ASPECTS OF THE BIOLOGY OF THE HAIR CRAB, *ERIMACRUS ISENBECKII*, IN THE EASTERN BERING SEA

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ABSTRACT

The distribution and relative abundance of the hair crab, *Erimacrus isenbeckii*, were determined from data collected during annual summer trawl surveys conducted by the National Marine Fisheries Service (NMFS) in the eastern Bering Sea, 1979-84. The estimated population was about 23 million crabs from 1979 to 1981, but declined sharply to 4.4 million by 1984. The majority (67%) of the population occurred in the Pribilof Islands area. Male crabs occurred at a mean temperature of 3.4°C and depth of 66 m, whereas females occurred at a mean of 2.4°C and 64 m. Females comprised <10% of the catch in NMFS surveys. Over 99% of the females caught were mature, but only eight were ovigerous with from 34,000 to 160,400 eggs. Length-width and length-weight relationships were calculated for males and females. The majority (77%) of *E. isenbeckii* caught during an independently conducted study in May 1983 were found on a mixed sand and shell substrate. Scientific literature (mostly Japanese) was reviewed to provide information on larvae, reproduction, molting, growth, feeding habits, predation, migration, behavior, fishing, and marketing.

The hair crab, *Erimacrus isenbeckii* (Brandt) (Fig. 1), is a medium-sized brachyuran in the family Atelecyclidae. Hair crab have been fished in Japanese and Korean waters for over 60 years (Kawakami 1934), and much literature is available on the biology, distribution, and abundance of the species in those waters. In contrast, fishing for hair crab in U.S. waters began in 1979 (Griffin and Dunaway 1985[3]). The recent development of a U.S. fishery for hair crab and the substantial decline of the eastern Bering Sea (EBS) population from 1981 to 1984 prompted an analysis of hair crab data collected by the National Marine Fisheries Service (NMFS) during the summers of 1979-84. This report presents data on the distribution and abundance of hair crab in the EBS during those years, as well as aspects of ecology, reproduction, molting, and growth. Additionally, we have summarized the literature concerning this species, since most of it is published in Japanese and not easily accessible to English-speaking readers.

REVIEW OF PUBLISHED LITERATURE ON *ERIMACRUS ISENBECKII*

The hair crab has a quadrangular carapace slightly longer than it is wide, and is densely covered with short bristles and sharp granular projections; seven teeth are present on each lateral margin. Chelipeds and walking legs are stout and spiny. The epistome has a nearly straight anterior margin. Rathbun (1930), Sakai (1939), and Kobyakova (1955) described the morphology of adult *E. isenbeckii* in detail. Five zoeal stages and one megalopa stage in the development of this crab are described by Kurata (1963). According to Kurata, the zoeae are relatively large, ranging from 2.7 to 6.5 mm in body length (orbit to midpoint of posterior edge of telson), depending on zoeal stage, and are equipped with a long dorsal spine (1.2-2.8 mm) and prominent lateral spines that are about one-fourth of the length of the dorsal spine. Abdominal margins of the carapace are fringed with setae; abdominal segments possess knobs, spines, and spinules. The megalopa is about 7.2 mm long. The rostrum is short and wide and ends anteriorly in three short teeth. Abdominal segments lack spines.

In the EBS, hair crab occur from the northern

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[3]Griffin, K., and D. Dunaway. 1985. Bering Sea area shellfish management report to Alaska Board of Fisheries. *In* Westward region shellfish report to the Alaska Board of Fisheries, p. 179-245. Alaska Department of Fish and Game, P.O. Box 308, Dutch Harbor, AK 99692.

