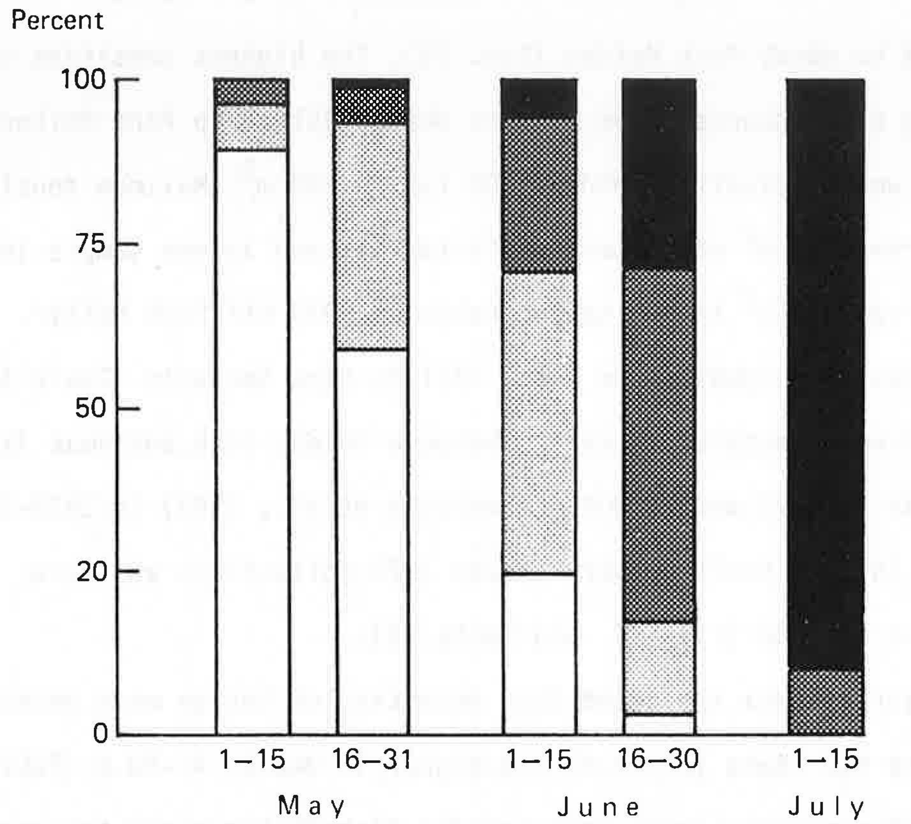

Figure 24. Percentages of 4 king crab zoeal stages in eastern Bering Sea, May-July 1969-70.

10/square meter of sea surface) in the more central and western sampling stations.

Armstrong et al. (1983) analysed over 1000 zooplankton samples taken in southeastern Bering Sea in 1976 through 1981. Red king crab larvae were absent over most of St. George Basin and occurred from off western Unimak Island eastward to about Port Heiden (Fig. 25). The highest densities of larval red king crab occurred from western Unimak Island to Port Moller where concentrations were typically 5,000-50,000 larvae/100 m^2. Maximum densities were 67,000 larvae/100 m^2 off Otter Pt., Unimak Island in one sample in 1977 and 114,000 larvae/100 m^2 in one sample taken in 1980 off Port Moller. Average abundance was highest from Black Hill to Cape Seniavin (Table 15). Although larvae were captured in waters between Unimak Pass and Amak Island by Haynes (1974) in 1970-71 and by NOAA (Armstrong et al., 1983) in 1976-77, they occurred there in very small numbers in the 1978 collections and were virtually absent in 1982 (Fig. 26 and Table 16).

The 1982 survey data indicated that densities of larvae were generally lower closest to the shore (20-40 m) and higher in depths 41-80 m (Table 16).

In the 1982 surveys, larvae were broadly distributed along the northern Aleutian Shelf in June from False Pass north eastward to C. Seniavin, whereas in August, their presence was limited to the easternmost stations off Port Heiden (Fig. 26).

Some indications of annual variation in the distribution and abundance of larval, eastern Bering Sea king crab are obtainable from Armstrong et al. (1983). Annual variation in levels of abundance are suggested but are difficult to quantify due to the small number of samples relative to the time-space dimensions of larval distribution. Their data also suggest that larval

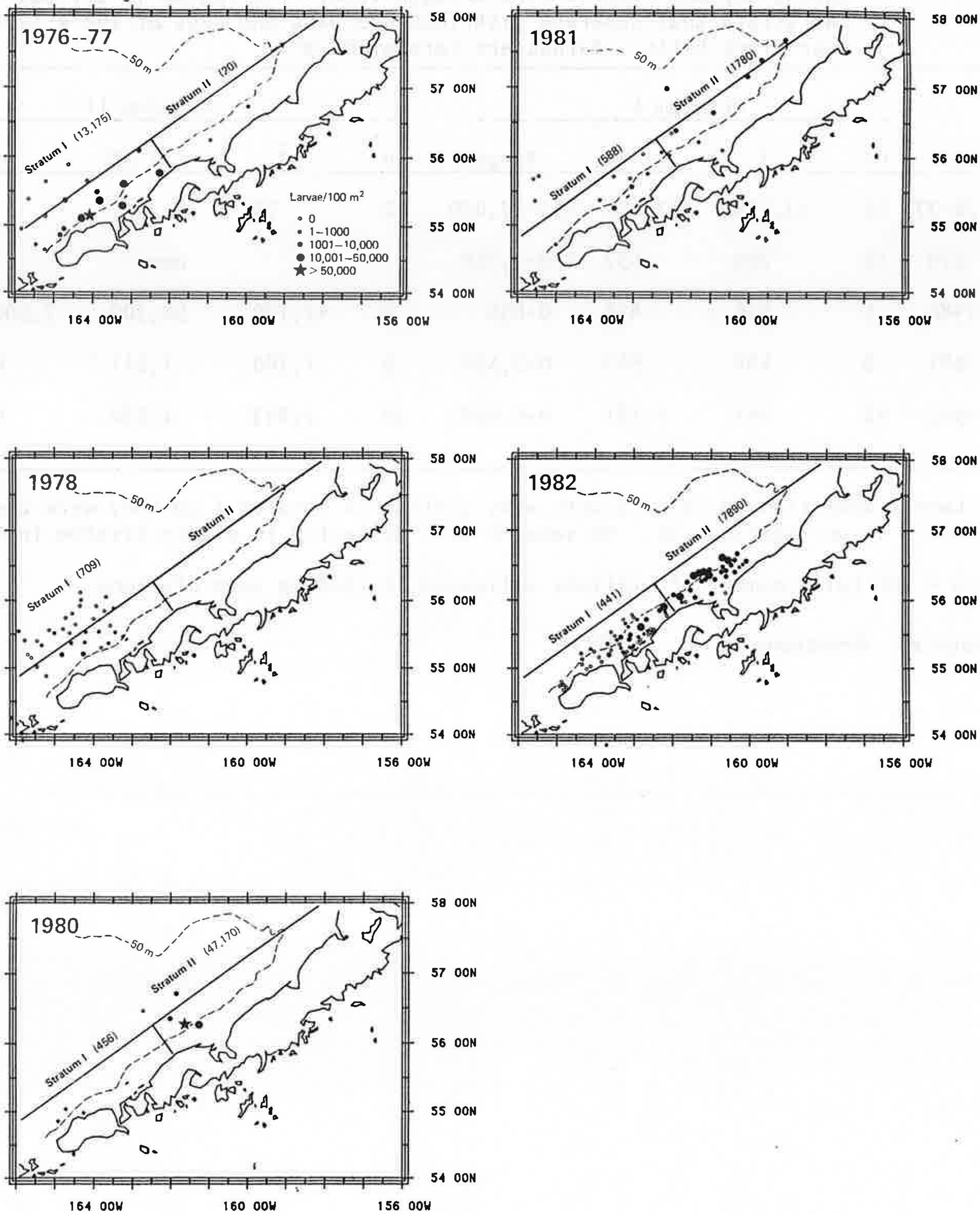

Figure 25. Annual differences in distribution and abundance of red king crab larvae along the northern Aleutian Shelf.

Table 15.--Mean abundance of larval red king crab along the North Aleutian Shelf during May and June in 1976 through 1982. The region is divided into two strata that separate distributions east and west of 162°W latitude near Black Hills. Values are larvae/100 m^2.

	Stratum I				Stratum II			
Year*	n**	$\bar{X}$	±1 SD	Range	n	$\bar{X}$	±1 SD	Range
1976-77	15	13,175	17,200	650-67,000	2	20		0-39
1978	12	709	537	170-1,760			none	
1980	5	456	421	0-850	3	47,170	58,300	7,500-114,000
1981	8	488	943	0-2,570	9	1,780	1,512	0-4,500
1982	48	441	1,181	0-6,620	30	7,893	1,584	0-36,240

* Larval densities in 1976-77 were very similar in Stratum I so they were combined for a larger sample size. No samples were collected in either Stratum in 1979.

**n = the total number of stations collected, including zero stations.

Source: Armstrong et al. (1983)

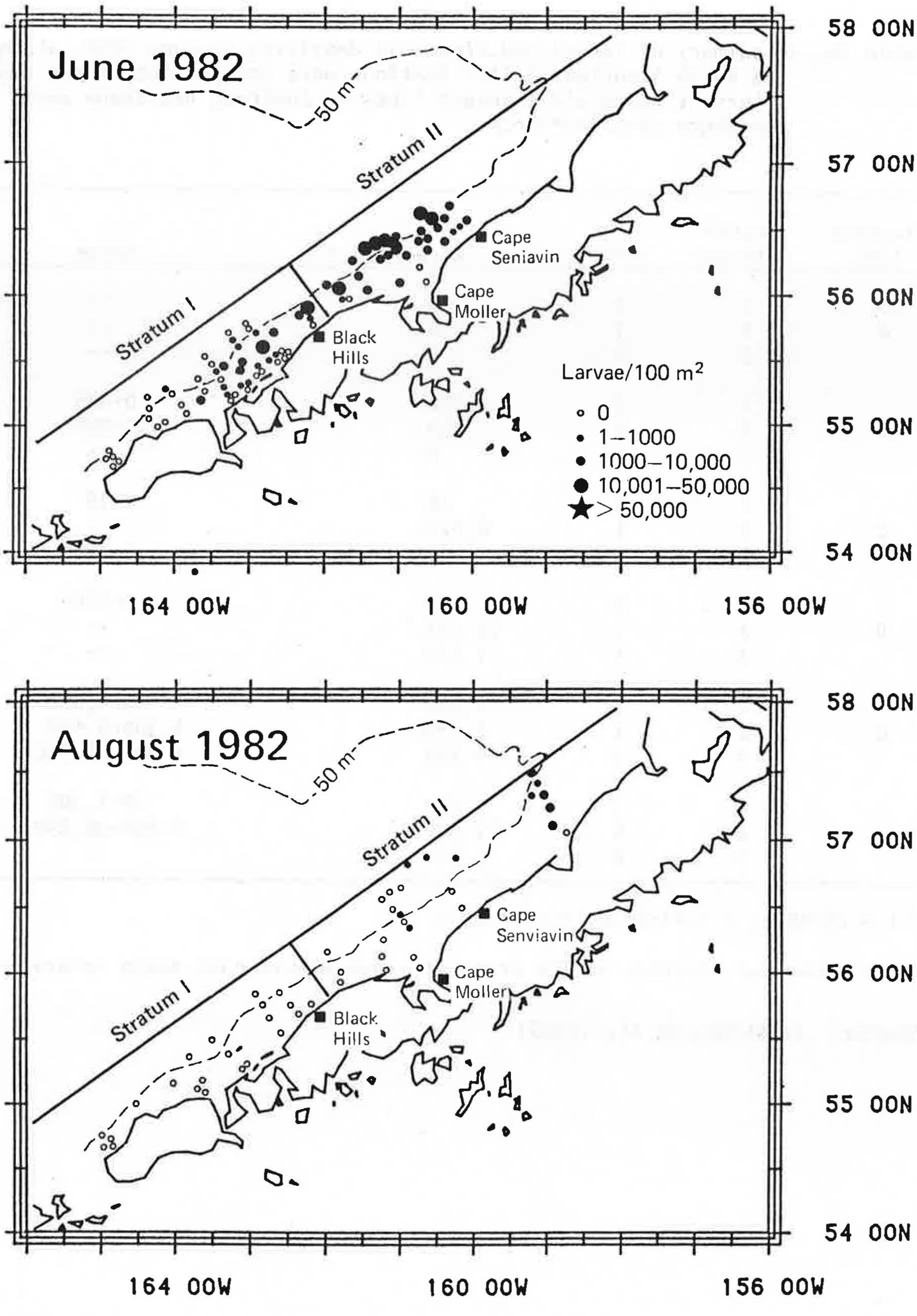

Figure 26. Distribution and relative abundance of red king crab larvae in June and early August 1982.

Table 16.--A summary of larval red king crab densities in June 1982, along the North Aleutian Shelf. Stations were grouped into three depth intervals along six transect lines to contrast nearshore and longshore distribution.

Transect line	Depth* interval	n**	$\bar{X}$ (no. larvae/100 m^2)	Range
	1	3	0	--
A	2	3	0	--
	3	2	0	--
	1	2	202	0-405
B	2	3	350	120-590
	3	2	0	--
	1	3	26	0-78
C	2	1	6,624	--
	3	3	80	0-126
	1	2	125	0-250
D	2	1	12,231	--
	3	1	1,120	--
	1	2	2,000	0-4,000
E	2	2	6,930	4,300-9,550
	3	5	15,350	8,800-24,700
	1	3	780	50-1,300
F	2	5	17,300	6,400-36,240
	3	0	--	--

* 1 = 20-40 m, 2 = 41-60 m, 3 = 61-80 m.

**n = number of stations on the transect lines within each depth interval.

Source: Armstrong et al. (1983)

abundance is greater eastward of Black Hill (Table 15). Excepting 1982, however, the number of stations and samples upon which such a conclusion is based is small. The evidence is, however, consistent with the views of Takeuchi (1962), Rodin (1970) and Haynes (1974) who concluded on the basis of their studies that the Port Moller area was the more important of the egg hatching sites for eastern Bering Sea red king crab.

Additional information on the relative abundance of the larval stages of king crab in eastern Bering Sea and the timing of development is presented by Armstrong et al. (1983). Stage I zoea occur from before April 18 into the first three weeks of June. Stage II larvae begin to occur in April, maximize in abundance in May-June and disappear after early July. Stage III zoea were encountered from about May 11 through August 10. Last stage zoea larvae occurred in samples collected from the June 1-21 period through August 10. Similarly, megalops larvae were first taken in the first three weeks of June and their abundance increased through the August 1-10 sampling period (Fig. 27). Armstrong et al. (1983) indicate that megalopae are common from early July to early August but there was no mention of their distribution or habitat. From Fig. 28 it appears that all megalopae encountered by Armstrong et al. (1983) were taken offshore of Izembek Lagoon. Examination of the proportion of earlier and later zoeal stages at scattered longitudinal intervals along the northern Aleutian Shelf indicates a tendency toward earlier hatching or more rapid development of larvae in the westward areas (Fig. 28).

Armstrong et al. considered that 1980 and 1982 were probably years of good larval production along the northern Aleutian Shelf. Collections of

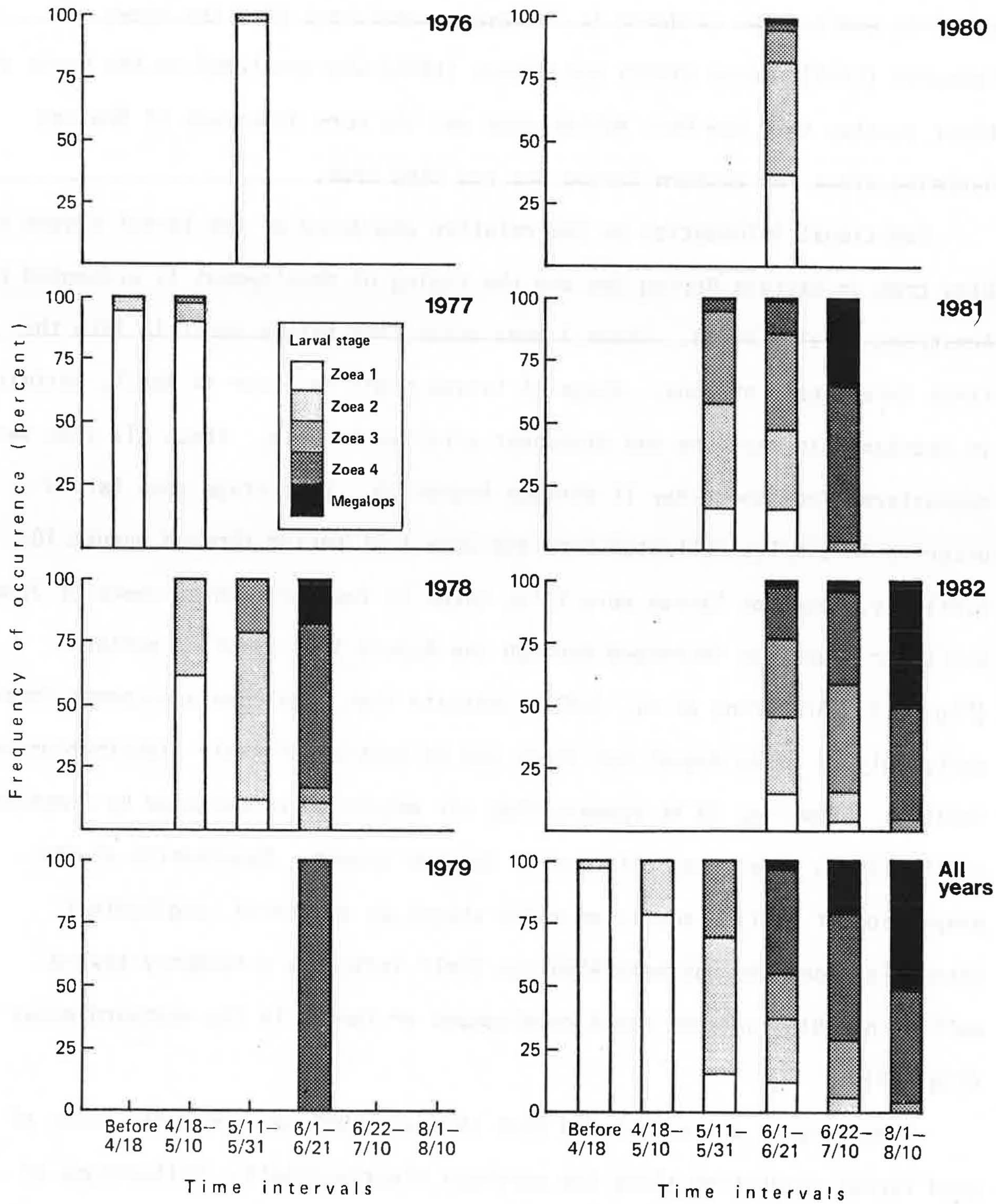

Figure 27. Frequency of occurrence of larval stages, April to August 1976-82.

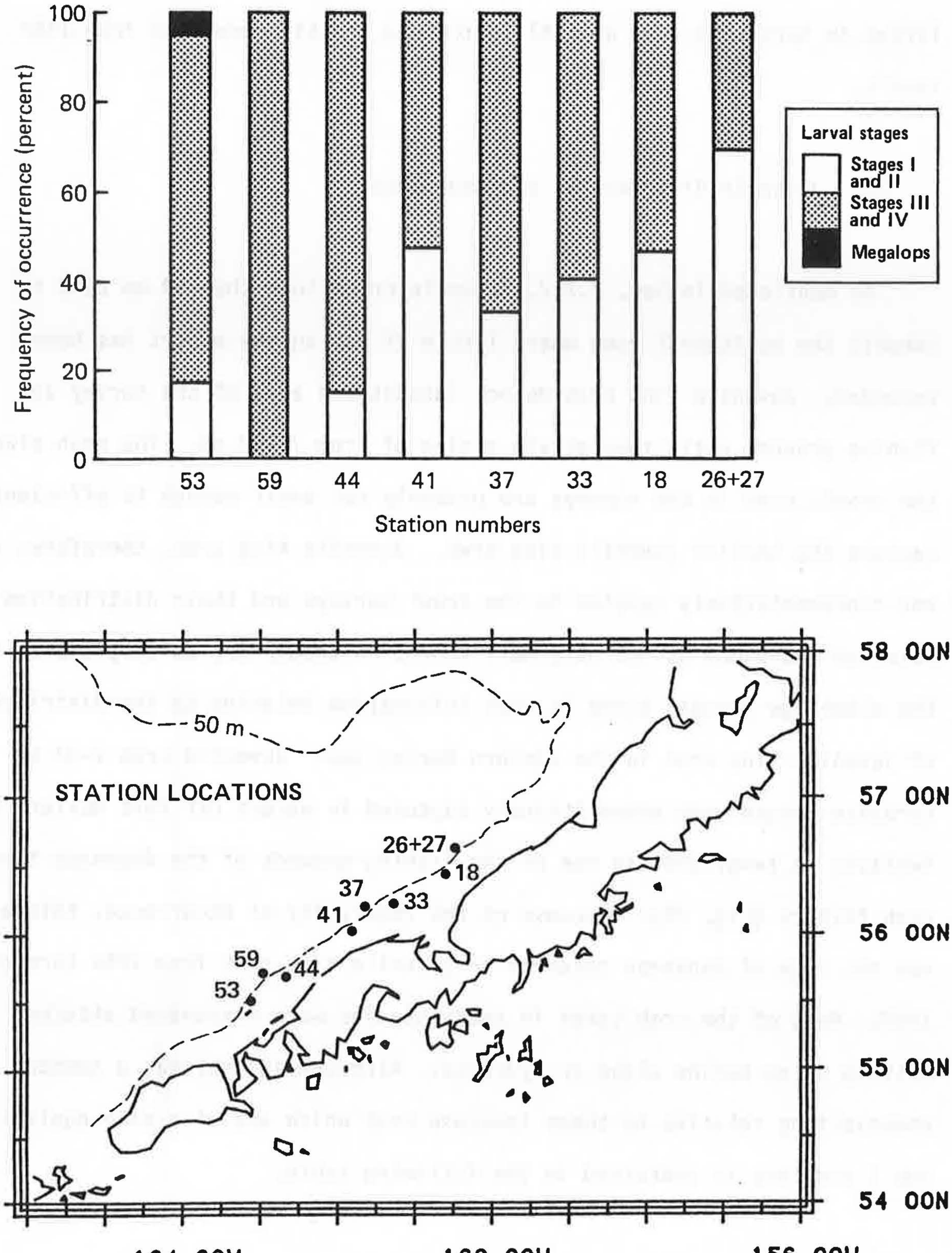

Figure 28. Differences in apparent hatch time.

larvae in April and June of 1983 indicate a drastic reduction from 1982 levels.

7.2 Juvenile Distribution and Abundance

As mentioned in Sec. 2.2.2, juvenile crabs less than 50 mm tend to inhabit the eulittoral zone where little if any survey effort has been expended. Juvenile king crab do not inhabit the area of the survey and fishing grounds until they attain a size of from 70-80 mm. The mesh sizes of the trawls used in the surveys are probably not small enough to efficiently capture the smaller juvenile king crab. Juvenile king crab, therefore, are not representatively sampled in the trawl surveys and their distribution and relative abundance is not very well known. Although not as complete as for the older age groups, there is some information relating to the distribution of juvenile king crab in the eastern Bering Sea. Juvenile crab 2-33 mm in carapace length were adventitiously captured in waters off Port Moller-Cape Seniavin in tanglenets in one of the fishing grounds of the Japanese tanglenet crab fishery (Fig. 29). Because of the regularity of occurrence, this area was the site of Japanese research on juvenile king crab from 1956 through 1960. Most of the crab taken in these studies were discovered attached to the netting or on marine algae or Hydrozoa. Although incomplete, a summary of observations relative to these immature crab which are of a size equivalent to age 3 and less is contained in the following table.