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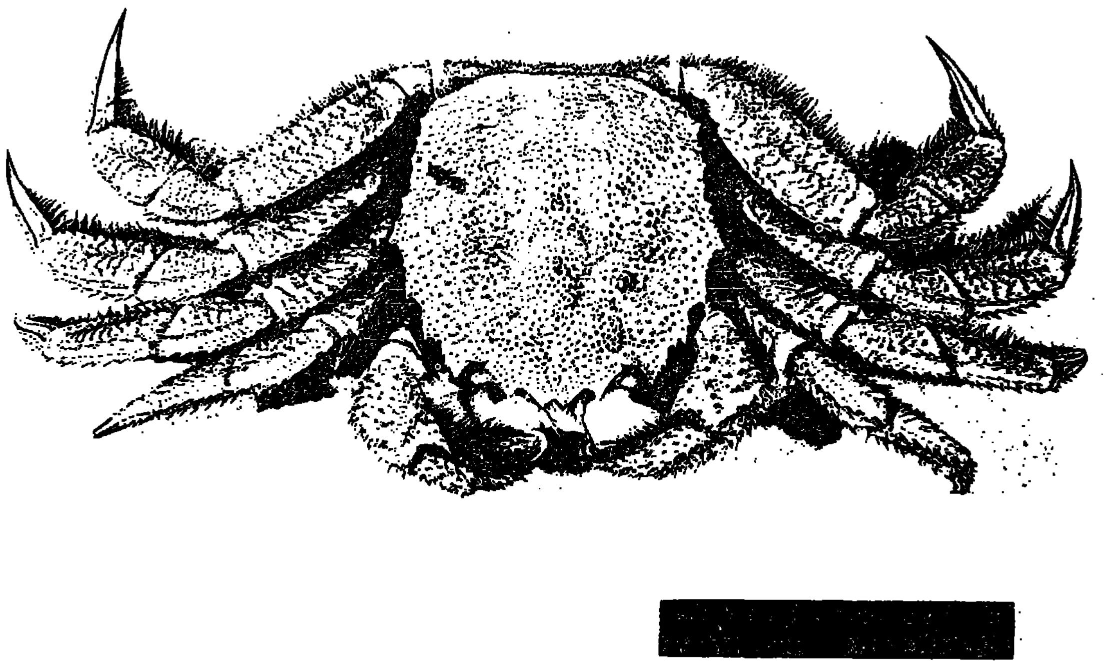


FIGURE 1.—Male hair crab, *Erimacrus isenbeckii*, from eastern Bering Sea. Dorsal view.

shore of the Alaska Peninsula to the Pribilof Islands and St. Matthew Island (Fig. 2). Hair crab are also found along the Aleutian Archipelago from Unimak Island as far west as long. 170°E (west of Attu Island; NMFS unpubl. data). In the western Pacific, hair crab occur along the eastern coast of Korea, the western and eastern coasts of Japan, and southern Sakhalin Island (Rathbun 1930; Tanikawa 1971). They are particularly abundant around the island of Hokkaido and along the Kurile Islands to southern Kamchatka, and are common along west Kamchatka to lat. 54°40′N (Vinogradov 1947). They are unknown from the western Bering Sea.

Dall reported hair crab from Kachemak Bay and Cook Inlet, AK (Rathbun 1930). These, however, were probably *Telmessus cheiragonus*, a similar atelecyclid that commonly occurs in the northern Gulf of Alaska (Calkins 1978), since no verified observations of hair crab have been reported east of Unimak Island despite numerous inquiries to commercial fishermen and biologists working in the northern gulf in recent years.

Sakurai et al. (1972) (Fig. 3, bottom) reported that primiparous (first time breeders) female hair crab off Hokkaido mate from December to February and multiparous (have bred more than once) females mate from August to November (the latter in deeper waters than the former). According to Sakurai et al., mating occurs immediately after molting when females are in the soft-shell condition. When the female is ready to molt, a male crab grasps her chelipeds and holds on to them until after ecdysis. While the female is still soft, the male inserts his copulatory processes into her genital openings and fills the spermathecae with seminal fluid containing spermatophores. The male then secretes a mucoid, proteinaceous substance from his seminal glands which congeals immediately into hard plugs that firmly close the female's genital apertures. The male may then mate with other receptive females. Primiparous

FIGURE 3.—Average molting (top, Abe 1984, see text footnote 13) and breeding (bottom, adapted from Sakurai et al. 1972) cycles of *Erimacrus isenbeckii* (through age 8) offshore of southeastern Hokkaido. It is uncertain when eggs hatch after the second spawning period. Carapace lengths were measured from the notch between the rostral spines. "C" numbers indicate postlarval instars.