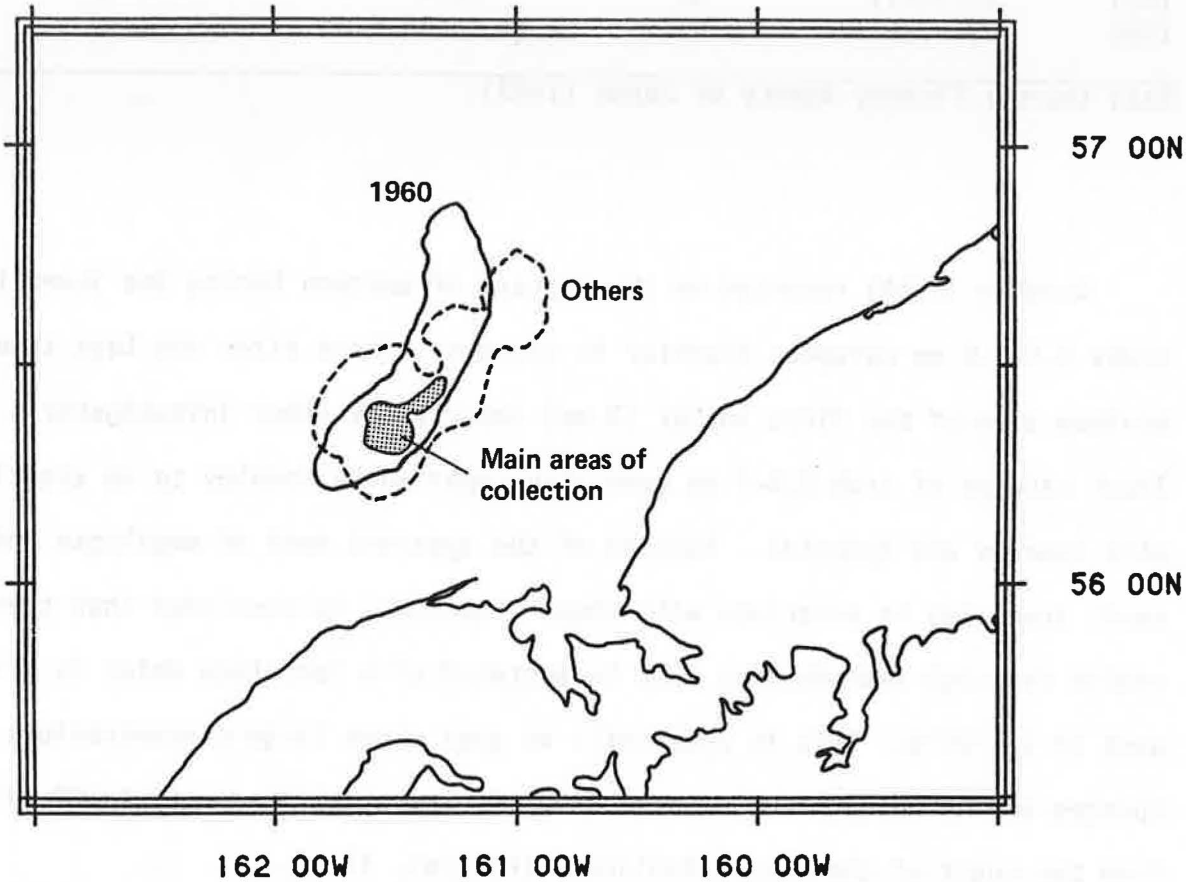

Figure 29. Areas in which juvenile crab were collected.

Table 17. The number and size of juvenile red king crab (2-33 mm carapace length) captured off Port Moller (1956-60).

Year	Dates	No.	Size Range	Bottom Temp. C°
1956	6/13-20	208	5 mm to 32.8 mm	1.57 - 1.86
1957	5/29-6/15	3,084	less than 20 mm	3.47
1958	5/29-6/18	2,172	----	3.75
1959	6/27-7/1	36	----	----
1960	6/1-7/6	506	9 mm to 16.6 mm	----

Data source: Fishery Agency of Japan (1963).

Korolev (1964) reported on the capture of eastern Bering Sea juvenile crabs 0.5-1.0 mm carapace diameter in sponges. These sizes are less than the minimum size of the first instar (2 mm) reported by other investigators. Trawl catches of crab 2.5-7 cm were also reported by Kosolev to be associated with sponges and hydroids. Because of the apparent need of megalopae and small juveniles to associate with these organisms, he concluded that the main region for crab reproduction must be eastward of a longitude which is slightly west of 161°25'W. This is apparently an area where large concentrations of sponges and hydroids occur, the northern limits of which run 60 to 70 miles from the coast of the Alaska Peninsula (Korolev, 1964).

Juvenile king crab are widely distributed over a large area of the northern Aleutian Shelf during the spring migration and spawning periods (Fig. 30). Adult males and females had similar distributions and formed areas of high density. The distribution of juveniles showed only one or two areas of relatively high abundance and their distribution seemed unrelated to that of the adults.

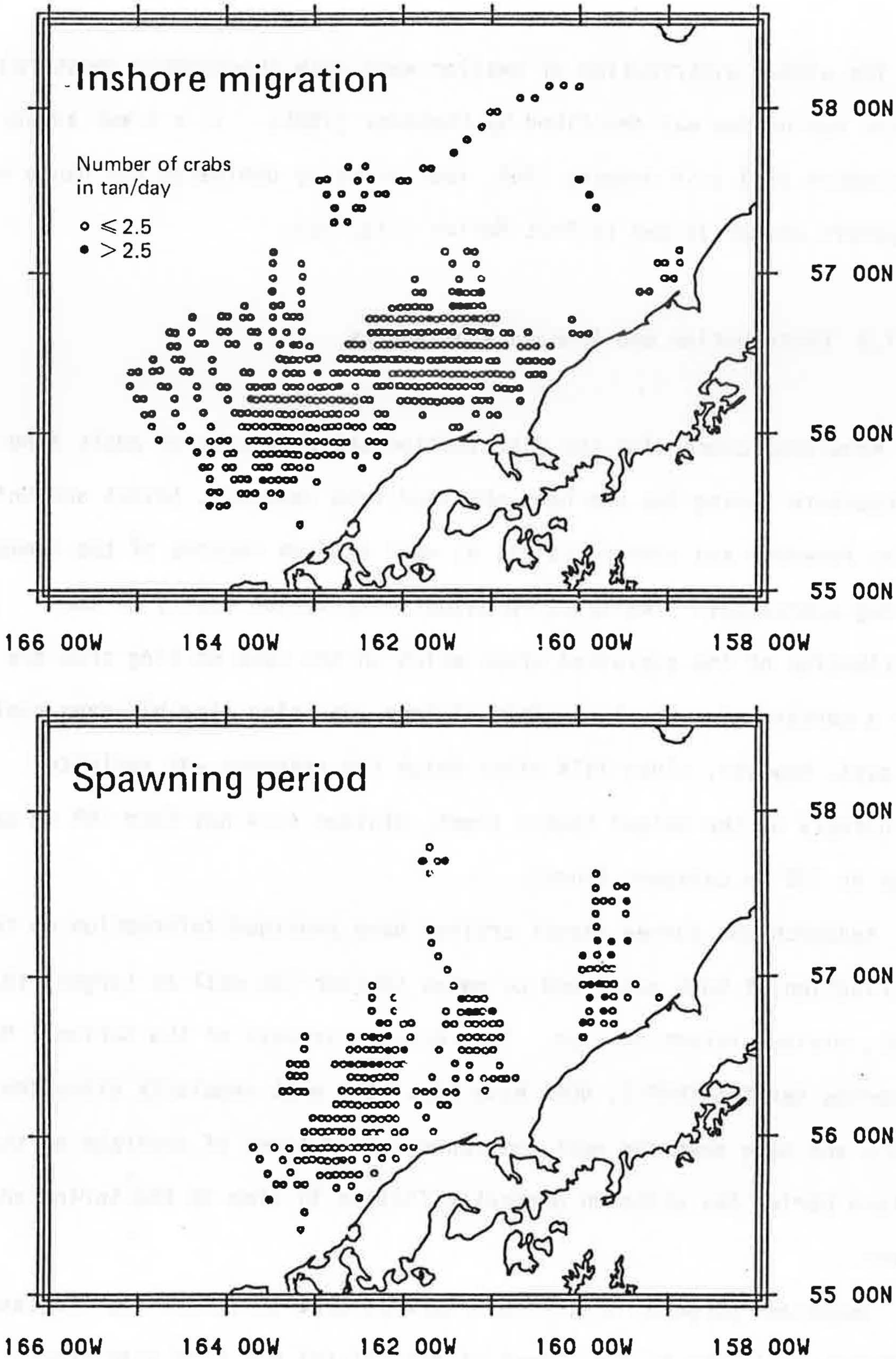

Figure 30. Distribution of juvenile crab during the spring migration and spawning seasons.

The winter distribution of smaller male crab (presumably immature) in eastern Bering Sea was described by Chebanov (1965). In a trawl survey from 15 December 1963 to 4 January 1964, smaller males dominated the hauls eastward of eastern Unimak Island to Port Moller (Fig. 31).

7.3 Distribution and Abundance of Adults

Knowledge concerning the distribution and abundance of adult king crab in southeastern Bering Sea was been obtained from Japanese, Soviet and United States research and survey cruises as well as from records of the commercial fishing operations. The latter provides information mostly on the distribution of the exploited stock which in the case of king crab are males over a certain minumum size. This minimum retention size has been smaller in the past, however, since 1974 after which the resource was exploited exclusively by the United States fleet, minimum size has been 165 mm carapace width or 135 mm carapace length.

Research and survey vessel cruises have provided information on the distribution of both sexes and on males smaller (as well as larger) than the legal, minimum retention size. The resource surveys of the National Marine Fisheries Service (NMFS), NOAA have been done most regularly since the early 1970's and have been the most comprehensive in terms of coverage of the eastern Bering Sea although generally limited in time to the spring and summer.

Important purposes of the MNFS surveys were to assess and forecast stock condition as inputs to management of the Bristol Bay king crab stock. As such, information on the distribution of king crab has been obtained for the

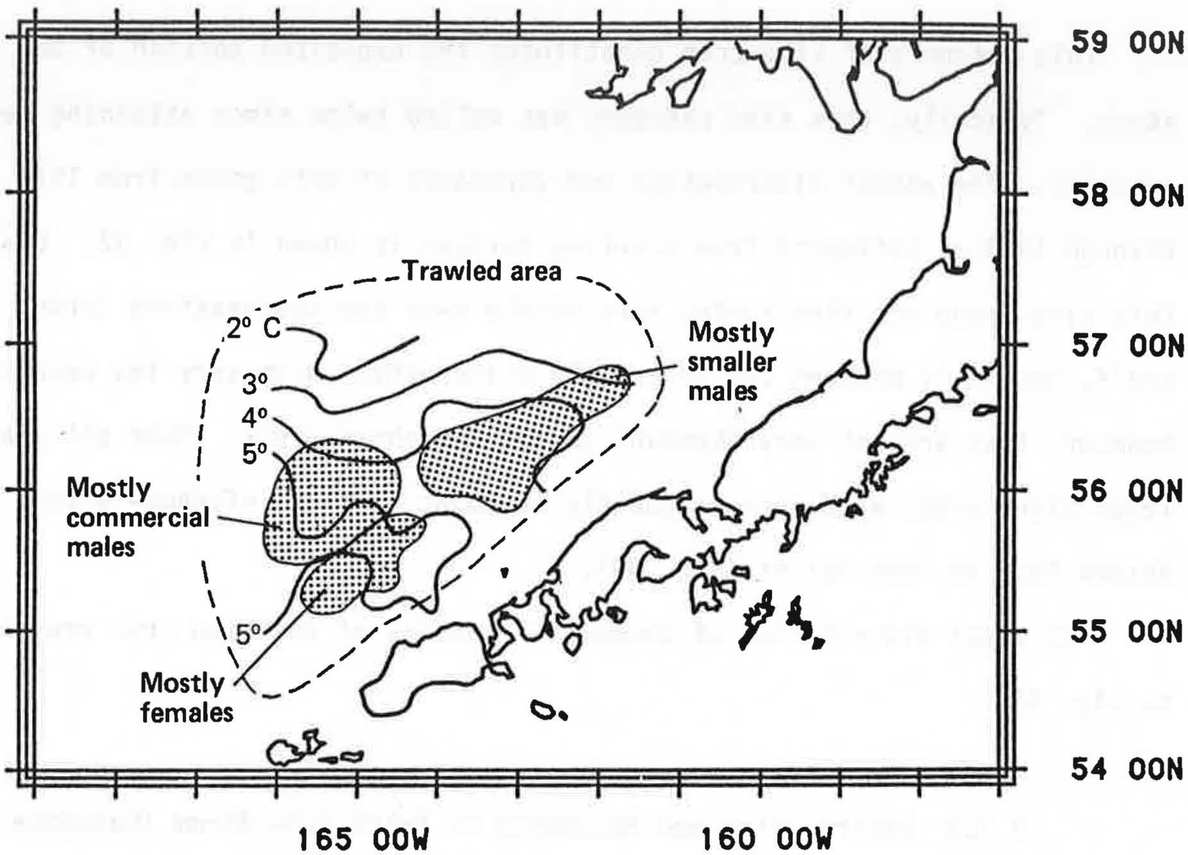

Figure 31. Winter distribution of king crab.

following five size and sex categories which are of relevance to the current management rationale for the eastern Bering Sea stock.

7.3.1 Distribution and Abundance of Legal-size Males over 134 mm (Carapace Length).

This category of king crab constitutes the exploited portion of the stock. Typically, this size category has molted twice since attaining sexual maturity. The annual distribution and abundance of this group from 1973 through 1983 as estimated from trawling surveys is shown in Fig. 32. Crabs of this size group are distributed very widely over the southeastern Bering Sea shelf, generally between the 50 and 100 m isobaths. With very few exceptions, however, they are not very abundant in the nearshore areas. Over all years, legal sized crabs were most frequently abundant in those offshore waters off Unimak Pass to Port Moller (Fig. 33).

The areal distribution of commercial catches of red king crab are shown in Fig. 34.

7.3.2 Distribution and Abundance of Males 110-135 mm (Carapace Length).

Crabs in this size category are sexually mature but below the minimum size for retention by the fishery. Their overall distribution and areas of highest density are quite similar to those for the legal sized male crab (Fig. 35). Areas of greatest abundance occur in the more offshore waters north of Unimak Island and Isembeck Lagoon to Port Moller (Fig. 36).

KING CRAB
1973–78
Males > 134 mm
Catch in number/mi^2

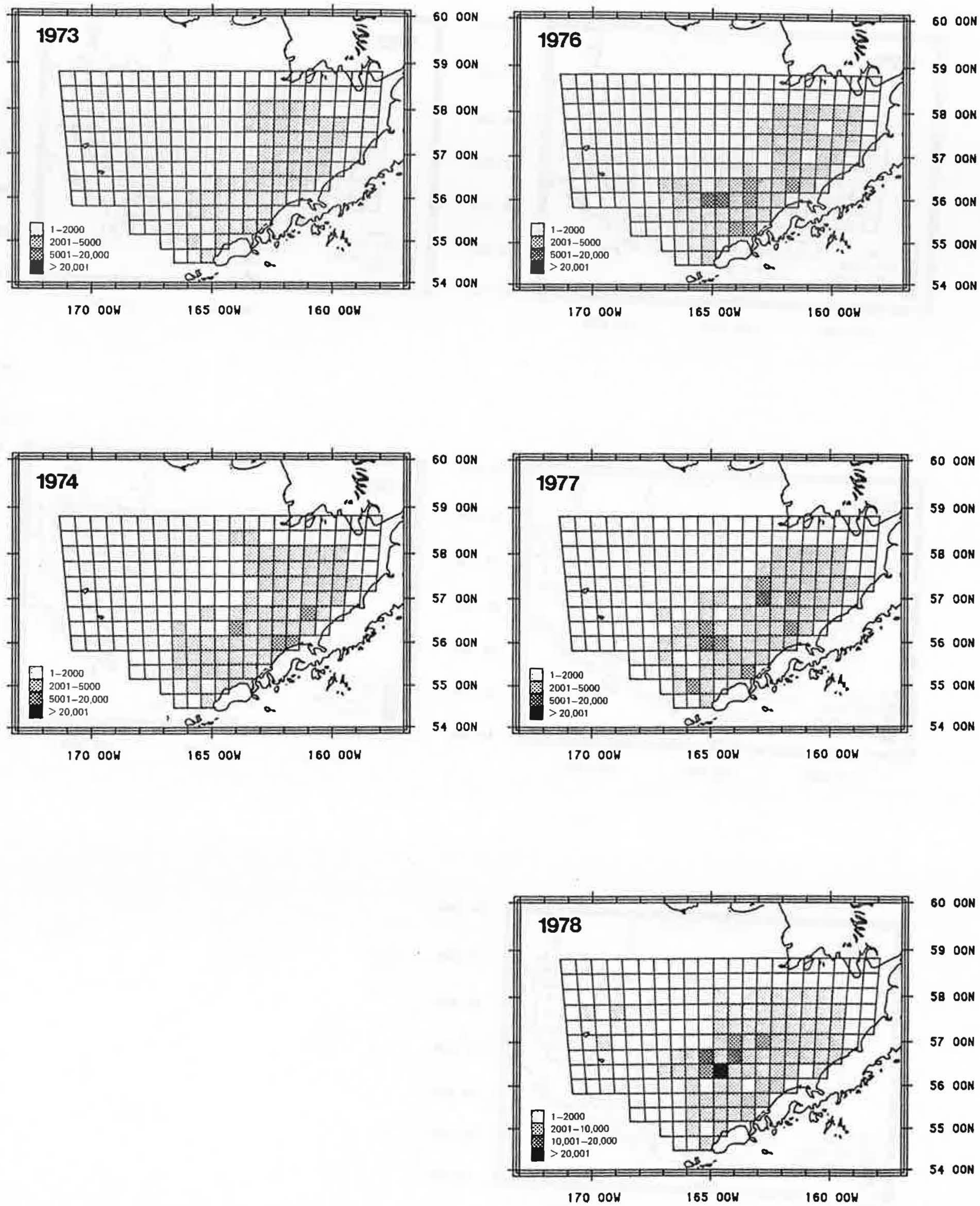

Figure 32. Annual distribution of legal males (>134 mm carapace length), 1973-83.

KING CRAB
1979–83
Males > 134 mm
Catch in number/mi²

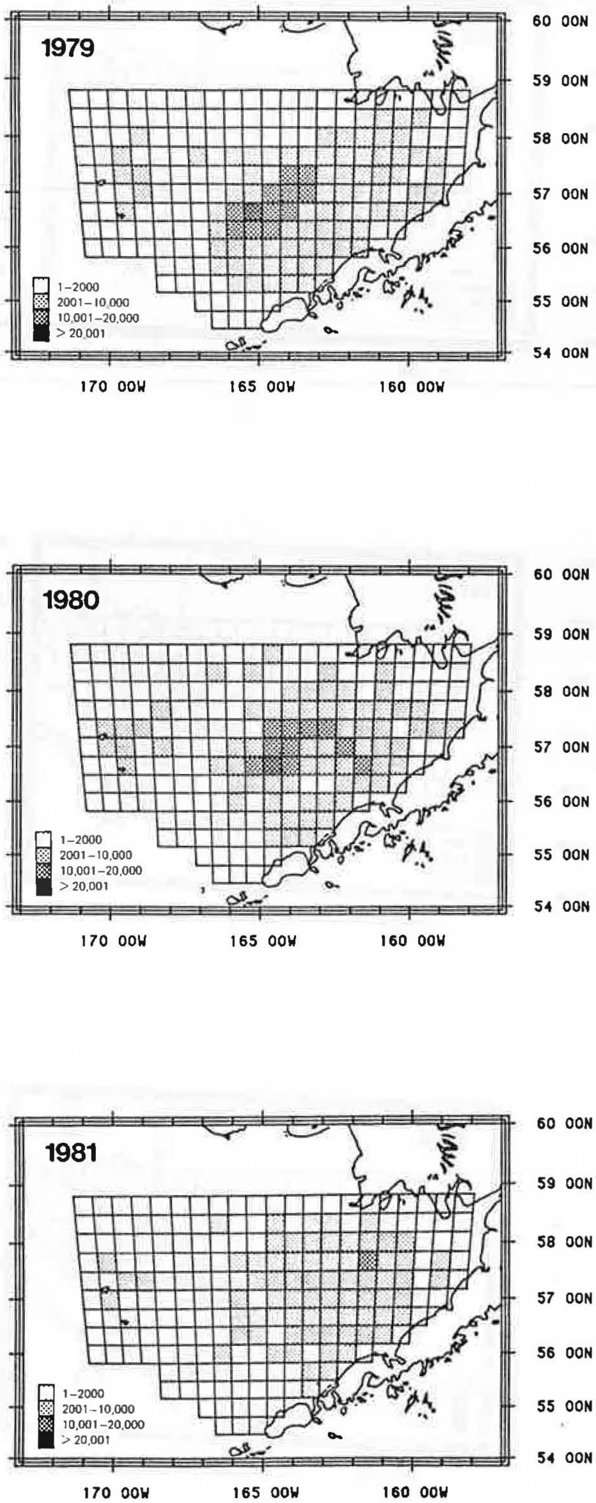

Figure 32. Continued.

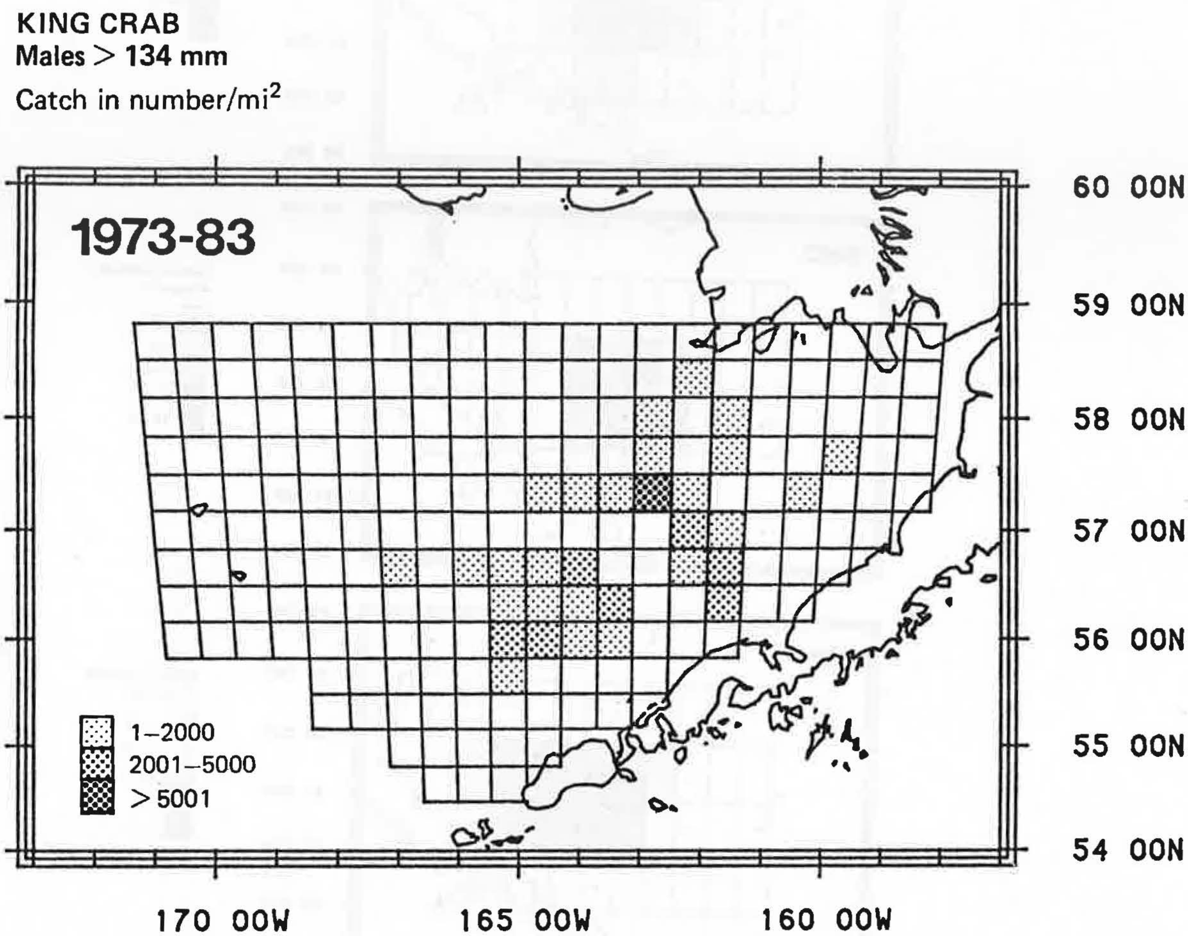

Figure 33. Areas of greatest abundance of legal males, 1973-83.