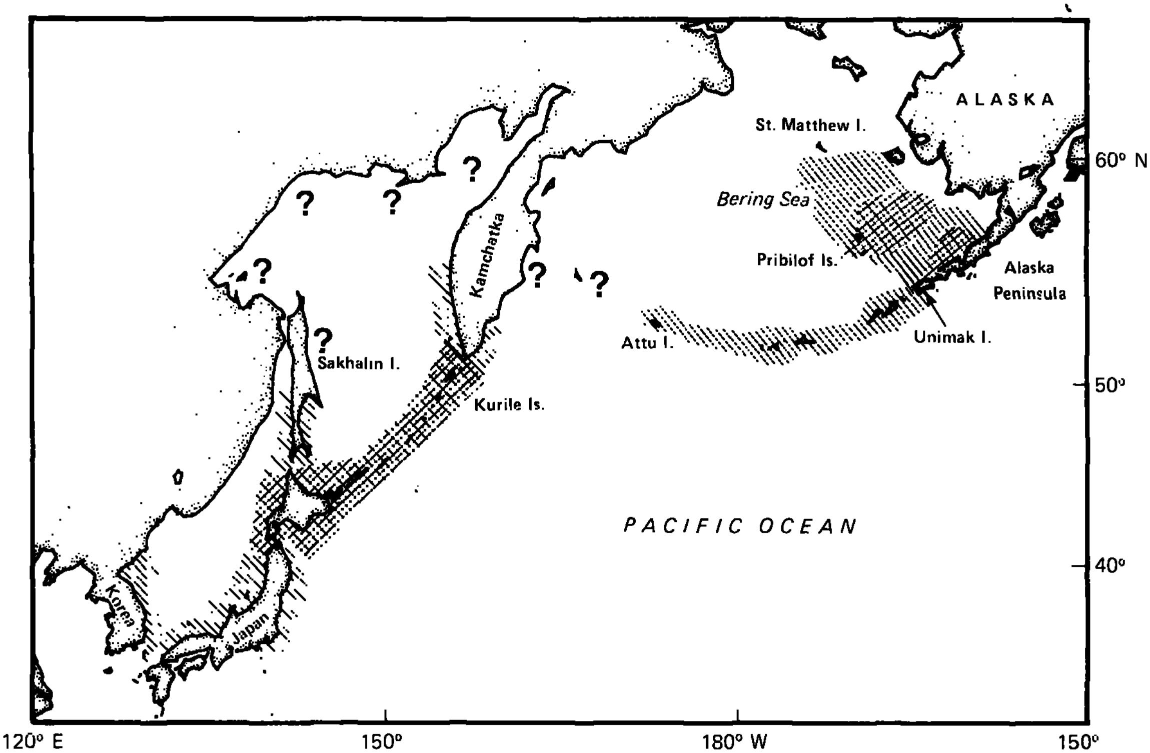
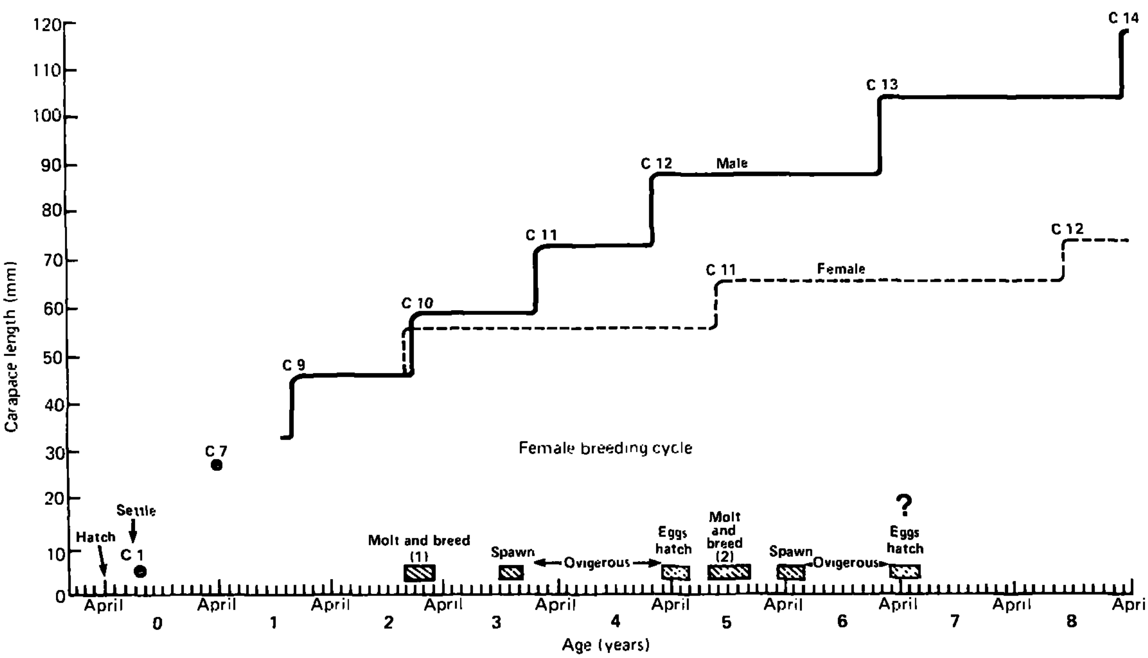