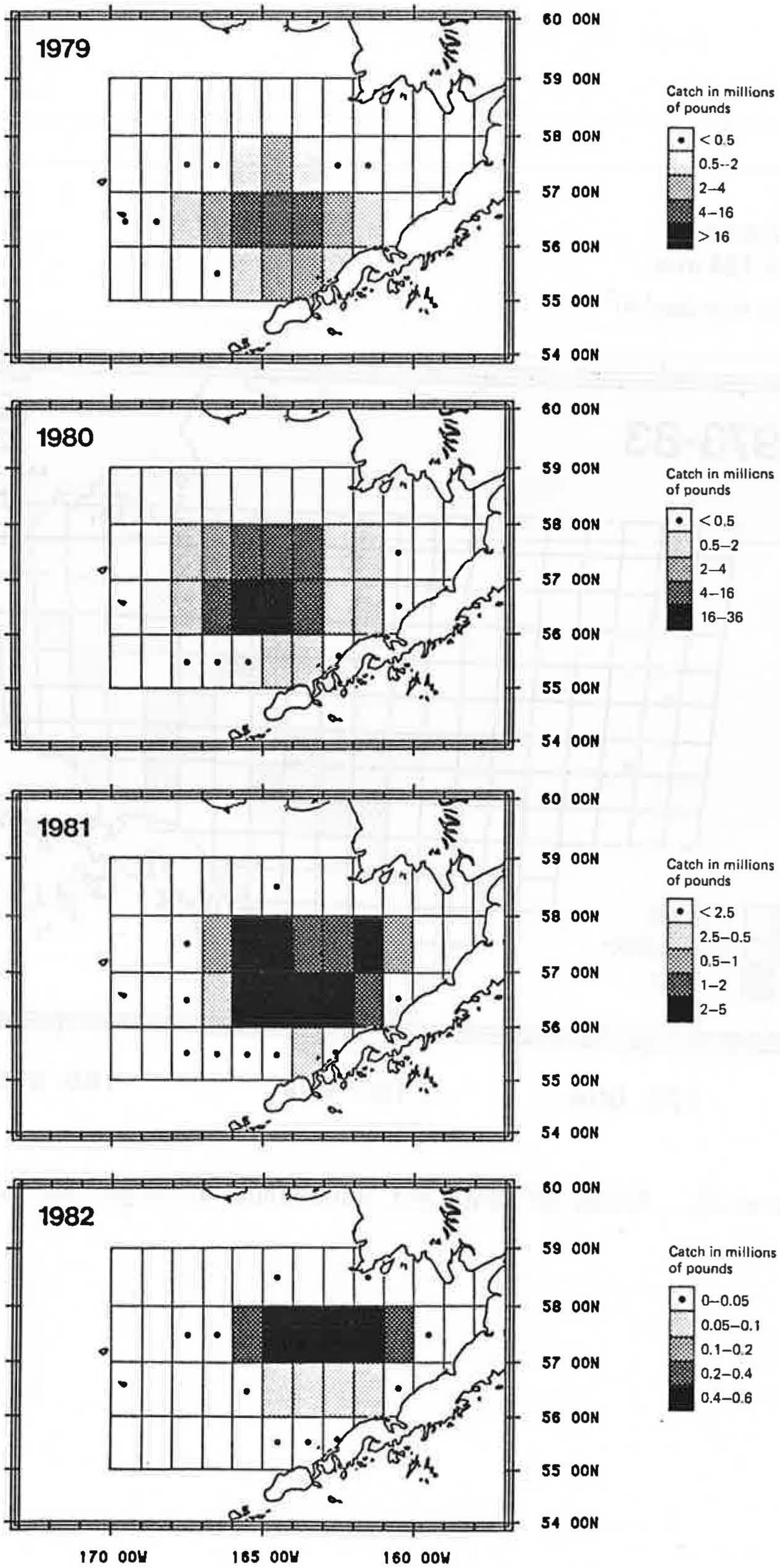

Figure 34. Areas of commercial catch of red king crab in eastern Bering Sea, 1979-82.

KING CRAB
1979–83
Males 110–135 mm
Catch in number/mi^2

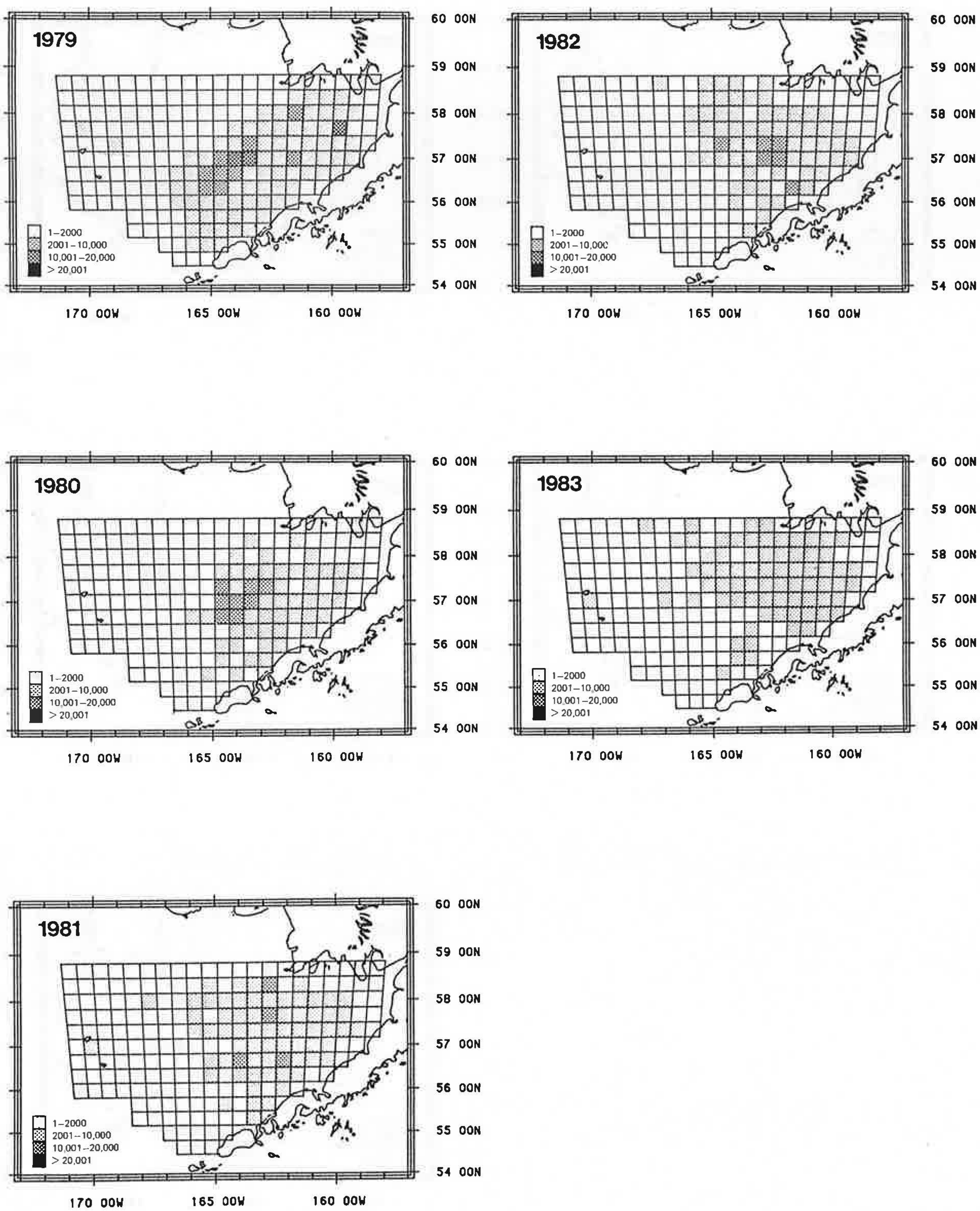

Figure 35. Distribution of male king crab 110 mm to 135 mm carapace length, 1973-83.

KING CRAB
1973–78
Males 110–135 mm
Catch in number/mi^2

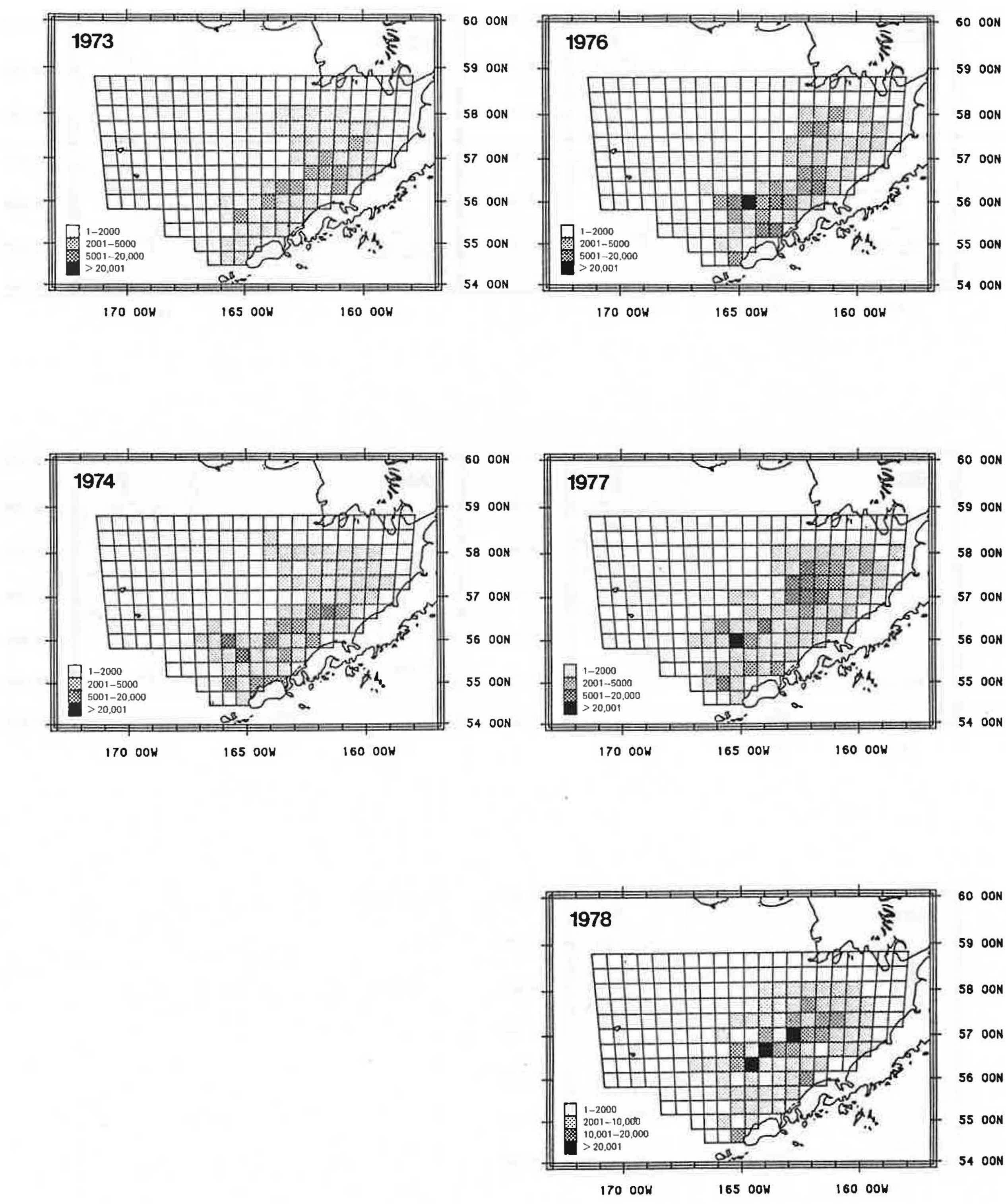

Figure 35. Continued.

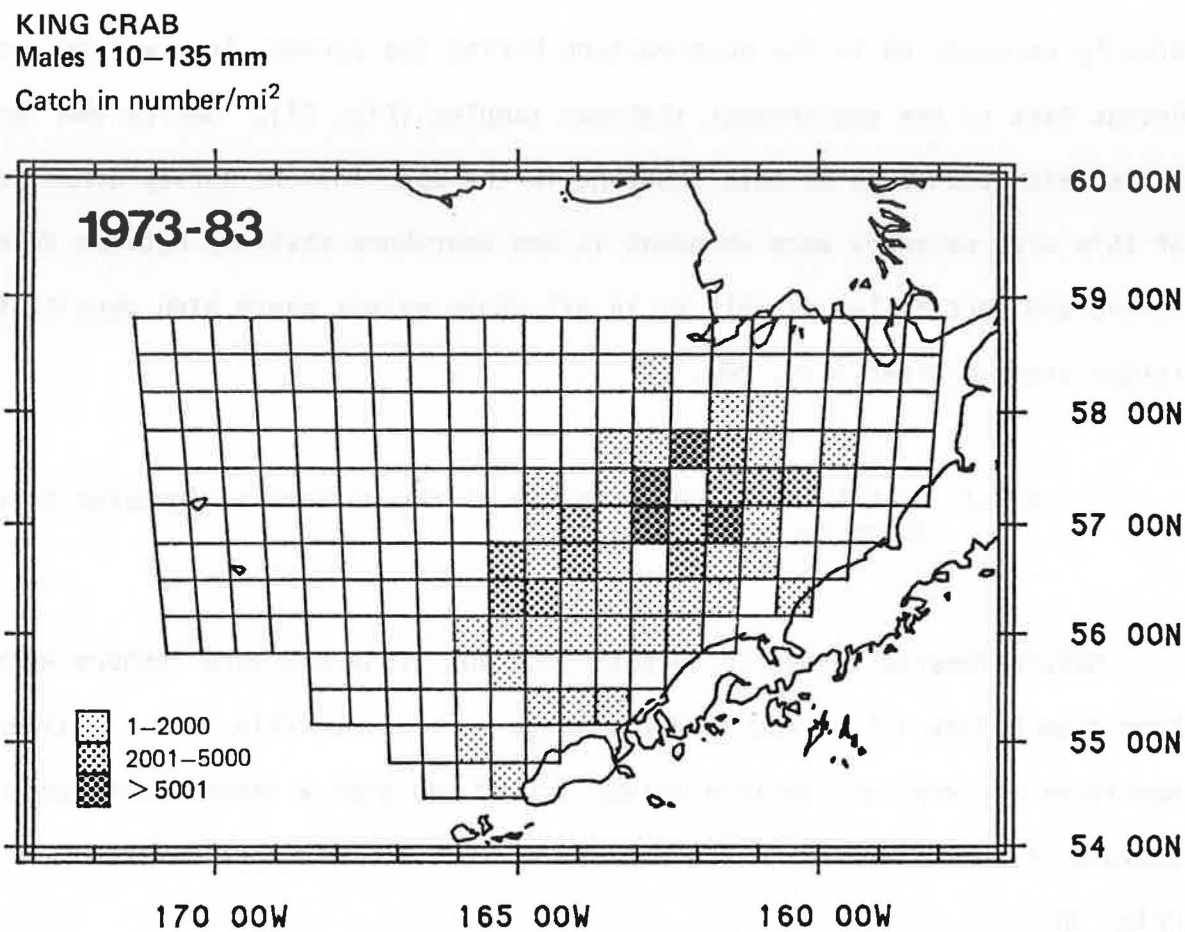

Figure 36. Areas of greatest abundance of males 110 mm to 135 mm carapace length, 1973-83.

7.3.3 Distribution and Abundance of Males less than 110 mm (Carapace Length).

Sexually immature male crab (less than 110 mm carapace length) were broadly encountered in the southeastern Bering Sea surveys from waters west of Unimak Pass to the easternmost stations sampled (Fig. 37). Unlike the larger males which tended to be less abundant in the more inshore survey areas, crabs of this size category were abundant in the nearshore stations between Unimak Island and Port Moller as well as in off shore waters where high densities of larger crab occurred (Fig. 38).

7.3.4 Distribution and Abundance of Mature Females (greater than 89 mm carapace length).

Mature females tended to be most abundant along the more inshore waters from from Unimak Island eastward almost to Port Heiden (Fig. 39). Maximum densities occurred off western Unimak Island and over a rather large area seaward of the Alaska Peninsula between Black Hill and Cape Seniavin (Fig. 40).

7.3.5 Distribution and Abundance of Immature Females (less than 90 mm carapace length).

Immature female king crab were broadly distributed from Unimak Pass to inner Bristol Bay (Fig. 41). They were most abundant in the nearshore areas westward of Cape Seniavin as well as in offshore waters north of Black Hill-Port Moller (Fig. 42).

KING CRAB
1973–78
Males < 110 mm
Catch in number/mi²

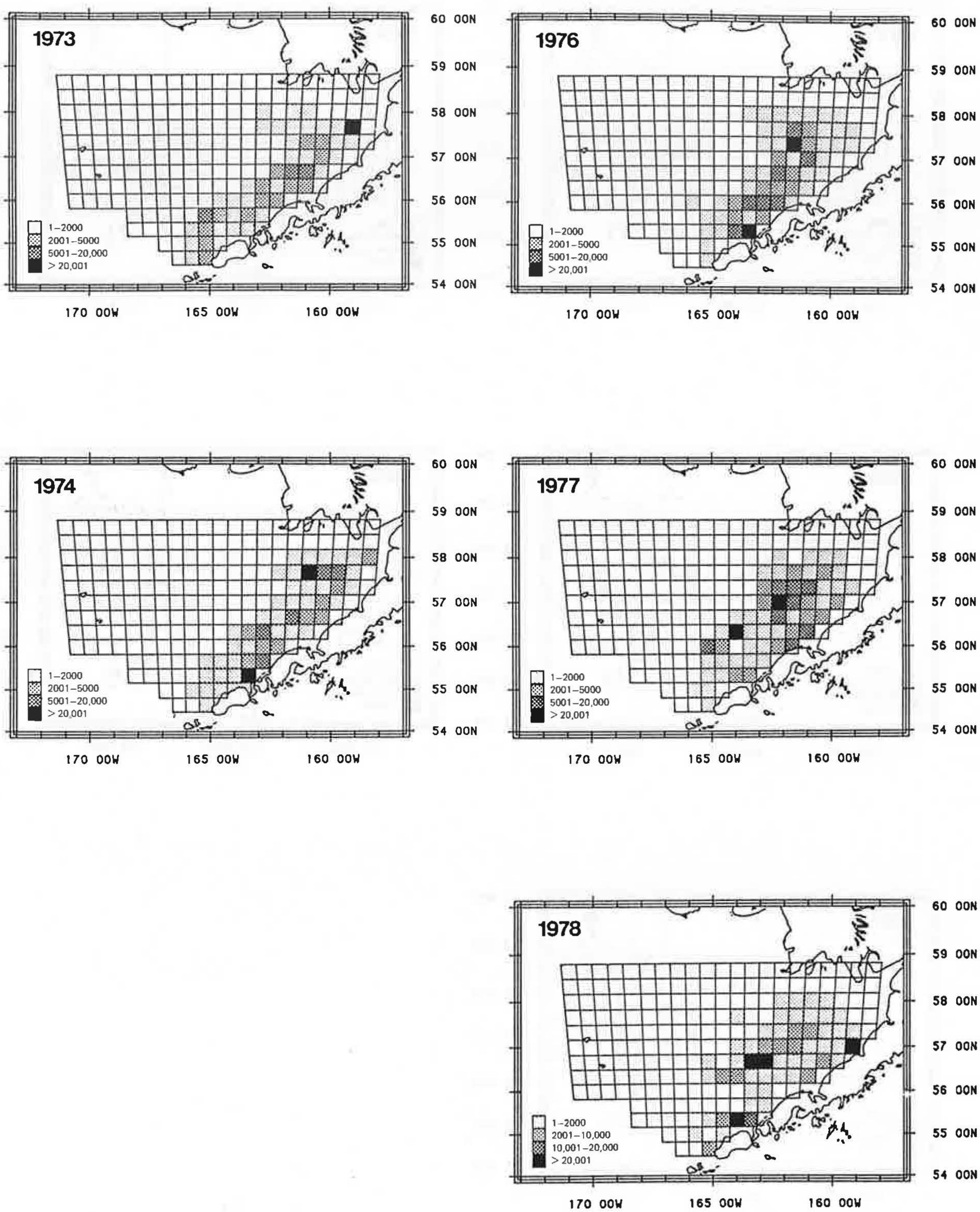

Figure 37.--Distribution of male king crab <110 mm carapace length, 1973-83.

KING CRAB
1979–83
Males < 110 mm
Catch in number/mi^2

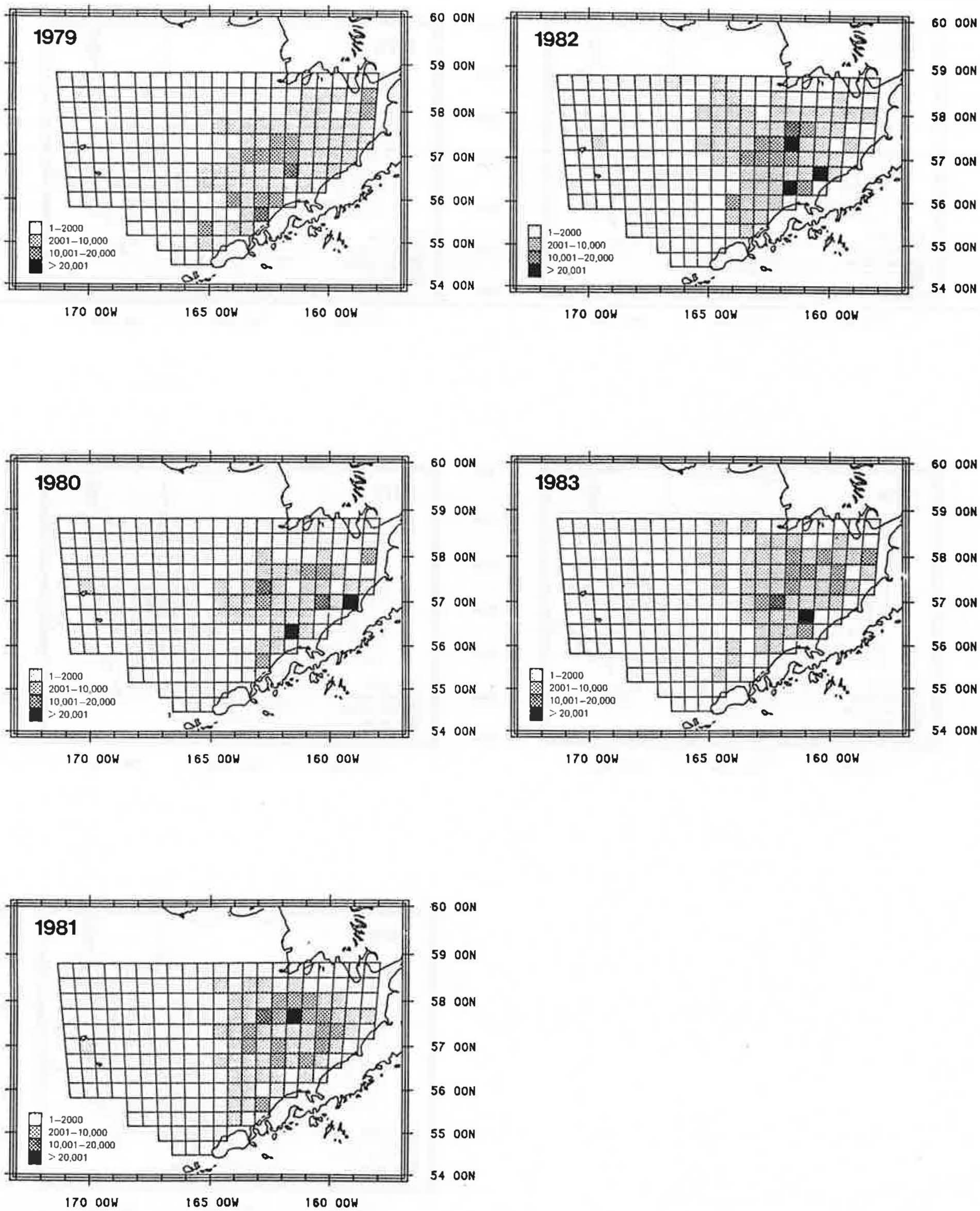

Figure 37.--Continued.

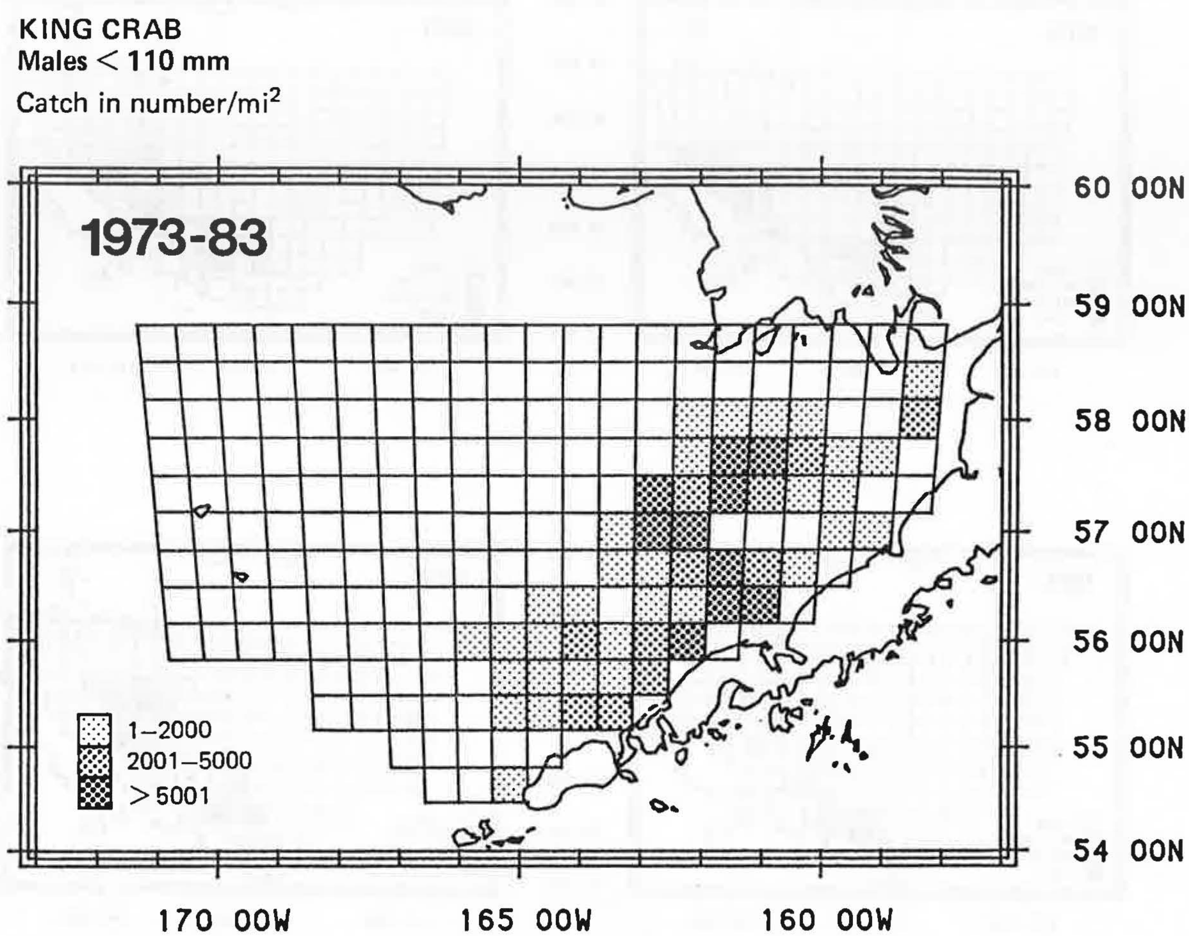

Figure 38. Areas of greatest abundance of males <110 mm carapace length, 1973-83.

KING CRAB
1973–78
Females > 89 mm (> 99 mm for 1973 and 1974)
Catch in number/mi^2

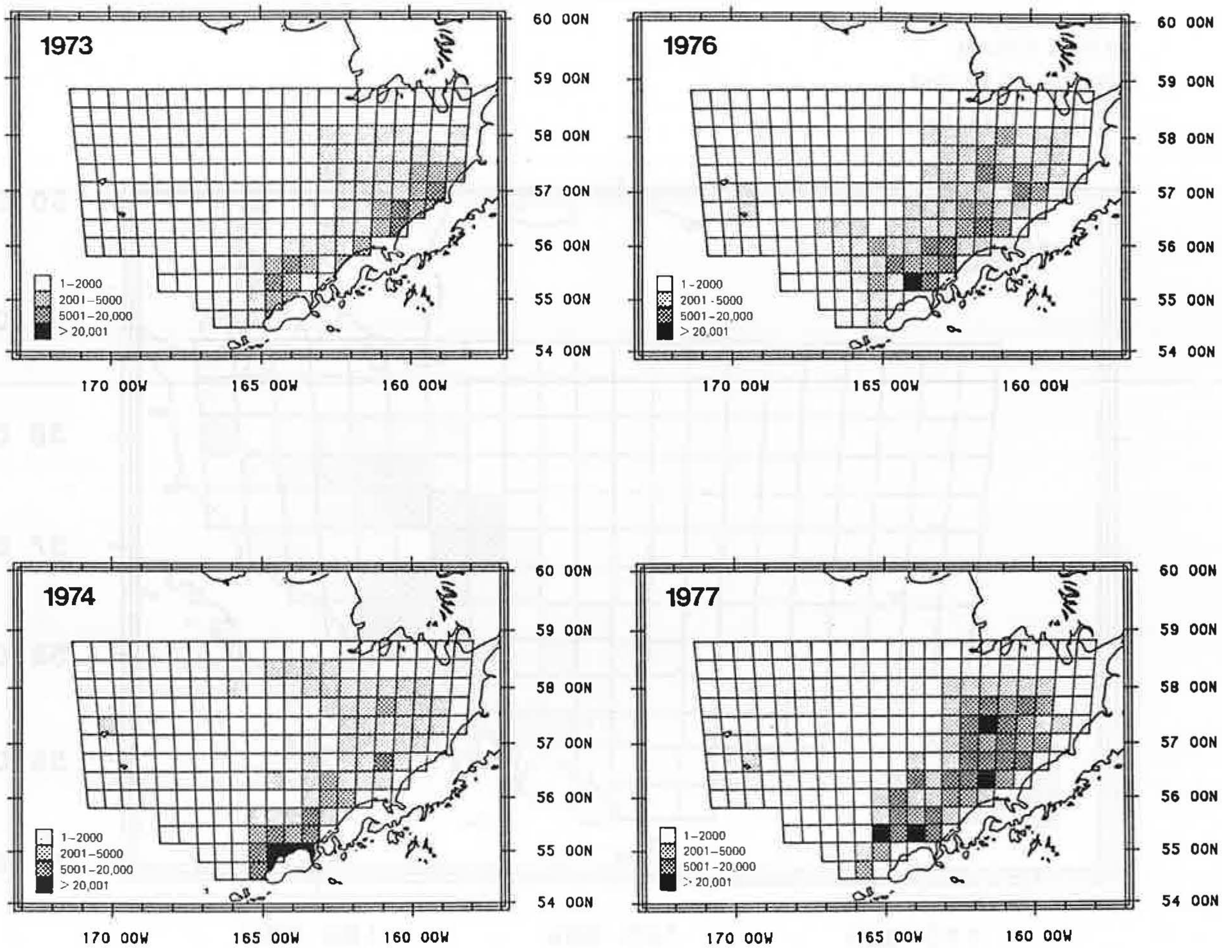

Figure 39. Distribution of female king crab >89 mm carapace length, 1973-83.

KING CRAB
1979–83
Females > 89 mm (> 99 mm for 1973 and 1974)
Catch in number/mi²

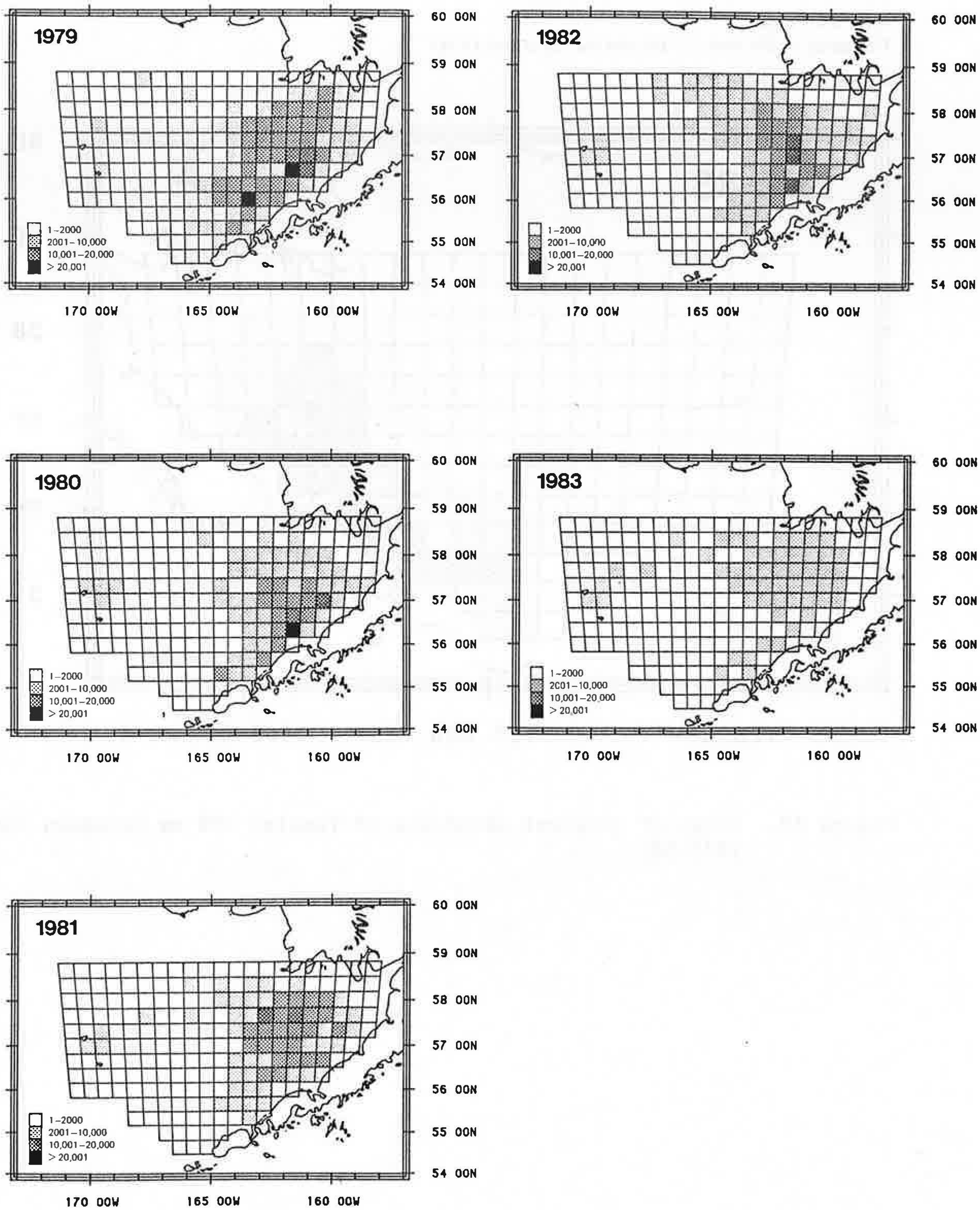

Figure 39. Continued.

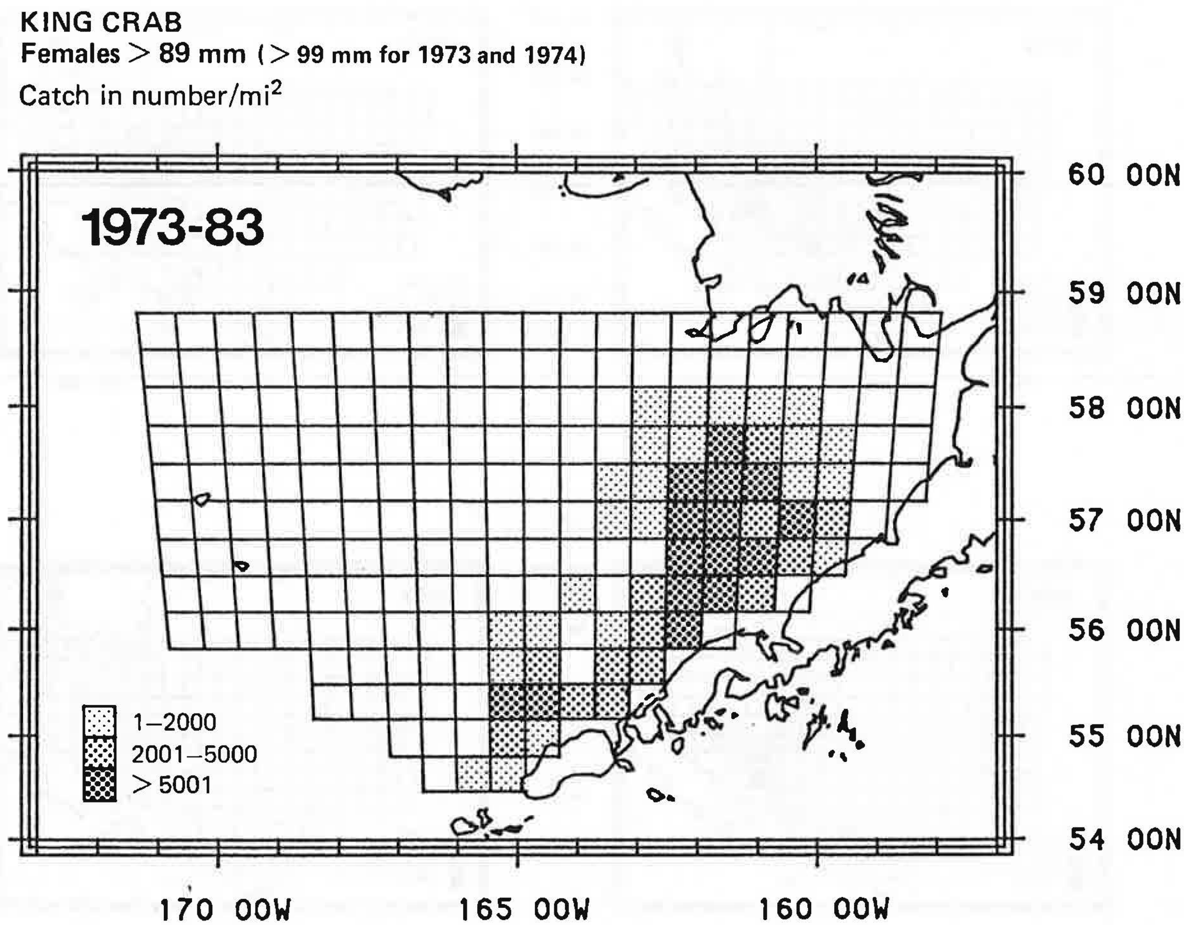

Figure 40. Areas of greatest abundance of females >89 mm carapace length, 1973-83.

KING CRAB
1973–78
Females < 90 mm (< 89 mm for 1973 and 1974)
Catch in number/mi^2

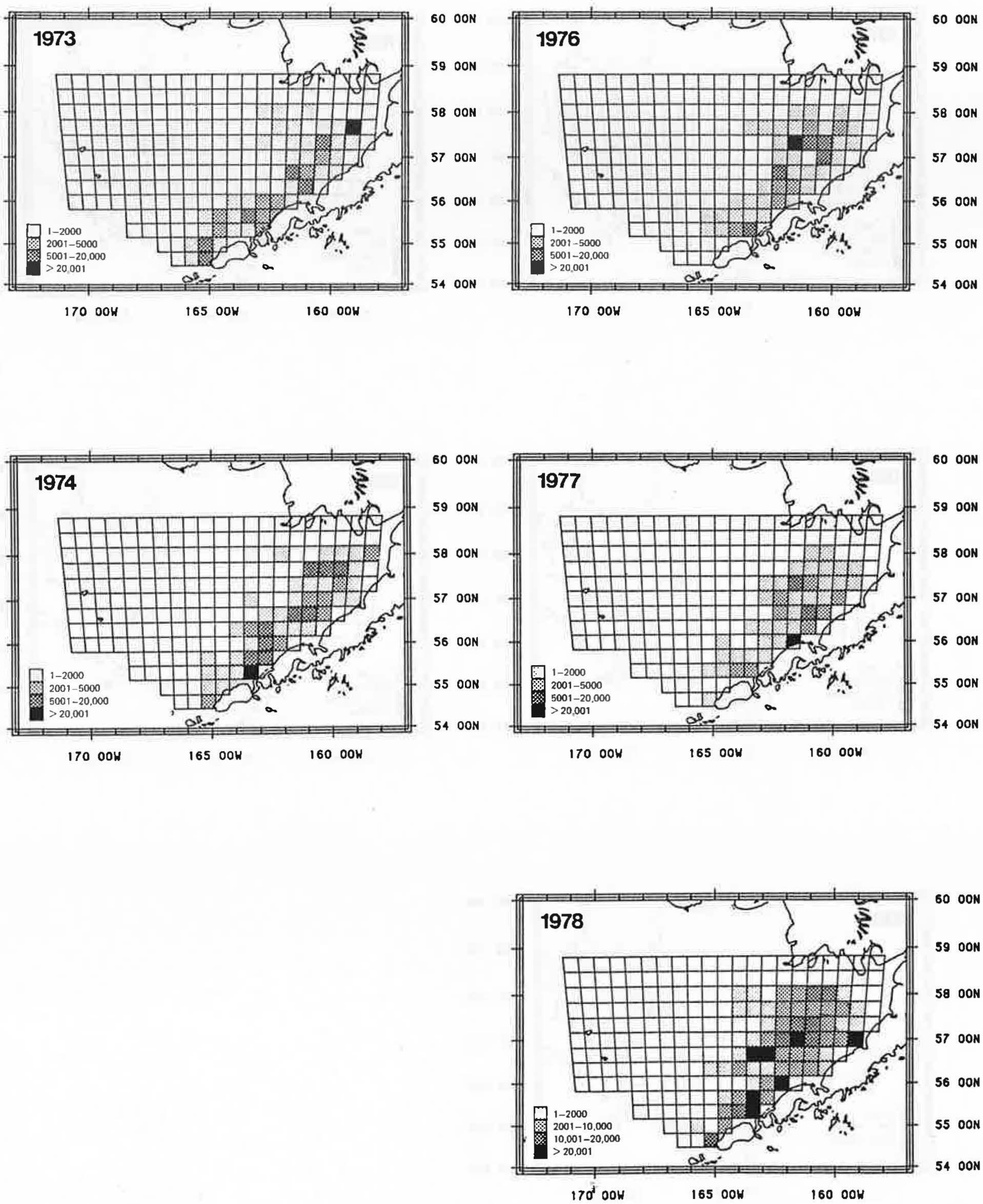

Figure 41. Distribution of immature females (<90 mm carapace length), 1973-83.

KING CRAB
1979–83
Females ≤ 90 mm (< 89 mm for 1973 and 1974)
Catch in number/mi^2

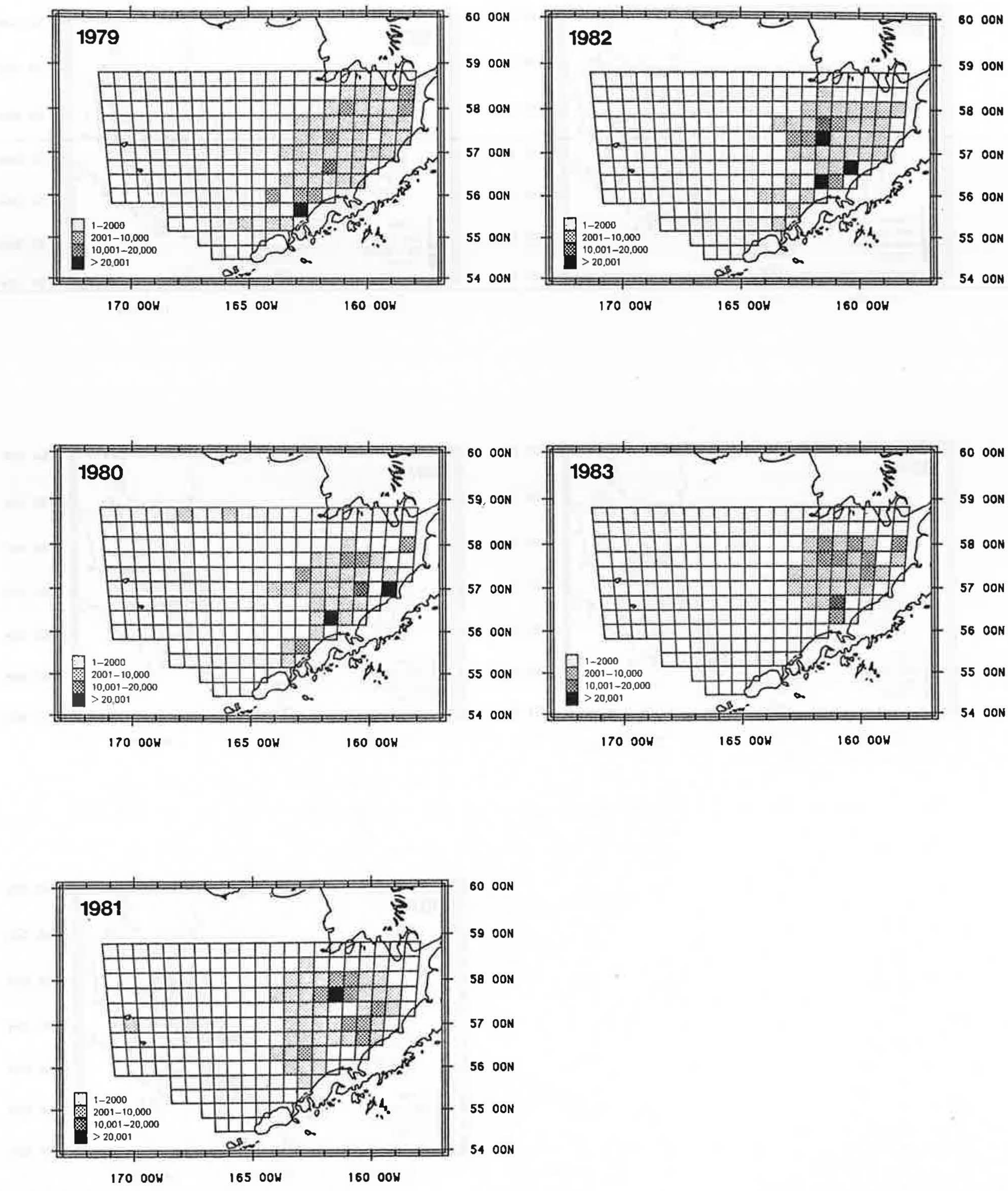

Figure 41. Continued.