FIGURE 2.—Known world distribution of *Erimacrus isenbeckii*. Areas of high and low density are indicated by crosshatching and parallel lines, respectively. Question marks indicate areas where hair crab are believed to occur but are not well documented.



females extrude eggs in October and November while multiparous females extrude eggs from March to May (Fig. 3) (Sakurai et al. 1972). This indicates a 4-10 mo interval between copulation and extrusion. Yoshida (1940) suggested that spawning occurs only in alternate years.

Oocytes are yellowish white and immature at the time of copulation in both primiparous and multiparous females. During the interval between copulation and extrusion, the oocytes mature into dark orange ova 0.6 mm in diameter (Sakurai et al. 1972). After extrusion, the embryos are carried for at least a year during which time they become dark brown; hatching occurs from about March to May. Sakurai et al. reported that an average of 40,000-50,000 eggs and a maximum of 160,000 eggs were produced and that external embryos were 0.8-0.9 mm in diameter.

The distribution and timing of the occurrence of hair crab larvae near Hokkaido, the Kamchatka Peninsula, and in the eastern Bering Sea have been the focus of several studies. Near Hokkaido, Takeuchi (1969) and Abe (1977) found stages I-III in May and June; stages IV and V in June and July; and megalops from June to August. Takeuchi determined that stages were roughly 2 weeks apart. Stages I and II were only found in the surface layer (0-19 m), whereas stages III-V occurred in the surface and middle (20-50 m) layers. Temperatures ranged from 6° to 11°C at the surface and from 2° to 10°C in the middle layer. Along the West Kamchatka Shelf, stage I larvae were found late-April to May and stages II-V in June and July (Makarov 1967). In the EBS, stages I and II were found late-April to June; stage III, May and June; and stages IV and V and megalops in June (Armstrong et al. 1983[4]). Hair crab larvae in all three geographical areas were concentrated over bottom depths of 20-200 m, although some have been found in waters outside that range.

Abe (1977) reported that settlement of hair crab larvae near Hokkaido occurred in July, in waters 20-50 m deep, 5°-7°C, on sandy mud or fine sand. Juvenile crabs remained in that same general area for the next 1.5 years as they grew from 5.1 mm to about 44.5 mm RL[5] (40.2 mm CL) in eight successive molts. Ovigerous females were found in that habitat during the spring. Adult hair crabs moved offshore during July through September, as nearshore water temperatures gradually increased from 6° to 15°C (Abe 1977). Matui (1970) found adults at depths of 20 m in April to 130 m in autumn, offshore of eastern Hokkaido, but hair crab have been found at depths of 5-364 m in other areas around Hokkaido, the Kamchatka Peninsula, and Korea (Kawakami 1934; Sakai 1939). Hair crab were found on a variety of substrates, including sand, mud, gravel, rock, and broken shells, but sandy mud seemed to be most common (Kawakami 1934; Sakai 1939; Matui 1970; Abe 1977).

After settlement in July, hair crab metamorphose to first postlarval crab instars (C1) with a mean size of 5.2 mm RL (Abe 1977, 1982) (Fig. 3, top). External sex characteristics are evident at stage C2 and a mean size of 7.0 mm RL. By the following April, 12 months after hatching, the crab reach stage C7 at a mean length of 27.4 mm RL. Approximately 33 months after hatching, the crab reach maturity at C10 with a length of 55-60 mm RL (50-54 mm CL) (Abe 1977, 1982); however, hair crab males do not mate until 4 years of age and 70 mm RL (64 mm CL) (Sakurai et al. 1972). The smallest recorded male with mature spermatozoa was 41 mm RL (37 mm CL) (Hirano 1935). Molting frequency and mean carapace length are the same for both sexes through stage C9 (Abe 1977, 1982), however, after maturity males molt more frequently (Sakurai et al. 1972) and show greater growth per molt (Abe 1982) than females. Males begin to molt annually at about 55 mm RL (51 mm CL), once every 1-2 years (tending toward 2) in the size range 89-95 mm RL (81-87 mm CL), and biennially at sizes >100 mm RL (91 mm CL) and growth rate decreases with age (Yamamoto 1971). Males 65-105 mm RL (59-96 mm CL) experience a 10-25%