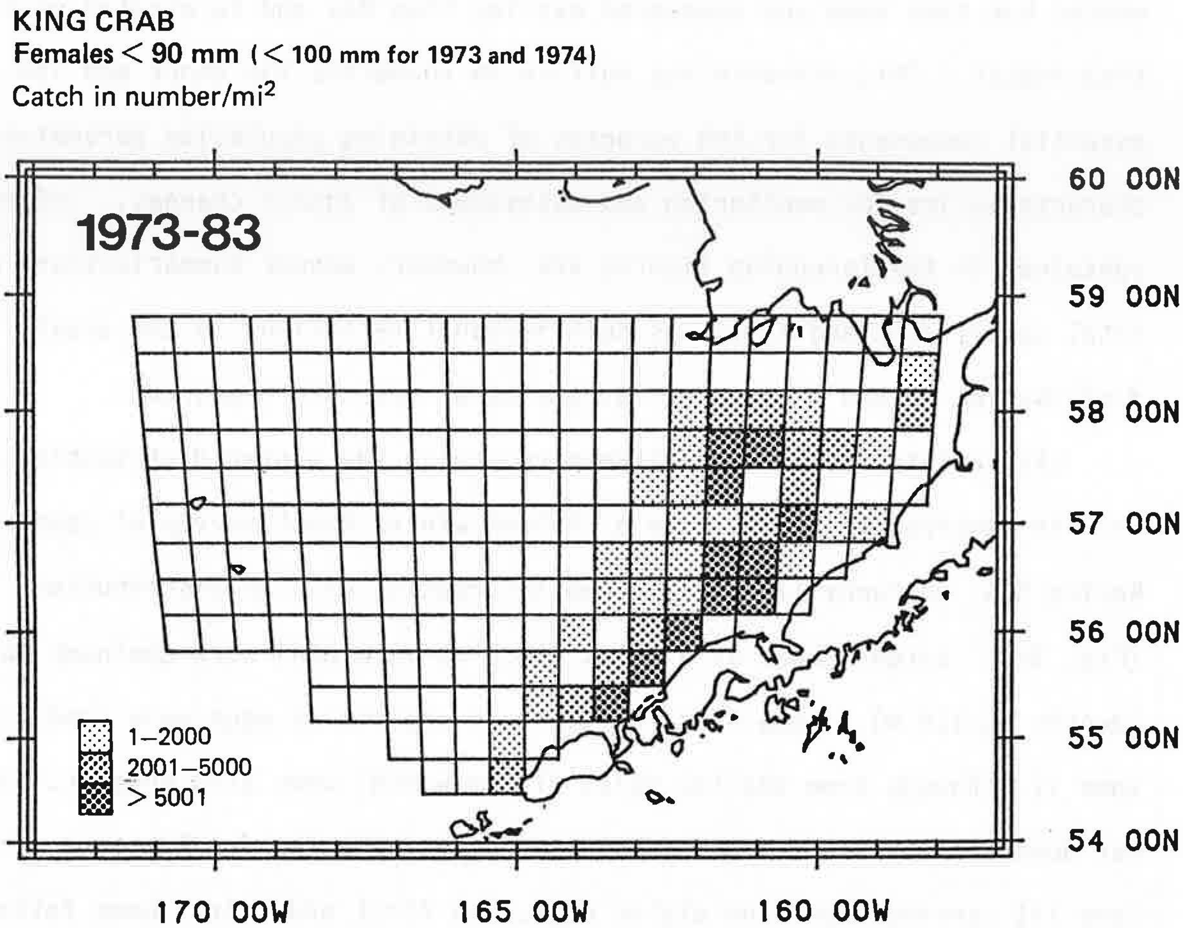

Figure 42. Areas of greatest abundance of immature females (<90 mm carapace length), 1973-83.

The NMFS studies survey many species of commercial importance other than king crab, therefore, the area surveyed is far larger than the habitat of that species. Also, the surveys have mostly been done in the spring and summer months but they have not commenced earlier than May and terminated no later than August. This schedule may suffice to enumerate the stock and its essential components for the purposes of obtaining population parameters and characteristics for monitoring and assessment of annual changes. Information contained in the foregoing figures are, however, annual summarizations over total survey area and time. As such seasonal variations in the areal distribution of the 5 size-sex categories of crab are obscured.

Little information is available regarding the winter distribution of king crab in eastern Bering Sea. In a 1963-64 winter trawl survey of eastern Bering Sea, Chebanov (1965) obtained information on crab distribution (Fig. 31). Larger legal size males (16.5 cm in width) were dominant in Zone I (depths 95-118 m). Females carrying brown and violet eggs were predominant in Zone II although some smaller males (14 cm width) were also present. Zone III was dominated by small males (90-95 m depth). The few females taken in Zone III carried brown and violet eggs. The first and third zones followed closely the 4° and 5°C isotherms while the predominant temperature in Zone II was 5°C.

Chebanov (1965) hypothesized that newly molted crab require calcium which is available from Ophiura sarsi (a brittlestar). He, therefore, reasoned that the distribution of king crab in the eastern Bering Sea would be associated with this species during or immediately after molting. After calcium deficits were met, crabs switch to a diet of molluscs.

8. THE SOUTHEASTERN BERING SEA RED KING CRAB FISHERY

8.1 History of the Fishery

The history of the eastern Bering Sea crab fishery has been described by Miyahara, 1954; Hoopes, 1970; Balsiger, 1974. The most recent and comprehensive review was given by Otto (1981).

Commercial exploitation of king crab in the eastern Bering Sea was initiated by Japanese interests in 1930. There was no operation in 1931 but the fishery recommenced in 1932 and continued through 1939. This fishery consisted of 1 or 2 factoryships which caught and processed a maximum of 2.1 million crab in 1933 to a minimum of 242 thousand crab in 1939 (Table 18). After a hiatus of 13 years, exploitation of eastern Bering Sea red king crab resumed in 1953 with a United States fishery consisting of a small trawler/processor and a Japanese expedition consisting of one large factoryship, 6 small tanglenet boats and 6 small trawlers (Miyahara, 1954). The United States fishery in eastern Bering Sea diminished to zero in 1959 and remained at low levels until after 1970. The Japanese fishery dominated catches until 1970, declined thereafter and stopped catching king crab after 1974. Soviet fisheries operated for 13 years from 1959 through 1971.

Post World War II landings of king crab from the eastern Bering Sea are summarized in Fig. 43. The total landings are characterized by modal catch of 26.8 thousand mt in 1964, a decline to 8.6 thousand mt in 1971, a steady and sharp increase to a maximum of 58.9 thousand mt in 1980, followed by a precipitous decline to 15.2, 1.4 mt and to zero mt in 1981, 1982 and 1983, respectively. The total catch through 1970 reflects the landings of the

Table 18.--Catch and pack of Japanese floating factoryships in the Bering Sea, 1930-39.

Year	Ships Operated	Ship Days Operated	Crabs Caught	Cases Packed 1/
	....	(Number)	....	....
1939	1	37	241,791	6,206
1938	1	67	461,040	13,385
1937	1	74	485,900	13,148
1936	1	51	290,900	7,849
1935	1	139	746,450	15,504
1934	2	242	1,347,025	30,364
1933	2	289	2,088,998	49,396
1932	1	125	1,178,280	34,365
1931	0	0	0	0
1930	1	95	1,001,600	24,572

1/ One case is equal to 96 1/2 lb. cans or 48 1-lb. cans.

Note: Information obtained from Japanese Fisheries Agency.

Source: Miyahara (1954)

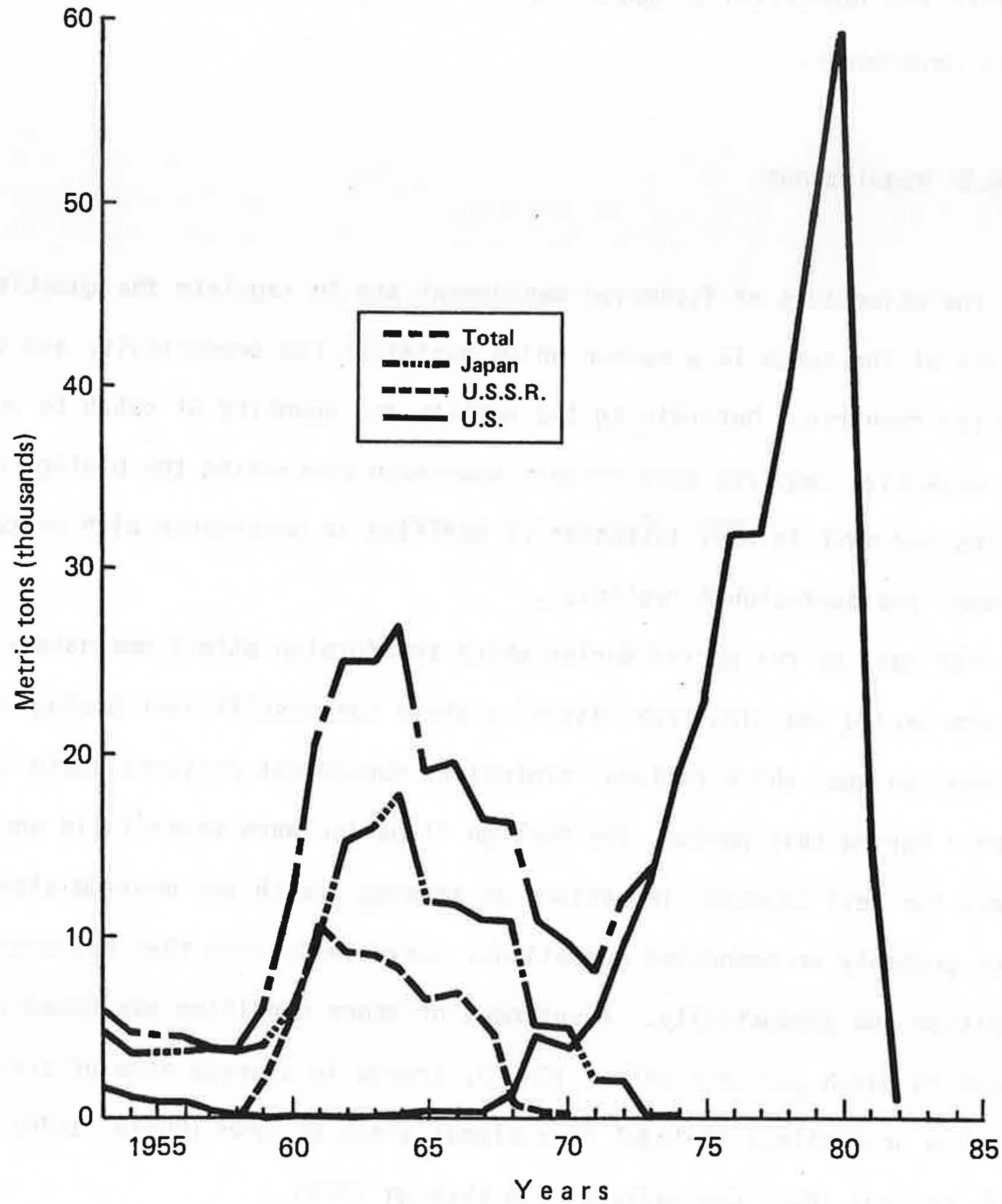

Figure 43. Annual all-nation red king crab catch in eastern Bering Sea, 1958-82.

foreign fisheries (particularly Japan). The total catch after 1974 was, of course, exclusively that of the United States fishery. The decline after 1964 reflects the imposition of quotas on the foreign fisheries by the United States government.

8.2 Regulations

The objectives of fisheries management are to regulate the quantity and quality of the catch in a manner which maximizes the productivity and yield from the resource. Determining the quality and quantity of catch to achieve this objective requires considerable knowledge concerning the biology of the species and must in many instances be modified in accordance with certain economic and operational realities.

For most of the period during which the foreign effort dominated the eastern Bering Sea king crab fisheries there was insufficient biological information upon which rational biological management measures could be based. During this period, the foreign fisheries were essentially unregulated except for self imposed limitations on seasonal catch and minimum size limits which probably accommodated operational convenience more than resource condition and productivity. Assessment of stock condition was based upon trends in catch per unit effort (CPUE), trends in average size of crab, and relative proportions of legal to sublegal sizes of crab (Rodin, 1970; Korolev, 1964; various INPFC Proceedings 1955 through 1974).

In 1964, the United States ratified the International Convention of the Continental Shelf (April 29, 1958) and declared king and Tanner crab as creatures of the United States continental shelf. As a consequence, quotas and other regulations were imposed in the eastern Bering Sea crab fishery through bilateral, executive agreements between the Government of the United States and the Governments of Japan and the Union of Soviet Socialist Republics, respectively.

Since 1974, the fishing has been exclusively by the United States fleet and subject to regulation by the Alaska Department of Fish and Game and the since 1976 by the North Pacific Fisheries Management Council (NPFMC) established by the Fisheries Conservation and Management Act of 1976 (FCMA-1976) under the authority of which the United States extended authority for management of fisheries stocks seaward to 200 miles. As required under this law, a fisheries management plan (FMP earlier referred to as NPFMC KC DFMP-1981) for eastern Bering Sea king crab was drafted in November 1981 which specified all considerations relevant to the rational management of stocks and orderly conduct of fisheries. Although statutory authority for management under FCMA was vested in the Secretary of Commerce, the NPFMC suggested that the State of Alaska develop the regulatory and management process subject to Council and Secretarial (Dept. of Commerce) review. It was also suggested that the implementation of the provisions of the FMP be delegated to the State of Alaska to avoid unnecessary and expensive duplication of effort and to utilize the established expertise of State biological, management and enforcement personnel.

The objectives and rationale for the management of eastern Bering Sea king crab, regulatory measures necessary to achieve these ends are discussed in detail in the NPFMC KC DFMP-1981. The DFMP also discusses in detail some reporting and inspection requirements which are necessary to assure compliance to regulations. Other considerations to minimize vessel, gear, and interfishery conflicts are also discussed.

Essential regulations for the king crab fishery in The Bristol Bay District (Statistical Area T) as cited in Article 12 of the 1982/83 edition of the Regulations of the Alaska Board of Fisheries for Commercial Fishing in Alaska is shown in Table 19.

8.3 Fishing Methods and Effort

Eastern Bering Sea king crab have been exploited by distant water fisheries utilizing factoryships and catcher boats and by the United States fleet which is an aggregation of independently operated vessels which typically deliver and sell catches to shorebased processing plants. Most crab were taken either in tanglenets or pots (traps) although some trawling was also utilized.

8.3.1 The Japanese Fishery

The Japanese fisheries in eastern Bering Sea were described by Miyahara (1954). The fleet composition, effort and catch for the Japanese fishery from 1953 through 1974, the last year of operation is given in the following table.

Table 19

ARTICLE 12
STATISTICAL AREA T (BRISTOL BAY AREA)
REGULATIONS FOR REGISTRATION AREA

5 AAC 34.800. DESCRIPTION OF STATISTICAL AREA. Statistical area T has as its northern boundary the latitude of Cape Newenham (58°39'N lat), as its southern boundary the latitude of Cape Sarichef (54°36'N lat), as its western boundary 168° W long and includes all waters of Bristol Bay.

Authority: AS 16 05 251(a)(2)

5 AAC 34.810. FISHING SEASONS. (a) After an opening time and date for taking king crab set forth in (b) of this section, no person may possess or transport aboard any registered king crab vessel or any tender, any species of king crab until that vessel has complied with the inspection provisions of sec. 30(b) of this chapter.

(b) Red, blue and brown king crab 6 1/2 inches (165 mm) or larger in width of shell may be taken or possessed from 12:00 noon September 10 through April 15 unless closed earlier by emergency order, except that red, blue and brown king crab seven inches (178 mm) or greater in width of shell may be taken or possessed during periods opened and closed by emergency order.

Authority: AS 16 05 060
AS 16 05 251(a)(2),(3)

5 AAC 34.815. HARVEST STRATEGY. This department shall manage the king crab fishery for a harvest of approximately 60 percent of the estimated population of legal size male red and blue king crab.

Authority: AS 16.05.251(a)(2),(3)

5 AAC 34.820. SIZE LIMITS (a) Male red, blue and brown king crab 6 1/2 inches (165 mm) or greater in width of shell may be taken or possessed.

(b) Male red, blue and brown king crab seven inches (178 mm) or greater in width of shell may be taken or possessed as provided in 5 AAC 34.810(b).

Authority: AS 16.05.251(a) (2),(3),(7)and(10)

5 AAC 34.825. LAWFUL GEAR (a) King crab may be taken by pots only. King crab taken by means other than pots must be immediately returned unharmed to the sea.

(b) Otter trawls with a ground line or head line exceeding 60 feet (18 m) in length may not be aboard any vessel engaged in taking or transporting king crab.

(c) In addition to the pot storage provisions of 5 AAC 34.050(c), king crab pots may be stored during the closed season in waters enclosed by a line from 55°53'N lat. 164°20'W long. to 56°20'N lat., 163°W long. to 56°20'N lat., 162°10' W long. to 56°03'N lat., 162°10'W long. to 55°18'N lat., 164°20'W long. to the starting point.

Authority: AS 16.05.251(a)(2),(4),(7),(10)

5 AAC 34.840. INSPECTION POINTS. Initial inspection points are located at Unalaska, Akutan and other points specified by the department Reinspection points are located at Unalaska, Akutan, King Cove and other points specified by the department.

Authority: AS 16.05.251(a)(2),(4),(7)

Table 20. Fleet composition, effort and catch of the Japanese crab fishery, 1953-74.

Year	Ships	Ind. boats1/	DL Boats2/	Tans3/	Pots3/	Crabs3/
1953	1	6	6	106.3		1,276
1954	1	6	6	60.5		1,061
1955	1	12	6	99.1		1,129
1956	1	2	8	147.1		1,079
1957	1	3	8	83.6		1,171
1958	1	2	8	98.7		1,130
1959	1	2	8	78.4		1,292
1960	1	3	9	93.1		1,611
1961 spr	2	4	11	166.4		1,946
1961 aut	3	16	0	90.3		1,082
1962 spr	3	12	19	300.7		3,236
1962 aut	2	12	4	136.2		1,715
1963	2	9	17	642.4		5,476
1964	2	12	17	638.9		5,895
1965	2	10	17	452.2		4,216
1966	2	10	19	447.3		4,202
1967	2	?	?	440.5		3,764
1968	2	16	17	484.7	151.6	3,853
1969	2	30	10	271.9	615.1	2,073
1970	2	40	5	252.3	797.1	2,080
1971	2	36	4	27.5	1,111.0	886
1972	2	36	4	12.1	1,104.0	874
1973	2	36	2	0	1,023.0	228
1974	2	30		0	852.2	476

1/ Independent boats.
2/ Deck loaded boats.
3/ 1000s of tans
1000s of potlifts
1000s of crabs

8.3.2 The Soviet Fishery

The Soviet eastern Bering Sea king crab fishery consisted of one factoryship and eight catcher boats in 1959. The principle gear used was tanglenets. Soviet effort utilized in the fishery from 1959 through 1971 is given in Table 21.

Table 21. Soviet effort in the eastern Bering Sea king crab fishery, 1959-71.

Year	Nets lift
1959	64.0
1960	191.6
1961	388.0
1962	419.7
1963	536.1
1964	607.5
1965	618.7
1966	617.2
1967	657.0
1968	241.0
1969	248.1
1970	228.9
1971	190.0

8.3.3 The United States Fishery

Fishing methods, vessels and gear are described in detail by Browning (1980).

The pots (traps) utililized by this fishery are steel frames enclosed in heavy nylon webbing and fitted with entry tunnels on opposing sides of the gear. These pots are built in several sizes--6 feet by 6 feet (1.8 X 1.8 m), 6.5 by 6.5 feet (2 X 2 m), 6.5 by 7 feet (2 X 2.1 m) and 8 by 8 feet (2.4 X 2.4 m). The pots are 31-36 inches in depth (.8-.9 m) and they may weigh from 300-800 pounds (136.1-362.8 kg.).

For fishing, the pots are baited and set in strings of from a couple of dozen to 100 or more pots. Each vessel fishes several strings which may be set parallel or in any direction desired by the skipper. Gear is soaked for 12 hours to a couple of days but may be retrieved earlier or later depending upon weather condition or forecasts.

Since 1966 the United States fishery has utilized pots exclusively. The effort expended annually in terms of vessels and potlifts and the catch in both numbers and weight from the United States eastern Bering Sea king crab fishery is given in Table 22. There was a rapid increase in the numbers of vessels participating in this fishery from 9 in 1966 to 236 in 1979 and 1980. The fleet increased not only in number but the older vessels were replaced by newer, larger (Table 23) and more efficient vessels. Increased efficiency is apparent in the annual average potlifts per vessel which increased from 302 in 1966 to over 3000 in 1972, 1977 and 1981.

9. CURRENT EASTERN BERING SEA CRAB FISHERY AND CONDITION OF THE STOCK

9.1 Management Philosophy and Goals

Management of the eastern Bering Sea king crab fishery considers not only matters relating to yield from the stock but also the safety of the fleet, facilitation of regulation, and minimization of conflict within the fishery and with the schedule and operation of other fisheries.

9.1.1 Management of Spawning Stock

The goal of eastern Bering Sea king crab management is to ensure a spawning stock of fertilized females which will maximize recruitment to the fishery. This requires the maintenance of some optimum number of mature females as well as a harvesting strategy which assures the retention in the

Table 22.--Historic U.S. red king crab catch in the Bristol Bay registration area of the Bering Sea, 1966 to 1982.

Year	Vessels	No. of Lndgs.	No. Crab	No. Pounds	Pots Lifted	Avg. Wt.	CPUE
1966	9	15	140,554	997,321	2,720	7.1	52
1967	20	61	397,307	3,102,443	10,621	7.8	38
1968	59	261	1,278,592	8,686,546	47,496	6.8	27
1969	65	377	1,749,022	10,403,283	98,426	5.9	18
1970	51	309	1,682,591	8,559,178	96,658	5.1	17
1971	52	394	2,404,681	12,945,776	118,522	5.4	20
1972	64	611	3,994,356	21,744,045	205,045	5.4	20
1973	67	454	5,000,383	28,190,214	200,909	5.6	25
1974	108	599	7,653,944	41,945,768	211,918	5.5	36
1975	102	592	8,745,294	51,326,259	205,096	5.9	43
1976	141	984	10,603,367	63,919,728	321,010	6.0	33
1977	130	1,020	11,733,101	69,967,868	451,273	5.9	26
1978	162	926	14,745,709	87,618,320	406,165	5.9	36
1979	236	889	16,808,605	107,828,057	315,226	6.4	53
1980	236	1,250	20,845,350	129,948,436	567,292	6.2	37
1981	178	1,026	5,307,947	33,591,368	542,250	6.3	10
1982	91	255	541,009	3,001,210	141,656	5.6	4

Source: Eaton (1983)

Table 23.--Number and size of U.S. vessels engaged in eastern Bering Sea crab fishery, 1966-77.

		Size	
Year	Total Number	Average keel length (feet)	Average net weight (tons)
1966	9	85.9	75.0
1967	20	95.8	114.1
1968	59	91.9	112.5
1969	65	93.0	116.3
1970	51	86.0	116.0
1971	52	85.0	117.1
1972	64	91.1	133.2
1973	67	92.4	141.0
1974	104	94.6	144.1
1975	104	90.5	131.0
1976	142	90.8	136.3
1977	144	93.3	138.4

Source: Eaton (1979)

spawning stock of a certain quantity and size group of males, which can effectively fertilize the females.

9.1.1.1. Female Brood Stock and Recruitment

The relationship between the number of fertilized females and the number of 5 year old recruits produced is shown in Fig. 44 from Reeves (1984). A fit of the data through 1981 to the Ricker (1954) model indicated that a maximum in recruitment occurs at an abundance of about 20 million fertilized females (Reeves, 1982). The comparatively short historical data base for this analysis was recognized by Reeves (1982) who anticipated that the acquisition of information from additional years might change the form of the spawner/recruit curve. In subsequent analyses which included data through 1983, the minimum spawning female population required to maximize recruitment was indicated to be in the range of 31-36 million (Reeves, 1984). At the current stage of knowledge, the spawner/recruit relationship was considered by Reeves (1982) to be a precautionary model delineating the spawning stock threshhold rather than a prognostic model for recruitment.

Regarding recruitment, from the data in Fig. 44, maximum recruitment of age 5 crabs (46 million) was produced by the smallest stock of fertilized female crab (11 million). Also, the very numerous fertilized females of 1973 (1974 hatching) produced a near record low recruitment of 5 year old recruits. With the exception of the 1971 brood stock, fertilized female spawning stocks ranging from 11 million (1970) to 126 million (1977) have produced recruitment of age 5 male crabs ranging from 11 million to 27 million. From these data it is apparent that a very wide range (about 120

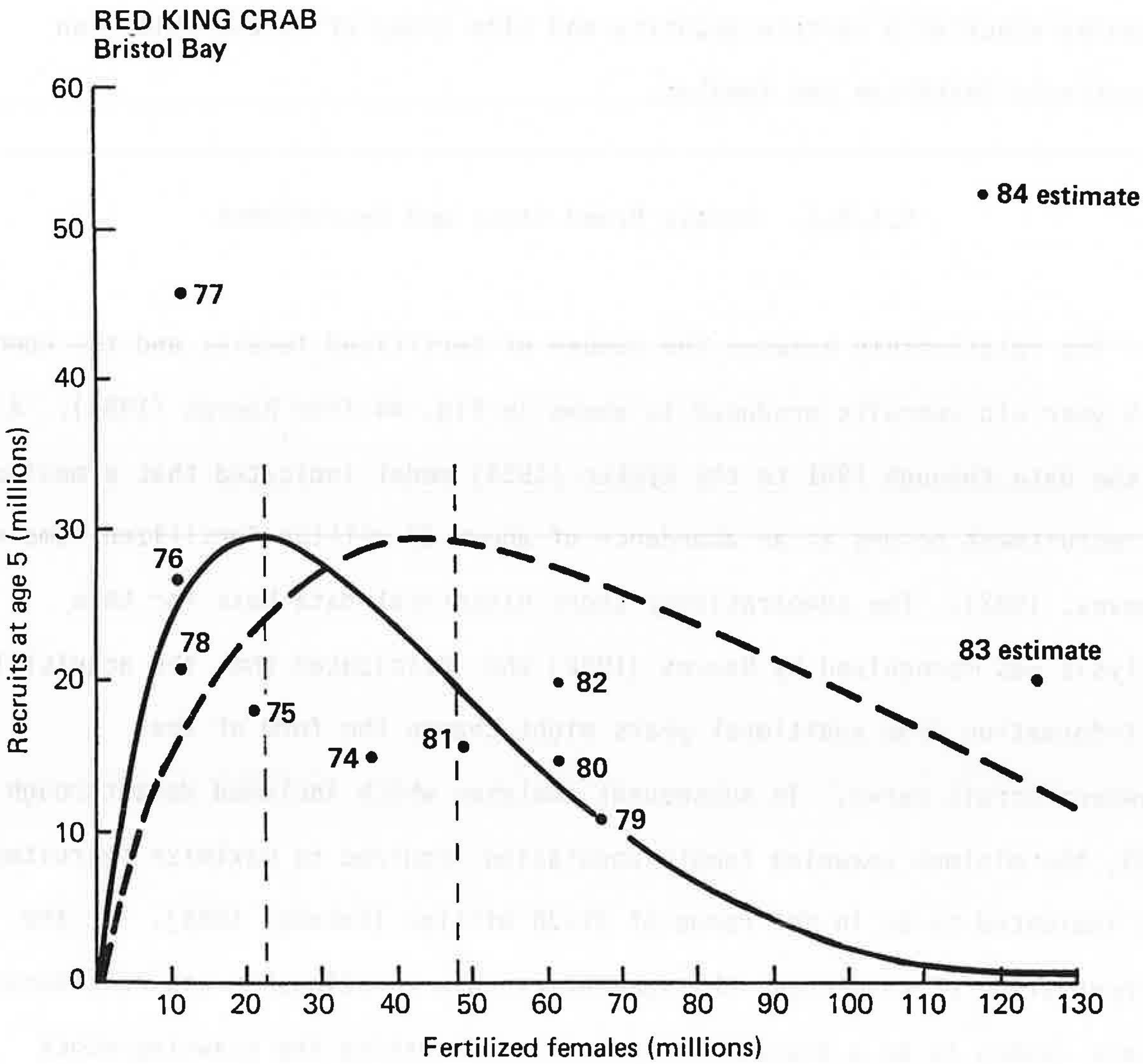

Figure 44. Spawner-recruit relationship for Bristol Bay red king crab.

million) of female spawning stock has produced a much more limited range (excepting 1977, 16 million) of 5 year old recruits. Therefore, although we may statistically specify a range of spawning stock sizes which will maximize recruitment, extreme variability in the spawner/recruit relationship precludes any reliable forecast of the recruitment from any level of female spawning stock size.

On the basis of trends indicated in Fig. 44, Reeves (1982) ascertained that recruitment of 5 year olds would be maximized by fertilized female spawning stock sizes of from 20 million to 40 million.

9.1.1.2. Minimum Retention Size

The allowable catch is the maximum harvest of males which does not result in a decline in the female spawning stock below optimum levels. To assure that males have the opportunity to spawn at least once before being subjected to harvesting, the minimum retention size is set at the size attained 3 years after 50% of the male population becomes sexually mature. This minimum size is 6 1/2 inches (165 mm) in carapace width or 135 mm in carapace length. Therefore, although male king crabs are essentially fully recruited to the survey trawl gear at age 5 which served as the reference age for the previous discussions concerning stock/recruitment, male crabs are actually recruited to the fishery at age 8 or 9.

An annual exploitation rate of 0.4 was estimated as satisfactory to achieve management goals. Due, however, to severe declines in population abundance since 1981, this rate has been adjusted downward to 0.2 in 1982 and to zero in 1983.

9.1.1.3. Fishing Season

Since the management of the fishery under the FCMA, the fishing season has been from September (Sept. 10 in 1982 regulations) to April. The allowable catch is generally taken in about a month, therefore, the season is always terminated within the calendar year.

Various factors have been considered in setting the fishing season. The season is set to protect molting and spawning crab or crabs in certain growth stages, to discourage small vessels from operating in bad weather, to maximize the quality and quantity of crab meat content and to minimize dead loss (mortalities in transporting crab to processors). Consideration is given to coordination with other fisheries which use the same vessels or facilities or for proper timing to better distribute fishing effort.

9.1.1.4. Storage of Gear Which is Not Fishing

From previous descriptions of gear it is clear that king crab pots are large, numerous and present considerable difficulties in transportation and storage. To mimimize these problems, provisions have been made to store unbaited pots in designated pot storage areas. The pot storage areas in easter Bering Sea are designated in the fishery regulations (Table 19).

9.2 Catch and Abundance

The commercial catch of red king crab from the eastern Bering Sea from 1953 through 1982 is shown in Table 24 and was discussed earlier (Fig. 43).

Table 24.--Annual red king crab catches in the Bristol Bay registration area of Bering Sea by United States, Japan and U.S.S.R., 1953-82.*

Year	United States	Japan	U.S.S.R.	Total
1953	2,935	10,374	0	13,309
1954	2,535	8,202	0	10,737
1955	2,269	8,185	0	10,454
1956	2,146	7,877	0	10,023
1957	749	8,197	0	8,946
1958	7	7,808	0	7,815
1959	0	9,031	4,334	13,365
1960	600	13,292	13,606	27,498
1961	427	20,884	23,708	45,019
1962	68	33,716	20,559	54,343
1963	653	35,430	19,533	55,616
1964	823	39,438	18,732	58,993
1965	1,429	27,025	14,269	42,723
1966	997	26,330	16,026	43,353
1967	3,102	23,638	9,998	36,738
1968	8,686	24,043	3,426	36,155
1969	10,403	12,210	2,173	24,786
1970	8,559	11,253	1,731	21,543
1971	12,946	4,722	1,412	19,080
1972	21,745	4,720	0	26,465
1973	28,190	228	0	28,418
1974	41,946	476	0	42,423
1975	51,326	0	0	51,326
1976	63,919	0	0	63,919
1977	69,968	0	0	69,968
1978	87,618	0	0	87,618
1979	107,828	0	0	106,828
1980	129,948	0	0	129,948
1981	33,591	0	0	33,591
1982	3,001	0	0	3,001
TOTAL	698,414	337,079	149,507	1,185,000
AVERAGE	23,280	15,321	11,500	39,500

* - All catches shown in thousands of pounds.

Source: Eaton (1983)

Table 25.--Population estimates for eastern Bering Sea king crabs from NMFS surveys (millions of crabs).

Bristol Bay and Pribilof Red King Crabs		
Year	Pre-recruits1/	Legals1/
1969	19.5	9.8
19702/	8.4	5.3
1972	8.3	5.4
1973	25.9	10.9
1974	31.2	20.8
1975	29.6	21.2
1976	49.3	32.7
1977	63.9	37.6
1978	52.5	46.6
1979	38.8	45.5
1980	23.9	36.1
1981	18.9	11.3
1982	17.1	4.4
19833/	10.5	1.5

1/ 5.2" - 6.4" = pre-recruits
>6.5" = legals

2/ 1971 excluded from population estimates

3/ Includes crabs from northern district

Source: Reeves (1983)

Table 26.--Annual abundance estimates (millions of crabs) for *P. camtschatica* in the Pribilof and Bristol Bay Districts from NMFS surveys.

Size: 1/	Males					Females			Grand Total
	<110	110-134	>134	120-134	Total	<90	>89	Total	
1969	41.0	20.3	9.8	9.6	71.1	18.3	28.5	46.8	117.9
1970	9.5	8.4	5.3	5.2	23.2	4.9	13.0	17.9	41.1
1972 2/	14.1	8.0	5.4	4.7	27.5	7.0	12.1	19.1	46.6
1973	50.0	25.9	10.8	14.2	86.7	24.8	76.8	101.6	188.3
1974	59.0	31.2	20.9	20.0	111.1	37.7	72.0	109.7	220.8
1975	84.9	31.7	21.0	18.6	137.6	70.8	58.9	129.7	267.3
1976	70.2	49.3	32.7	30.7	152.2	35.9	71.8	107.7	259.9
1977	80.2	63.9	37.6	35.3	181.7	33.5	150.1	183.6	365.3
1978	62.9	47.9	46.6	30.9	157.4	38.2	128.4	166.6	324.0
1979	48.1	37.2	43.9	27.4	129.2	45.1	110.9	156.0	285.2
1980	56.8	23.9	36.1	15.3	116.8	44.8	67.6	112.5	229.3
1981	56.6	18.4	11.3	8.9	86.3	36.3	67.3	103.6	189.9
1982	107.2	17.4	4.7	8.5	129.3	77.2	54.8	132.0	261.3
1983 3/	43.3	10.4	1.5	4.9	55.2	24.3	9.7	34.0	89.2
	(51.5)	(12.6)	(1.9)	(6.0)	(66.1)	(30.2)	(12.5)	(42.7)	(108.8)
Limits 4/									
Lower	34.0	8.8	1.1	4.1	45.8	17.4	7.6	26.8	77.3
Upper	52.6	12.0	1.9	5.8	64.7	31.2	11.8	41.2	101.4
±%	21	15	27	17	17	28	22	21	13

1/ Carapace length (mm).

2/ Limited survey in 1971, not used for population estimate.

3/ 1983 data includes small numbers of crab from the Northern District; numbers in parens were computed by multiplying catches of the R/V *Alaska* by 1.56.

4/ With 95% confidence; precision for numbers in parens differs by less than 1% from the percentage given.

Source: Otto et al. (1983)

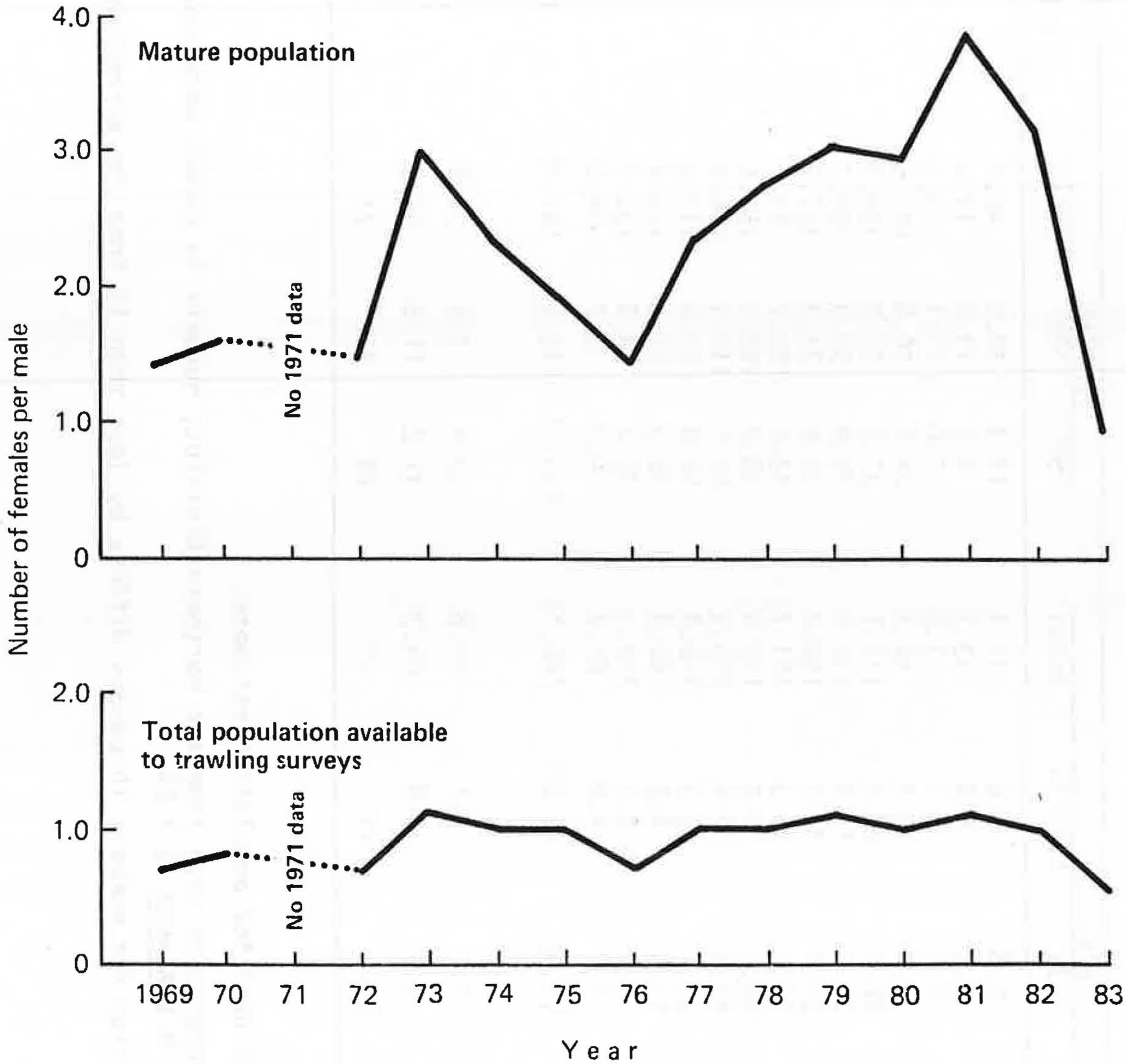

Figure 45. Sex ratios for Bristol Bay red king crab population.

Population estimates for males in the eastern Bering Sea king crab stock have been obtained annually in surveys by MNFS research vessels. The population of legal sized crab increased from about 5 million in 1970 to about 46 million in 1978 and 1979. Since 1980, the number of legal size males has dwindled to 1.5 million crab in 1983 (Table 25).

Pre-recruits were at a maximum in 1977 (64 million) but their numbers have gradually declined to about 10.5 million crab in 1983 (Table 25). In the 1982 survey, it appeared that a large year class had been recruited to the trawl survey (Table 26). There was, however, no sustained indications of the presence of such a year class in the 1983 survey in which the estimate of the number of immature males was the lowest since 1972.

The estimate of the mature female population has decreased from a high of 150 million in 1977 to 9.7 million in 1983 (Table 25). This is about one half the lower limit of the range of 20 million to 40 million fertilized females which present management rationale considers necessary to maintain optimum productivity. There are no signs of improvement in the female spawning stock in the immediate future, inasmuch as the abundance of immature females is also at the lowest levels since 1973.

9.3 Sex Ratio

In a polygamous species such as the king crab it seems intuitively reasonable to maintain more females than males in the spawning population. The ratio of females to males was calculated for the adult and total populations for the years 1969 through 1983 in Fig. 45 from data in Table 25. Whereas, the number of adult females has outnumbered adult males by

2 and 3 times since 1977, the 1983 survey indicates that there are as many if not slightly more males than females both of which are at very low levels of abundance.

9.4 Area of Fishing

The areas of fishing and the distribution of fishing effort for the years 1979 through 1982 was previously discussed in Section 7.3.1 of this report and Fig. 34.

9.5 Condition of the Stocks

From the foregoing discussion, it is quite clear that several principal components of the Bristol Bay red king crab stock have catastrophically declined. Abundance of legal males (greater than 134 mm) is the lowest on record--so low that no fishery on Bristol Bay red king crab was permitted in 1983. The abundances of pre-recruit and males less than 110 mm are also at very low levels. Under normal conditions of molting, growth and natural mortality, recruitment would be expected to be about 4 million crab for each of the next two years. Under abnormally high mortalities, survival to recruitment may be reduced by one-half. In either event, for the next two years, the abundance of legal crab can be expected to be low (Otto, et al., 1983).

The record low population of only 9.7 million mature females in the Bristol Bay red king crab stock is of particular concern. This is about half the lower limit of the range of 20-40 million fertilized females which was suggested by Reeves (1981) as the reasonable number necessary to maximize recruitment. To add to the concern, the estimated numbers of immature females is the lowest in the past decade.

There have been conjectures but no satisfactory explanation for these catastrophic declines in the eastern Bering Sea red king crab stock. Otto etal (1983) have discussed possible causes. Unusually high predation of crab as a result of the increasing abundance of cod and halibut has been identified as a likely source of reduced survival of king crab. A protozoan parasite and one or several viruses may also be involved.

9.6 Size Frequency Distribution

The size frequency distribution of female and male king crabs captured in the annual trawl surveys 1975 through 1983 is given in Fig. 46 and for the exploited population from 1977 through 1982 in Fig. 47.

9.7 Fisheries Imposed Mortality

The trawl and longline fisheries for groundfish and the king and Tanner crab fisheries have been considered as likely sources of mortality to eastern Bering Sea king crab.

9.7.1 Discards in King and Tanner Crab Fisheries

Observations were made of 746 potlifts during the red king crab fishery in September and October 1982 (Griffin et al., 1983). In these potlifts, for

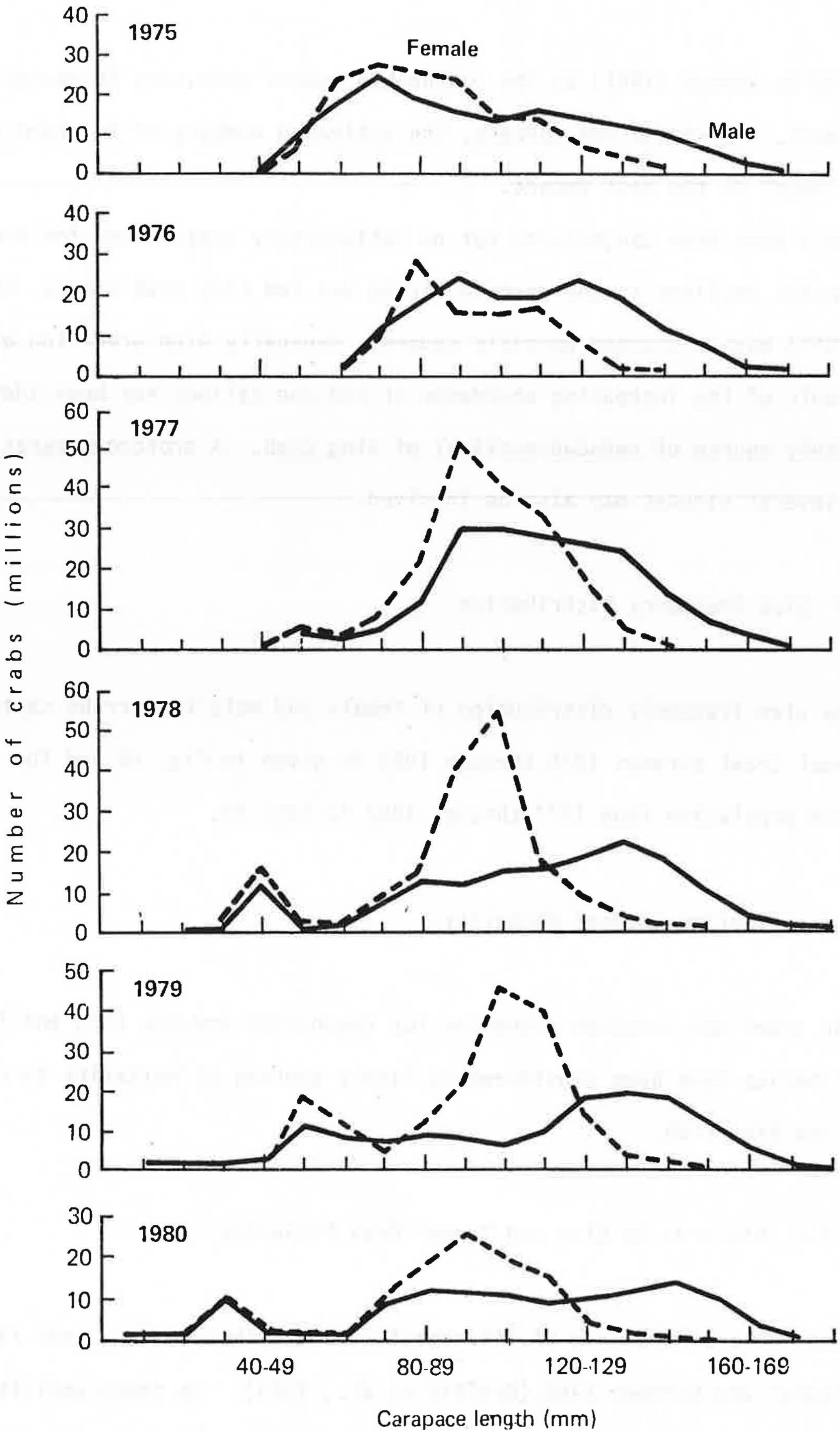

Figure 46. Size frequency distribution of Bristol Bay red king crab taken in trawl surveys.