[4]Armstrong, D. A., L. S., Incze, D. L. Wencker, and J. L. Armstrong. 1983. Distribution and abundance of decapod crustacean larvae in the southeastern Bering Sea with emphasis on commercial species. Final Rep. to Natl. Oceanic Atmos. Admin., OCSEAP contract no. NA81-RAC-00059. Office of Marine Pollution Assessment, Alaska Office RD/MPF24, P.O. Box 1808, Juneau, AK 99802.

[5]Japanese scientists have traditionally measured crab lengths from the notch between the rostral spines ("rostral-length", RL), whereas NMFS scientists measure from the right orbit ("carapace length", CL). We converted rostral lengths to orbit lengths with the following equations, determined for crab in the size range of 40-100 mm CL:

Males:	$CL = -0.81 + 0.921\ RL$	$R^2 = 0.982$	$N = 122$
Females:	$CL = -2.10 + 0.943\ RL$	$R^2 = 0.998$	$N = 8$

These equations have similar slopes but significantly different intercepts ($P < 0.05$). All NMFS crab measurements in this report are carapace lengths (CL). Japanese data are reported in original units (RL) and corresponding carapace lengths are also given for crabs >40 mm CL.

growth rate for carapace length (Yamamoto 1971) and females of 50 mm RL (45 mm CL) an 8-17% growth rate (Sakurai et al. 1972).

Molting periods for adult hair crab vary with sex and locality. In general, males distributed along the coasts of Hokkaido and Korea molt between the months of January and July (Yoshida 1940; Domon et al. 1956; Matui 1970; Sakurai et al. 1972) and females molt during the periods of April to June (Yamamoto 1966) or August to February (Sakurai et al. 1972).

Amphipods, anomurans, and isopods are important food items of the hair crab and peak feeding occurs at midday (Hirano 1935; Sakurai et al. 1972; Abe 1973). Hair crab are prey to fish species including various cottids (Sakurai et al. 1972; Abe 1973, 1982), salmon (Takeuchi 1972), and cod (June[6]), and are occasionally eaten by red king crab, *Paralithodes camtschatica*, (Cunningham 1969).

Hair crab migrate between shallow and deeper waters for mating purposes or in response to temperature changes (Yamamoto 1966; Sakurai et al. 1972). Primiparous females mate nearshore during winter, whereas multiparous females mate in deeper waters during autumn. Juveniles remain nearshore in water temperatures up to 15°C in late summer but adults move offshore. Hair crab also migrate along shore possibly to avoid increased densities (Hirano 1935; Abe 1977). Hirano reported that the longest straight-line migration of a tagged crab was 18 km over a 16-d period and the greatest migration speed was 1.39 km/day; however, the remaining 180 crabs recovered (442 tagged crabs released) within a 48-d period were at the site of release or within 7 km.

Hair crab have been fished in Japanese and Korean waters with the use of conical pots (Fig. 4), trawls, and gill nets (Matui 1970; Yamaha Fishery Journal 1981). In any month of the year fishing occurs at some location around Hokkaido; it occurs from about November to April offshore of southern Hokkaido (Kawakami 1934; Yamaha Fishery Journal 1981) and from March to December offshore of northern Hokkaido (Kawakami 1934; Matui 1970; Tanikawa 1971). Management measures have included area closures, total catch limits, pot limits, legal-size restrictions, and male-only restrictions (Matui 1970; Yamaha Fishery Journal 1981). Hirano (1935) and Kawakami (1934) believed that hair crab are especially vulnerable to fishing pressures owing to "localized" migratory behavior, low number and fecundity of females, and the extended breeding period. By 1980, about 10 t of hair crab were harvested offshore of Hokkaido every day, with 90% of the harvest transported live to fish markets throughout Japan (Iversen[7]), and the remaining 10% sold frozen.

U.S. fishermen began to land hair crab from the EBS in 1979 (Table 1). The majority of the commercial harvest has occurred incidental to snow (Tanner) crab (*Chionoecetes* sp.) fishing in the Bering Sea during the months of March through June, however, fishing season is not restricted. Only male crabs are landed. The Pribilof District (see Results for description of district) contributed 94-98% of the total Bering Sea catch during 1980-84. Harvested crabs averaged 105.7 mm CL and 0.91 kg in 1984. Landings ranged from 2 t in 1979 to a peak of 1,108 t in 1981. Modified, baited king and Tanner crab pots are normally used. Pribilof Islanders, however, conducted an experimental

[6]J. June, Fisheries Research Biologist, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115, pers. commun. December 1982.