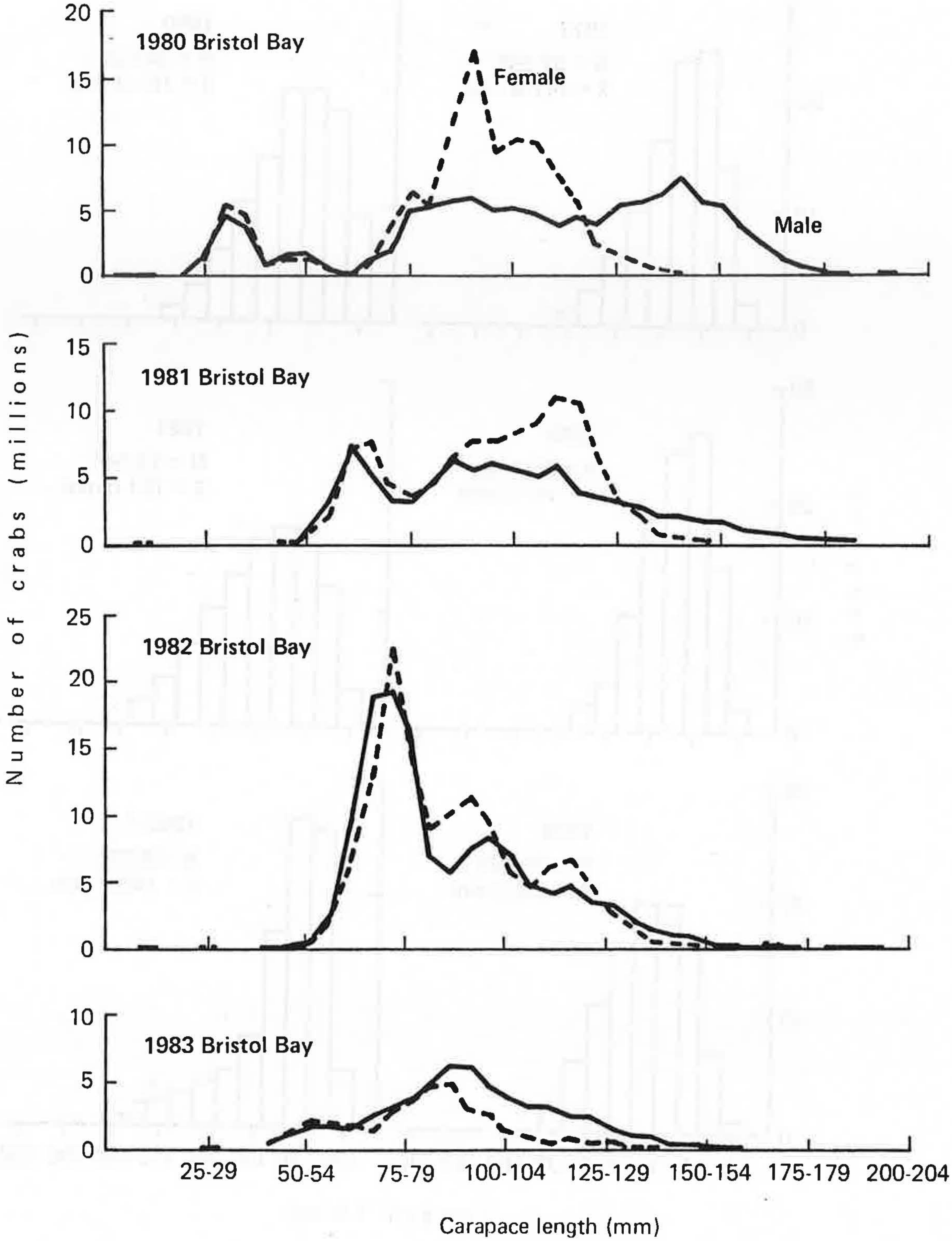

Figure 46. Continued.

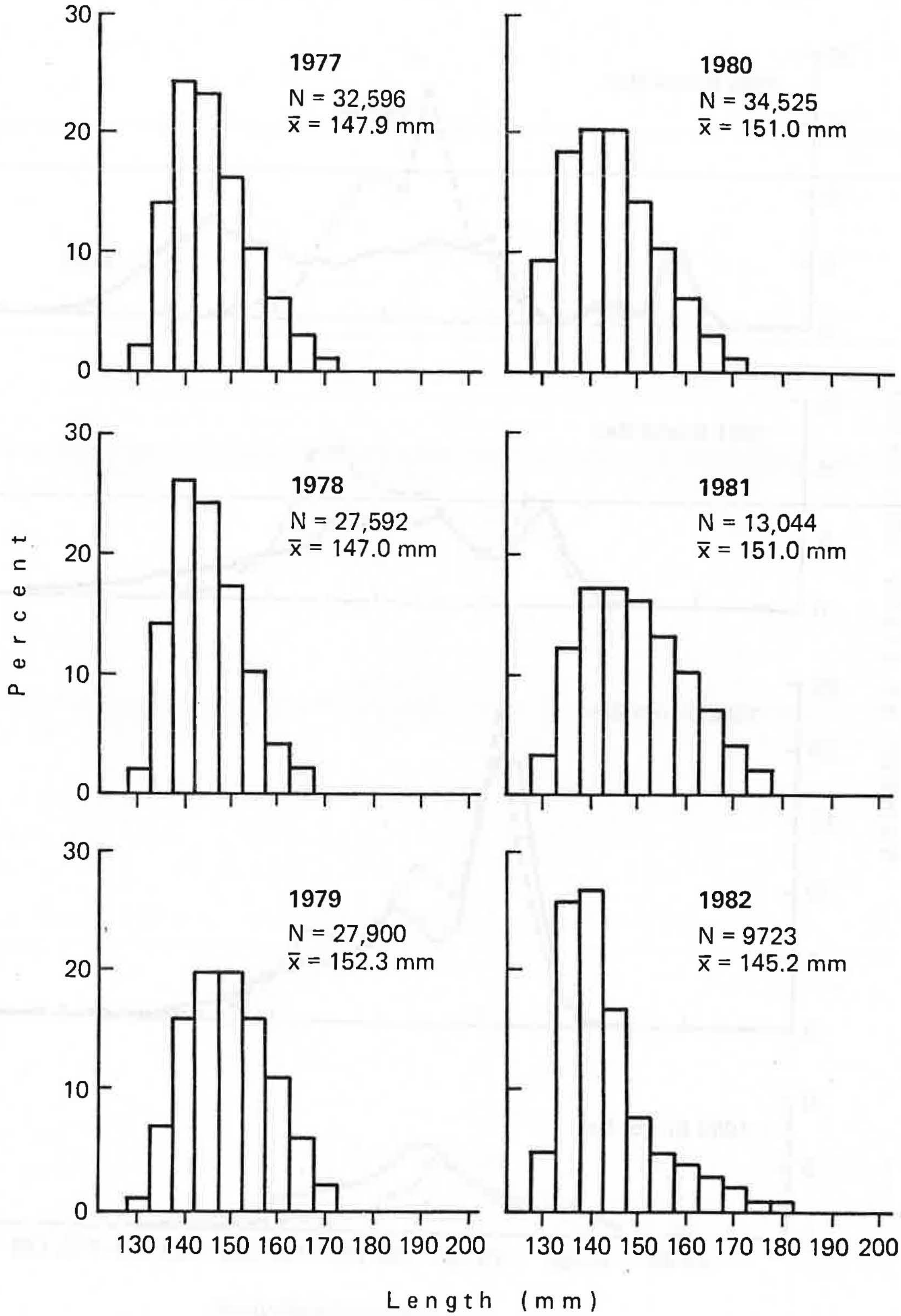

Figure 47. Size frequency distribution of Bristol Bay red king crab taken in the fishery.

each legal male caught, one female and 7.3 sublegal males were caught and discarded.

If the ratios of 7.8:1 (sublegal males:legals) and 1:1 (females:legals) are applied to some recent years catches, as many as 152 million sublegals and 20.8 million females may have been caught and returned to the sea in the 1980 eastern Bering Sea king crab fishery (Table 27).

Table 27. Discard of crabs 1977-82 assuming ratio of discards to legal crab in 1983 observations.

Year	Est. No. of Sublegals (million)	Est. No. of Females (millions)
1977	85.4	11.7
1978	107.3	14.7
1979	122.6	16.8
1980	151.8	20.8
1981	41.3	5.3
1982	3.7	0.5
Total	512.1	69.8

King crab are also taken incidentally in the Tanner crab pot fishery and the trawl fisheries. In observations made during the Tanner crab fishery in March and April of 1983, 1.6 king crab were discarded for every legal Tanner crab caught (Griffin et al., 1983).

No reliable estimates are available on the survival of crab discarded and returned to the sea from the king or Tanner crab fisheries. Otto et al., (1983) express the view that the incidental catch by directed and non-directed fisheries have had some influence but do not account for the declines in the abundance of king crab (Table 26).

9.7.2 Incidental Catch of King Crab in Trawls and Longlines.

The annual incidental catch of king crab by the trawl and longline fisheries operating east of 170°E in the eastern Bering Sea is given in Table 28.

Table 28. Incidental catch of red king crab by trawl and longline fisheries east of 170° in eastern Bering Sea.

	1980		1981		1982	
	(Nos)	(mt)	(Nos)	(mt)	(Nos)	(mt)
Trawl						
Foreign	157,954	208	115,751	143	129,530	150
Joint-Venture	289,540	241	1,082,163	642	193,896	90
Total Trawl	447,494	449	1,197,914	785	323,426	240
Longline	11,034	7	6,935	5	6,898	5.6
Grand Total	458,528	456	1,204,849	790	330,324	245.6

1 Nelson et al (1980).
2 Nelson et al (1981).
3 Nelson et al (1982).

The incidental catch of king crab by trawlers and longliners in eastern Bering Sea may exceed 1 million animals, however, this quantity is small by comparison to the potential number of crabs which might be caught and dicarded by the king crab fishery per se. The mortality resulting from handling of crab in their capture, handling and return to the sea has not been determined.

Concern has also been expressed regarding the possible mortalities caused by crab pots which are stored without bait in the southeastern Bering Sea. Crabs may also be crushed by the setting of crab pots or by the action of the ground lines on trawls. Trawling may also disturb the substrate or habitat of juvenile crab. Evaluation of these possible sources of mortality has not been documented.

10. EFFECTS OF OIL ON KING CRAB

The impact of an oil spill on eastern Bering Sea king crab stock will depend upon the chemical composition and physical properties of the petroleum or petroleum derivative, the concentrations and duration of hydrocarbons in the water column and near or on the benthos, the time and area of the spill and the developmental stage of the oiled crab. Meteorological conditions will, of course, influence the transport and weathering of the spill and hydrographic variables will also be involved in the distribution of hydrocarbons beneath the sea surface. Water temperature is important in that it can be expected to affect the rates of hydrocarbon uptake and metabolization as well as the decomposition and weathering of hydrocarbons in the environment.

An oil spill accident in the eastern Bering Sea can affect the king crab resource and the fishery in several ways. Certain hydrocarbons in sufficient concentration may cause acute or chronic lethal effects to adults, juveniles, larvae or eggs of king crab. Sublethal effects such reduced fecundity, feeding or growth rates, modifications of behavior or interference with chemical communications systems may also occur. Crabs may become unacceptable for human consumption because of visible fouling or offensive odor and taste due to accumulation of hydrocarbons in the flesh. This may lead to consumer wariness and avoidance of crab from and even outside the oil impacted sites, irrespective of demonstrable adulteration of the products. Fouling of fishing vessels and gear and the pre-emption of fishing areas and times are also possible consequences of oil spills.

Available evidence indicates that the sensitivity of crab to hydrocarbons is dependent upon the life history stage of the animal as well as the concentration and chemical composition of the petroleum or derivitive.

10.1 Sensitivity of Eggs and Larvae to Petroleum Hydrocarbons

10.1.1 Eggs

Information on the effects of petroleum hydrocarbons on the development of red king crab eggs could not be found. In his discussion of the impacts of the AMOCO CADIZ accident, Laubier (1980) noted no significant difference in the fishery statistics for lobsters in 1978 (year of the accident) and 1979. However, the number of egg-bearing females was extremely low in both years (Leglise & Raguenes, 1979; Laublier, 1980). This caused concern for the productivity of the population 4 and 5 years after the spill. It was suspected that the spider crab, <u>Maria squinado</u>, was similarly impacted.

Although there is no information on the effect of oil on the development of king crab eggs. If analogous to fish and eggs are relatively more senstive, then oil concentrations less than those which have lethal effect on king crab larvae (0.8-0.9 ppm for 72 hrs) might be acutely toxic to certain embryonic stages. Latent mortality to larvae caused by developmental aberrations attributable to hydrocarbon exposure might also be expected.

It should be reiterated that king crab eggs are carried by the female for more than 11 months of the year. This provides the embryos protection from predation and extreme fluctuations in the external environment. The fate of the embryo is, however, inextricably tied to the well being of the mother. The distribution of egg-bearing females and their sensitivity and exposure to oil is, therefore, very relevant to assessing the impact of oil on the embryonic development of king crab.

10.1.2. Larvae

Mecklenburg and Rice (1976) conducted experiments on the sensitivity of king crab and coonstripe shrimp (Pandalus hypsinotus) to water soluble fractions (WSF) of Cook Inlet crude oil. The 96 hour mean tolerance limits (96TLm = concentration at which 50% of the animals died after 96 hours) for stage I larvae of both king crab and coonstripe shrimp were 4.2 to 8.6 ppm. It was found, however, that concentrations 20 to 70 percent less than the 96 TLm caused a cessation in swimming and ultimate death. Molting of stage I larvae was inhibited. Molting success was affected by duration of exposure and concentration of oil. Molting was permanentlyinhibited in larvae exposed to concentrations of 0.8 to 0.9 ppm for 72 hours. Although experimental evidence is lacking, similar effects may occur with much lower concentrations if duration of exposure were increased from 72 or 96 hours to the 2 to 3 week intermolt interval of each of 4 zoeal crab stages.

King crab larvae were also found to be more susceptible to toxicity during molting than during the intermolt stage. Stage I larvae were unsuccessful in molting at WSF of 0.69 ppm while the 96 TLm for the intermolt stage I larvae was 8.0 ppm.

Crustacean larvae may be less resistant to hydrocarbon toxicity than adults because the former undergo 5 molts at 2 to 3 week intervals. Earlier stages of crustacean larvae are generally more sensitive to petroleum hydrocarbons than later larval stages (e.g., for Lobster; Wells, 1972: for crab; Katz, 1973).

10.1.3 Juveniles

The 96 hour TLm for juvenile king crab was 4.21 ppm with Cook Inlet crude oil (202 ppb UV naphthalene equivalents) and 5.10 ppm (408 ppb UV naphthalene equiv.) with No. 2 fuel oil (Rice et al., 1976). Juvenile crab were able to cleanse themselves shortly after removal to clear sea water. Methylnaphthalene concentrations were below 1 microgram /gram (wet weight) after 96 hours (Rice et al., 1976).

Oxygen consumption rate in juvenile crab was depressed by 50% after 1 hour exposure to oil concentrations of 7.45 ppm and was depressed further with time. After 4 hours, 3 of the 6 crabs were dead. WSF of 6.58 resulted in 30% reduction in oxygen uptake, however, after three hours these crabs began to recover. At concentrations of 1.48 ppm, oxygen uptake of crabs exposed to oil did not differ from that of the controls (Rice et al., 1976). Smith (1976) reported on histological and structural alterations in the gill epithelial cells in juveniles held in sea water containing WSF of crude oil for 6 days. Epithelial cells in the gills are necessary for respiration and excretion.

The extent to which these changes affect the viability of king crab was not discussed.

10.1.4. Adults

Acute toxicity to adult king crab was studied by Rice et al., (1976) in bioassays using WSF and oil-water dispersions (OWD) of Cook Inlet treated and Prudhoe Bay crude oils. Their results using Prudhoe Bay crude are summarized in the following table.

Table 29. TLm (median tolerance limit) at 24, 48 and 96 hour exposure to Prudhoe Bay crude for adult king crab (in ppm).

Exp.	Temp.	WSF	OWD
24TLm 50	3.8-7.8 C.	2.53 (2.30-2.79)	18.07 (12.93-25.24)
48TLm 50	"	2.47 (2.26-2.70)	12.60 (10.00-15.71)
96TLm 50	"	2.35 (2.16-2.55)	5.30 (0.93-30.11)

WSF of Cook Inlet oil, benzene and naphthalene depressed the heart rate of adult king crab. Heart rate returns to normal as crude oil or aromatics concentration in sea water decline. There was a tendency for the heart rate to decrease further during each depression/recovery cycle. Benzene produced quicker response and more severe and longer lasting heart rate depression than naphthalene or crude oil (Mecklenburg et al., 1976).

Oxygen consumption rate parelled the decrease in heart rate. The depression of oxygen consumption under oil exposure depended on the size of crab. Larger crab were thought to have greater ability to degrade oil (Mecklenburg et al., 1976).

10.2 Tainting of King Crab from Exposure to Oil

Tainting is defined as any alteration to the appearance (including color), texture, odor or flavor of king crab caused by exposure to oil. If severe enough, any one of these oil spill abberations will not only destroy the marketability of the tainted crab but may also trigger consumer suspicion and avoidance of untainted king crab from non-oiled waters.

Tainting is generally associated with the odor or taste of food products. Generally, the human olfactory system has comparatively high sensitivity to phenols, and sulphur compounds. Major tainting components of petroleum are phenols, dibenzothiophenes, naphthenic acids, mercaptans, tetradecanes and methylated naphhthalenes (Connell & Miller, 1981).

Kerhoff (1974), Paradis & Ackman (1975) and Hardy et al. (1976) found tainting of fish and shellfish to be caused at levels of crude or refined petroleum products in the range of 4 to 300 ppm.

The concentrations of hydrocarbons in the environment per se may not necessarily be indicative of the level of tainting achieved in the tissues of marine animals. Some animals may have enzyme systems which very efficiently degrade and metabolize petroleum hydrocarbons. On the other hand, other animals are known to accumulate certain petroleum components and biomagnify them in various body tissues.

Biomagnification factors (concentration of a component in a tissue divided by the concentration of that component in the water) of 4 naphthalenic hydrocarbons in gill, viscera and muscle tissue were calculated by Rice, et al. (1976). Data from Rice et al. (1976) are summarized and given in Table 30.

Table 30. Biomagnification of naphthalenic hydrocarbons in king crab. Ratios of tissue concentrations to exposure water concentrations for gill, viscera and muscle tissues.

Tissue	Naphth.	Methyl-Naphth.	Dimethyl Naphth.	Trimethyl Naphth.
Gill	N.A.	---	---	---
Viscera	250	1,260	1,260	800
Muscle	20	60	60	---

The bioaccumulation of hydrocarbons by king crab was very high, particularly in the viscera and for methylnaphthalenes, dimethylnaphthalenes, and trimethylnaphthalenes. The accumulation of several hydrocarbons with exposure time and schedules of depuration are given in Table 31.

Connell and Miller (1981) cited experiments done by Wilder (1970) with Bunker C oil and oil plus detergents. He found that external contamination did not necessarily lead to tainting in the muscles of lobster (Homarus americanus). The consumption of oil and its presence in the gut did not lead to tainting of the muscle tissues. Lobsters which were fed herring coated with oil showed no indication of tainting whatsoever (Anon., 1970).

Table 31.--Aromatic hydrocarbons in king crab tissues.

[c indicates <0.05 µg/g, d <0.2 µg/g]

Exposure/ depuration time (hours)	Amount of given component[a] (µg/g)					Total aromatic hydrocarbons (µg/g)
	X	N	MN	DMN	TMN	
	GILL TISSUE					
Control	0.3	d	d	d	d	<10
Exposure						
3	0.5	d	d	d	d	<10
10	0.2	d	d	d	d	<10
20	0.2	d	d	d	d	<10
48	0.2	d	d	d	d	<10
96	0.3	d	d	d	d	<10
Depuration						
3	0.2	d	d	d	d	<10
10	0.6	d	d	d	d	<10
20	0.4	d	d	d	d	<10
48	0.2	d	d	d	d	<10
96	0.2	d	d	d	d	<10
	VISCERAL TISSUE					
Control	2.0	c	3.2	0.2	c	40
Exposure						
3	1.9	2.0	2.7	0.5	c	35
10	3.0	c	1.9	1.6	0.1	55
20	4.0	2.5	9.4	4.8	0.2	60
48	1.0	1.8	15.8	6.5	0.4	40
96	1.2	1.8	13.9	6.0	0.2	40
Depuration						
3	3.0	2.5	14.4	2.7	0.1	35
10	4.0	0.2	5.4	1.4	c	35
20	1.8	0.9	6.9	1.2	c	40
48	1.5	0.7	4.3	0.5	c	30
96	1.8	c	0.5	0.1	c	20

Table 31.--Continued

[c indicates <0.05 μg/g, d <0.2 μg/g]

Exposure/ depuration time (hours)	Amount of given component[a] (μg/g) X	N	MN	DMN	TMN	Total aromatic hydrocarbons (μg/g)
			MUSCLE TISSUE			
Control	0.1	c	c	c	c	<1
Exposure						
3	c	0.05	0.05	0.05	c	1
10	0.2	0.1	0.2	0.2	c	4
20	0.7	0.2	0.6	0.3	c	5
48	0.1	0.1	0.3	0.1	c	2
96	0.1	0.1	0.4	0.1	c	2
Depuration						
3	0.1	c	0.1	c	c	2
10	0.5	c	0.1	c	c	3
20	0.2	c	c	c	c	2
48	0.1	c	0.1	c	c	1
96	0.1	c	c	c	c	1

[a] X = A biogenic polyene with a retention time similar to that of a C_{28} n-paraffin; N = naphthalenes; MN = methylnaphthalenes; DMN = dimethylnaphthalenes; TMN = trimethylnaphthalenes, methylethylnaphthalenes, and propylnaphthalenes.

Table from Rice, et al., 1976

Other investigators have reported the tainting of lobster by petroleum hydrocarbons. Lobster taken after the Torrey Canyon spill reportedly tasted of paraffin. The crab, Cancer pagurus, was also reported to be tainted (Simpson, 1968). Chemical analyses of crustaceans after the AMOCO CADIZ spill showed preferential hydrocarbon accumulation in the hepatopancreas (290 ppm) rather than in the flesh, although the concentrations in the latter were in the range of 40-60 ppm (Leglise, 1979).

Although Laubier (1980) made no mention of tainting in lobsters or other crustaceans, the tainting of oysters by petroleum hydrocarbons was discussed. Oysters showing total hydrocarbon concentrations of 20 to 30 ppm were considered to be slightly polluted by fossil fuels. On a practical basis, an average value of 60 plus or minus 20 ppm, wet weight was considered as the upper limit for human consumption.

11. PROVISIONAL APPRAISAL OF THE EFFECTS OF OIL SPILLS AT PORT MILLER, PORT HEIDEN AND OFF CAPE NEWENHAM ON RED KING CRAB

This report has summarized knowledge concerning the distribution, reproduction, age and growth, commercial harvest and current condition of the eastern Bering Sea red king crab stock. Available information on the sensitivity of larvae, juvenile and adult king crab to some hydrocarbons was also presented. From this information it is possible to make some preliminary appraisals of how oil spills at various sites in the eastern Bering Sea might be expected to impact the king crab resource.

From the available information, it is possible to approximate the vulnerability of different life history stages and physiological states of king crab to petroleum hydrocarbons. The effect of the timing of a spill can be evaluated, at least by season. For reasons which will be discussed later, however, oil impact appraisals in this report will stop short of quantitatively estimating the petroldeum-imposed mortality to king crab or the consequencies of this mortality to the productivity of the stock--only the possibilities of such effects would be discussed.

11.1 Potential Impacts of Spills in the Spring and Summer

From the foregoing discussion, it is apparent that oil spills in the eastern Bering Sea might have some lethal or sublethal effects on the red king crab population or cause operational disruptions to the fishery. The impacts will depend upon a number of factors. The most obvious of these are, the type and amount of petroleum product involved, the timing and location of the spill, the distribution and persistence of the hydrocarbons in the water column and on (or in) the bottom, and the number, age, sex and physiological or life history stage of the king crab inhabiting the oiled area. Operational disruptions would include the pre-emption of fishing grounds by the spill or cleanup activity, and the possible tainting of crab.

There is adequate evidence that the earlier life history stages and certain physiological stages of marine animals are particularly sensitive to petroleum hydrocarbons. It is therefore, useful to review the seasonal events and distribution of eastern Bering Sea red king crab relative to the hypothetical oil spill sites off Port Moller, Port Heiden and Cape Newenham.

As is the case with temperate and subarctic marine organisms, the biology and distribution of red king crab in the eastern Bering Sea is a chronological sequence of seasonal events. The seasonal occurrence of life history events such as the spring spawning migration, egg release and hatching, mating, molting, and feeding migrations have been determined. Although past observations indicate some annual variations, there is sufficient consistency to permit some reasonable approximations of the timing and areal dimensions of these seasonal sequence of events.

Events critical to the perpetuation and productivity of the eastern Bering Sea red king crab stock occur during the spring and summer. It is during the spring that both male and female adult king crab form separate aggregations during the spawning migration on the northern Aleutian Shelf. During this spawning migration, females release eggs which they have carried for almost a year. The emerging larvae molt five times through 4 zoeal and 1 megalops stage before attaining the first adult form during the summer.

Mating of king crab also occurs in the late spring and early summer. This entails chemical communications of the female with the male by the release of pheromones. Also during mating, the female molts - a necessary prerequisite of ovulation.

Available evidence indicates that juvenile red king crab less than three years old (40-50 mm carapace length) are year round residents of the eulittoral zone. Therefore, they too would inhabit the nearshore waters of the NAS during the spring and summer.

There are no reliable estimates of the number of larvae in the eastern Bering Sea for any past year and no method for predicting larval abundance in any future year. The available information has been primarily useful for identifying the areas and timing of egg hatching, spawning migrations and mating. Although some of the available information may be useful as indices for comparing time/area variations in relative abundance within a year, their utility as indices of annual variation have not been demonstrated. With regard to enumerating the larvae of king crab (eggs and ichthyoplankton in general) the fundamental problems of developing adequate sampling gear, strategies and designs for quantitative assessments need yet to be resolved.

No reliable estimates are available for larval mortality of red king crab in eastern Bering Sea. Considering the relatively high fecundity of the species (55,000 to 445,000 eggs/female), the mortality rate of larval king crab can be surmised to be very high. For king crab in the Sea of Nemuro, mortality from the Zoea I stage to the megalops stage was calculated to be about 96% of which 93% (about 2 trillion larvae) was estimated to occur before the second zoeal stage. Marukawa (see Sec. 6.2.2) estimated that only 14 out of 1 million larvae hatched survived to attain the commercially desired size of 160 mm carapace width. Haflinger and McRoy (1983) calculated that 18 billion larvae were consumed by predators in the northern Aleutian shelf in a one month period. Total mortality could be expected to be considerably greater since the authors considered their calculations to be a very conservative estimate of the mortality attributable only to predation.

The accuracy of these estimates are not amenable to simple verification nor are they directly applicable to estimating larval mortality in eastern Bering Sea king crab in any past or future year. They do, however, illustrate that larval mortality is normally very high. Even if the mortality attributable to oil could be estimated with reasonable accuracy, such mortality would be expected to be but a small part of total larval mortality. Whether the effects of such mortality could be accurately assessed against the background of very large and no doubt, highly variable natural mortality is problematical.

The assessment of the effects of larval mortality (natural or oil-imposed), is frustrated because quantitative association between larval population size and stock productivity does not exist. No data are available on the relationship of larval survival or numbers and subsequent recruitment to the exploitable population. We have, however, discussed in Sec. 9.1.1.1, the relationship of the number of fertilized females and resulting recruitment. A broad range of females (11 million to 67 million) has produced recruitment ranging from 11 million to 46 million with the largest recruitment resulting from the least abundant female spawning stock.

Assuming no large annual variations in the average number of eggs per female, there should be a direct relationship between the number of fertilized females and the number of larvae hatched. The relationship between larval abundance and recruitment then can be expected to be extremely variable and difficult to predict. Even if the component of total mortality which is attributable to an oil spill can be calculated, the assessment of its impact on population productivity will be extremely difficult considering the extremely variable and unpredictable recruitment which has resulted from the large range of natural fluctuations in spawners and larvae. The dynamics of the red king crab population abundance observed to date, one could not reliably and quantatively predict the impact of oil spill mortality or whether the change will be manifest as an increase or decrease in population productivty.

Available data indicate that juvenile red king crab of less than 50 mm carapace length inhabit the eulittoral zone throughout the year. In the spring and summer months this size group of crab have consistently occurred in waters offshore of the Port Moller-Cape Seniavin area. From the available data, oil spills at either the Port Moller or Port Heiden sites which persist for 96 hours at concentrations of about 4 ppm crude oil of 5 ppm No. 2 fuel oil can be expected to kill half the juvenile king crab which are impacted. Contamination at these levels have been shown (see later discussion) to be a relatively small area in relation to the plausible distribution area of juveniles.

The estimated proportions of the eastern Bering Sea king crab population in each of the subareas (Fig. 48) of eastern Bering Sea as estimated from results of the Northwest and Alaska Fisheries Center trawl surveys in 1975 and 1979 are given in Tables 32 and 33. The proportions of the red king crab population in area 1 within which are located two of the hypothetical spill sites were 70% and 81%, for 1975 and 1979, respectively. Two percent(1975) and 11% (1979) of the population were estimated to inhabit subarea 4 (containing the site of the third hypothetical spill site) during the period of the surveys. Nine percent (1979) and 28% of the population were estimated to be outside the areas contaminated by the hypothetical spills (Table 32).

Immature male and female crab are relatively abundant from False Pass eastward to Port Moller. They are most extensively distributed in highest abundance in waters between 161° and 163°W and south of 58°N. In 1975, 94% of the immature females and 86% of the immature males occurred in subarea 1. In the 1979 survey virtually all the immature males and females were taken in subarea 1 (94% and 99%, respectively). Considering information from all

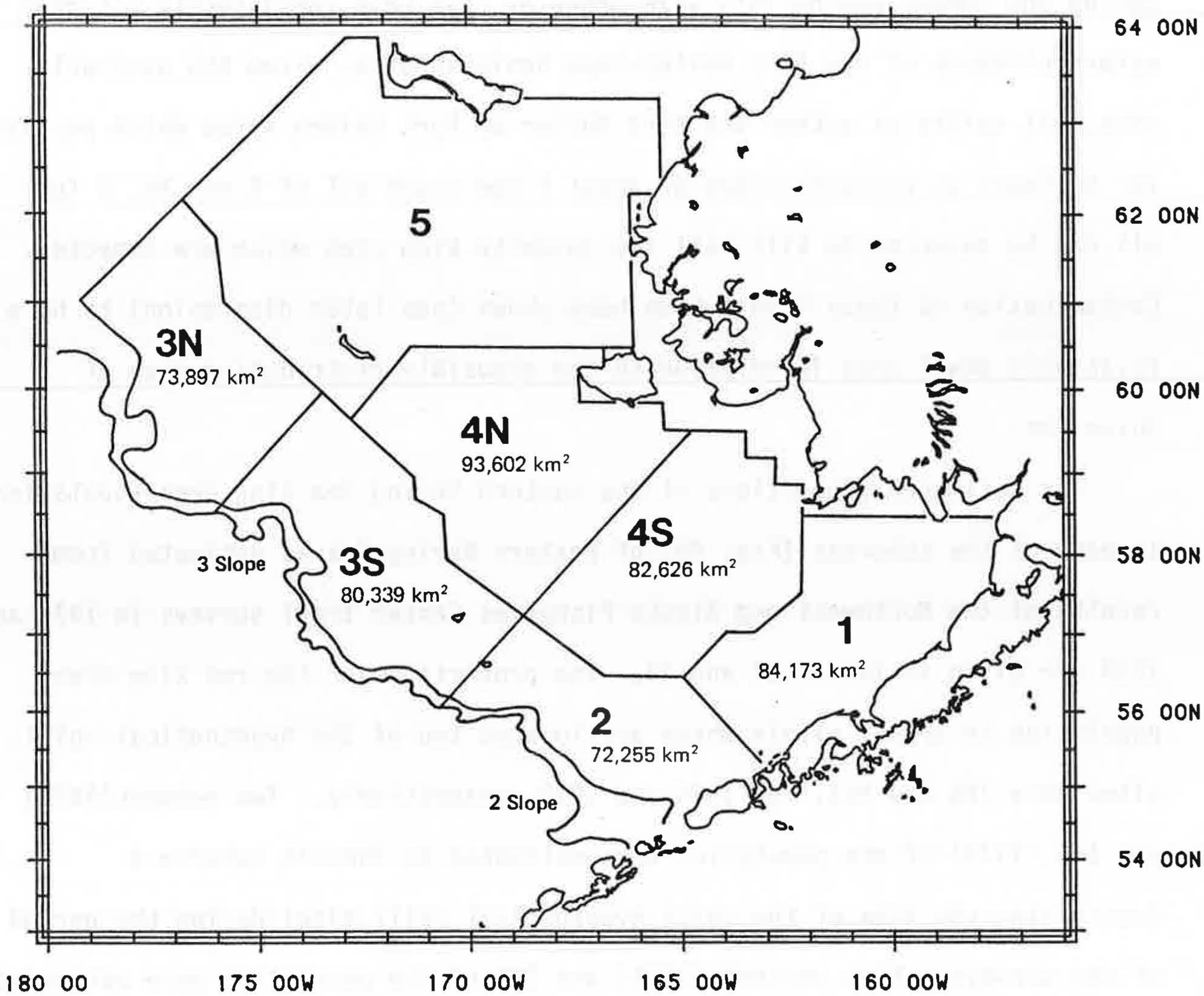

Figure 48. Subareas of the trawl survey area.

Table 32.--Estimated population of red king crab (males and females) during the 1975 and 1979 eastern Bering Sea trawling surveys.

Subarea	Estimated population (millions of crab)		Proportion of total estimated population	
	1975 1/	1979 2/	1975 1/	1979 2/
Inner Shelf				
4	2.3	25.8	0.02	0.11
1	85.1	196.1	0.70	0.81
Outer Shelf				
3	0.1	0.3	<0.01	<0.01
2	34.1	20.0	0.28	0.08
TOTAL	121.9 3/	242.3		
95% Conf. Int.	(91-153)	(181-303)		

1/ Pereyra, et al. (1976).

2/ From Pers. Comm. T. Sample.

3/ This estimate is less than half the population estimate for the same population and year as given in Table 26.

Table 33. Estimated population (in millions) of red king crab by subarea, sex and carapace length groups in the eastern Bering Sea in 1975 and 1979.

Subarea	Males				Females			
	<110	110-134	>134	Total	<90	>89	Total	TOTAL
1975 1/								
Inner Shelf								
4	0.4	0.8	0.6	1.8	0.2	0.3	0.5	2.3
1	20.5	15.1	12.8	48.4	13.2	23.5	36.7	85.1
Outer Shelf								
3	0	0	0	0	0	0.1	0.1	0.1
2	2.8	5.3	5.0	13.1	0.6	20.7	21.3	34.4
TOTAL	23.7	21.2	18.4	63.3	14.0	44.6	58.6	121.9
1979 2/								
InnerShelf								
4	0.4	5.7	13.3	19.4	0.1	6.2	6.3	25.7
1	32.3	25.4	19.0	76.7	22.5	96.8	119.3	196.0
Outer Shelf								
3	0	0.1	0.2	0.3	0	t	t	0.4
2	1.5	3.8	6.7	12.0	0.2	7.8	8.0	20.0
TOTAL	34.2	35.0	39.2	108.4	22.8	110.8	133.6	242.1

1/ Pereyra, et al. (1976)

2/ T. Samples (Pers. Comm.)

3/ This estimate is less than half the population estimate for the same population and year as given in Table 26.

years, this category of immature crab can be expected to be impacted by spills at the Port Moller and Cape Newenham sites.

Adult female king crab appear to be distributed in the northern Aleutian Shelf and inner Bristol Bay areas in the spring, summer and autumn. In the 1975 survey, 53% of the mature females were indicated to occur in subarea 1 and 97% in 1979. Very limited observations indicate they may be further to the westward (north of Unimak Island) in the winter (Fig. 31). During the spring migration, spawning period and postspawning feeding migrations, females occur along Unimak Island and the Alaskan Peninsula with heaviest concentrations off the Black Hill to Cape Seniavin areas.

Mature male red king crab of prerecruitment size (110-134 mm carapace length) appear to be most abundant south of 58°W between 161° and 163°W. In 1975 and 1979, about 70% of this size group were taken in subarea 1. In 1975 and 1979, 75% and 89% of these prerecruits were taken in subareas 1 and 4 combined.

Data from the 1975 survey indicates that during the spring and summer months, most of the legal size males occur in subarea 1 (70%) with very few in subarea 4 (3%). Indications from the 1979 survey are that legal size males are more evenly distributed between subareas 1 and 4 (48% and 34%, respectively).

11.2 King Crab Distribution in Fall and Winter.

Information on the distribution of legal size crab in autumn is very good because in recent years the fishery has been permitted only in September or later. During the fishing seasons of 1979 through 1982, the areas from which most king crab landings were taken have been west of 161°W. This longitude is west of both the Port Heiden and Port Moller and beyond the expected eastward flowing trajectory from oil spills at these sites. The latitude of the Cape Newenham spill site, however, is on the northern border of some very productive fishing areas. The impact of spill scenarios at the Cape Newenham site in terms of effects on the resource, tainting of the catch, pre-emption of fishing areas will depend upon wind conditions prevailing at the time of the spill. The king crab pot storage area appears to be east of the spill trajectory of a spill at Port Moller and well south of the expected trajectory of a spill at Cape Newenham. Unless very strong easterly winds accompany the former or very strong northerly winds are associated with the latter, the special crab pot storage area designated in the Alaska Fishery Regulations should not be impacted by any of the proposed hypothetical oil spill scenarios. The regulations do, however, permit pot storage during the closed season in waters shallower than 30 fathoms (55 m) in depth. Any pots stored in the Port Miller or Port Heiden areas under these regulations may become foiled for shorter periods of time.

As previously mentioned, given the uncertainties concerning the trajectory and fate of oil in the hypothetical spill scenarios and the absence or inadequacies in critical information regarding the toxicology, distribution and population dynamics of the eastern Bering Sea king crab, it is not possible to forecast with reliability, the impact of an oil accident on population productivity.

11.3 Impact Estimates from Hypothetical Oil Spill Scenarios

Hypothetical oil spills of Prudhoe Bay crude oil and automotive diesel fuel are given in Table 34. The areas contaminated by various concentrations of water soluble fractions (WSF) from these oil spill scenarios was provided by the Rand Corporation. Contamination, uptake and depuration of hydrocarbons by various commercially valuable species in eastern Bering Sea were simulated by Gallagher and Pola (1985) and Pola, Miyahara and Gallagher (1985). Estimated concentrations and areas contaminated in the hypothetical spills as given by Gallagher and Pola (1985) are summarized in Table 35.

The effect of petroleum hydrocarbons on red king crab was discussed in the previous section. Information relating to the toxicity of WSF on the life history stages of king crab is summarized below.

No information was available regarding the effect of petroleum hydrocarbons on eggs.

Stage 1 zoea were unsuccessful in molting at WSF concentrations of 0.69 ppm while the 96TLm for stage 1 larvae during the intermolt stage was 8.0 ppm. Molting was, however, permanently inhibited at 0.8-0.9 ppm with exposure time of 72 hrs. For purposes of this discussion we will assume WSF >1.0 ppm are lethal to larvae.

Juveniles survived 96 hours of exposure to concentrations of 5.1 ppm and cleansed themselves shortly after removal to clear water. Three of 6 juvenile crab died after four hours of exposure to 7.45 ppm.

The 96TLm50 for adults was reported as 2.35 ppm (WSF) and 5.3 ppm (OWD). It does not seem reasonable, however, that the threshhold concentration for mortality in adults should be lower than for juveniles. It

Table 34.--Hypothetical oil spill scenarios.

Scenario	Oil type	Volume	Duration	Temperature	Simulation grid	Locations in Bristol Bay
Well blowout	Prudhoe Bay crude	20,000 bbl/day	15 days	9.3°C	(50 x 50)	Port Moller Port Heiden Cape Newenham
Tanker accident	Automotive diesel	200,000 bbl (instantaneous)	10 days	9.3°C	(32 x 34)	Port Moller Port Heiden Cape Newenham

Source: Gallagher & Pola (1985)

Table 35.--Estimated concentrations and area contaminated by simulated oil spills at Port Heiden, Port Moller and off Cape Newenham.

	Conc./days	Area contaminated %	Area contaminated Km^2
Blowout Scenario			
WSF1/	0.1-1.0 ppm/17	3	300
TARS	0.1-1.0 ppm/8	3	300
Accident Scenario			
WSF	max >5 ppm/4	2	50
	1-5 ppm/12	10	450
	0.1-1 ppm/15	22	1000
TARS	5 ppm/15	5	225
	1-5 ppm/28	19	825
	0.1-1 ppm/30	28	1200

1/ Less than 0.5 ppm in all areas.

Source: Summarized from Gallagher & Pola (1985).

is assumed, therefore, that concentrations necessary to affect mortality in adults is at least as great as that which is lethal to larvae (max. = 8.0 ppm) and juveniles (7.45 ppm). For purposes of the following discussions, 96TLm50 for both juvenile and adult crab will be a 5.0 ppm.

These data indicate that first stage larvae, particularly during molting are most sensitive to hydrocarbon toxicity with a lower threshhold of about 0.7 ppm (WSF).

11.3.1 Well Blowout

In the well blowout scenarios, maximum subsurface WSF concentrations never exceed 0.34 ppm (Pola, Miyahara, and Gallagher, 1985). This concentration is well below the minimum concentration which has been experimentally shown to affect larvae. We can, therefore, expect that the well blowout scenario will have no effect on eastern Bering Sea crab stocks.

11.3.2 Tanker Spill

The tanker spill of 200,000 bbl of automotive diesel fuel results in contamination levels which are assumed to be toxic to adult king crab (i.e., >5 ppm). These concentration are estimated to occur in about 2% of the contaminated area (50 km^2). This area of comtamination is indeed very small considering that the eastern Bering Sea king crab stock is distributed over about 200,000 km^2 (trawl survey subareas 1, 2 and part of 4, see Fig. 48).

During the months of the survey (1975 & 1979), about 90% of the red king crab population was estimated to be in subareas 1 & 4 (Fig. 48 & Table 32). A spill at the Port Moller or Port Heiden sites might be expected to contaminate 0.06% of subarea 1 at concentrations >5 ppm. Assuming the number of adult crab exposed to such comtamination is proportional to the area, one-half of 0.06% (assuming LD_{50} = 5ppm) or 0.03% of the adult population of king crab in subarea 1 and less thn 0.03% of the total eastern Bering Sea adult stock may suffer mortality from the simulated spill.

Since we are assuming the same toxicity level (5.0 ppm) for juveniles, the proportion of mortalities to the juvenile king crab population can be expected to be similar to that of the adults. Although not reflected in either the 1975 or 1979 surveys (Table 33), juveniles would be expected to be more numerous than adults (juveniles may not be as available to the trawl gear and they are not as efficiently retained by the gear). Most of the juveniles in the 1975 and 1979 surveys were taken in subarea 1 (Table 33). The trawl surveys, however, may not sample in areas inhabited by most juveniles and crab younger than 5 years are not efficiently retained by the sampling gear. There are, therefore, no reliable quantitative estimates of the numbers or areal distribution of juvenile king crab upon which to base an estimate of oil-imposed mortality.

Within the area impacted by the hypothetical oil spill scenarios, king crab larvae are mostly confined to the Port Moller-Port Heiden areas (Subarea 1) and during the months of May-August. The available evidence indicates that Port Moller is the most important egg-hatching area and larval abundance the greatest in the Port Moller to Cape Seniavin area (Sect. 7.1). An instantaneous spill of 200,000 bbls of automotive diesel fuel may result in WSF concentrations which are potentially lethal to larvae (>0.8 ppm) over 10 to 20% (1000 km^2) of the contaminated area. The actual impact of this contamination in mortality to larvae and on the productivity of the eastern Bering Sea crab stock is difficult to estimate. There are no reliable quantitative estimates of the temporal-spatial distribution of king crab larvae. Natural mortality sustained by the successive larval stages of king crab is not known. Although not quantitatively estimated, natural mortality in the larval stages is extremely large and variable. The detection and evaluation of oil-imposed mortality against a background of large and highly variable on-going natural mortality problematic. Even if oil-imposed mortality could be successfully isolated from natural mortality, we have no knowledge as to whether such mortalities are simply additive or whether and to what extent density related compensatory mechanisms may come into play.

The eastern Bering Sea king crab stock is presently in extremely poor condition. The level of abundance of the exploitable stock is so low that no fishery was permitted in 1983. The abundance of pre-recruits is at a near record low level, indicating that the moratorium (or low level of fishing) may continue in the foreseeable future. Of most concern, however, from the standpoint of stock productivity is the evidence that the abundance of adult females is the lowest on record and less than half the lower range of the number of females required to maximize the yield from this stock. The abundance of immature females is also near the record minimum level (Table 25 and Sect. 9). There has been no good explanation for this decline in females for a resource in which the fishery targets exclusively on larger males. Increased predation, diseases and mortalities imposed by the king and Tanner crab and trawl fisheries have been advanced as possible causes. Regardless of the causes, the fact remains that the eastern Bering Sea king crab stock has suffered a catastrophic decline. Although the records have indicated that the highest stock recruitments have been produced from the lowest recorded female, spawning populations, we are not assured that such the relationship was not attributable to sampling errors or variations or to unusually favorable survival conditions. Given the many uncertainties regarding our knowledge of eastern Bering Sea king crab stock dynamics there are no indications which suggest any substantial improvement in the condition of the eastern Bering Sea king crab stock in the foreseeable future.

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