[7]R. Iversen, Regional Fisheries Attache, U.S. Embassy, Tokyo, Japan, APO San Francisco, CA 96503, pers. commun. August 1982.

TABLE 1.—Statistics of the U.S. commercial fishery of *Erimacrus isenbeckii* in the eastern Bering Sea (modified from Griffin and Dunaway, see text footnote 3). Mean length determined from port sampling, mean weight from landing records.

			Crab catch				Crab size	
Year	Vessels	Landings	number (× 1000)	Metric tons	Pots lifted	Crabs/ pot	Mean weight (kg)	Mean length (mm)
1979	11	16	2	2	9,908	0.2	0.95	111.8
1980	9	17	25	24	14,506	1.7	0.95	114.5
1981	67	192	1,127	1,108	172,695	6.5	1.00	104.8
1982	48	159	467	423	117,518	4.0	0.91	103.1
1983	52	161	575	550	84,346	6.8	0.95	103.2
1984	19	74	398	364	42,806	9.3	0.91	105.7

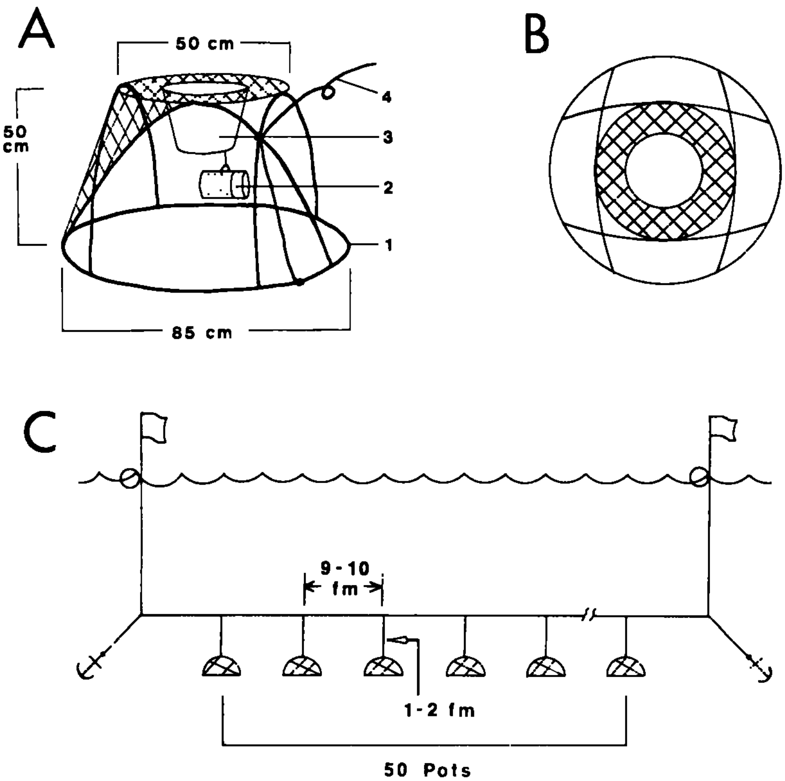


FIGURE 4.—Construction design and fishing method of Japanese hair crab pots. A, Side View: 1, lower ring of steel, upper ring and lateral bars of bamboo; 2, baitcan; 3, polyethylene cylinder entrance (28 cm top diameter, 25 cm bottom diameter, 19 cm high); 4, branch line attached to lateral bars and lower ring. Mesh shown only on top and one side. B, Top view: C, Longline method of pot fishing (fm = fathoms).

fishery for hair crab during the summer of 1980 with the use of small conical crab pots (Merculieff[8]). All hair crab harvested in the United States have been exported to Japan as live or whole-boiled product, and prices to fishermen have ranged from \$0.50 to \$1.60/lb.

MATERIALS AND METHODS

Hair crab were caught by NMFS during annual summer trawl surveys (primarily designed to assess the abundance of king crab, Tanner or snow crab, and ground-fish species) in the EBS from 1971 to the present, but detailed data on hair crab have been collected only since 1979. Fishing was conducted with a 400-mesh eastern otter trawl in 1979-80 and with an 83-112 eastern otter trawl in 1981-84; effective widths were 12.2 and 15.2 m, respectively (both nets were described by Wathne (1977)). Studies comparing the two nets showed no differences in size selection for king and Tanner crabs. We assumed the same for hair crab, which were too scarce for comparison. These differences in net widths have very minimal effect on the presentation of crab abundance, which is by order of magnitude (0-1, 1-10, 10-100 crab/nmi towed).

In all years, the survey area extended from the Alaskan coast out to approximately the 200 m isobath and included Bristol Bay and the Pribilof Islands area, where hair crab densities are usually greatest (Fig. 5). Only the northern limit of the survey area varied annually. Hair crab were also collected during NMFS cruises to the EBS in February of 1983 and 1985 and during an Outer Continental Shelf Environmental Assessment

[8]Merculieff, L. 1981. Final report on the Pribilof hair crab project. Unpubl. manuscr., 18 p. Tanadgusix Corp., St. Paul Island, AK 99660.

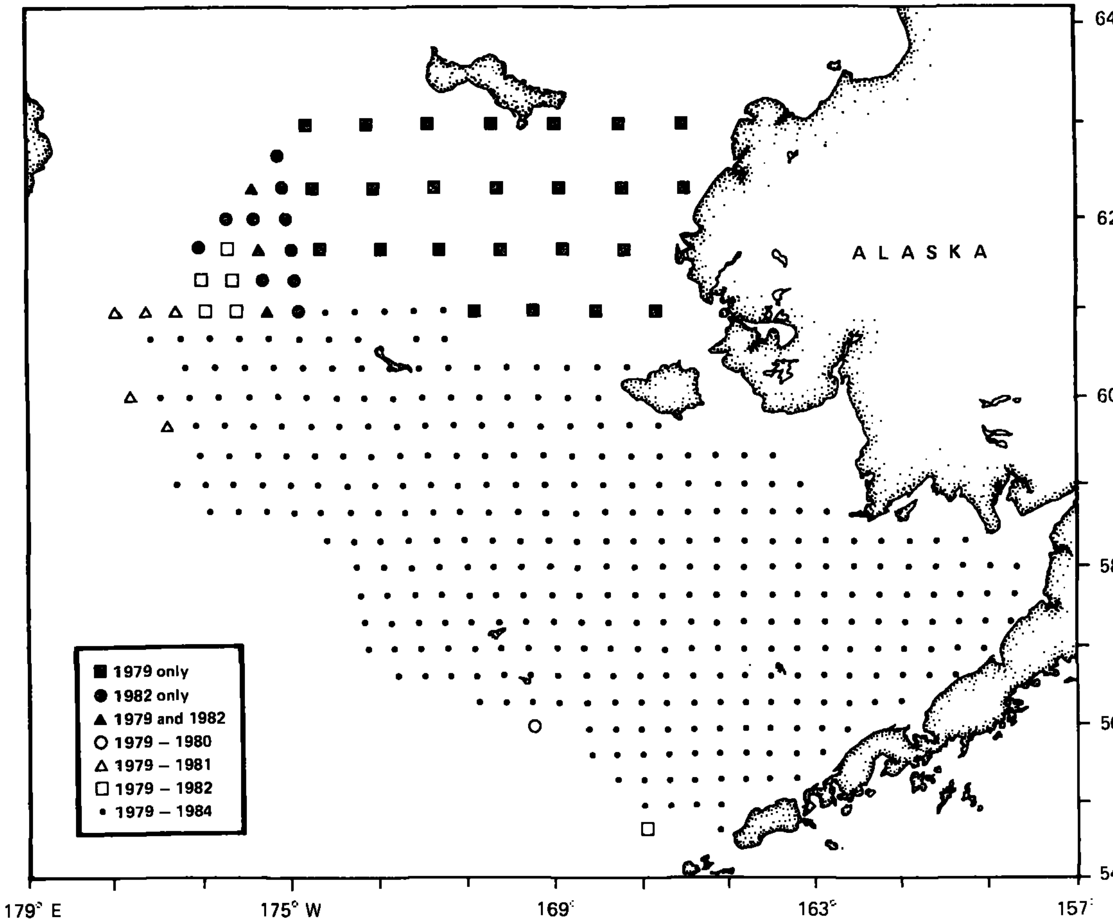


FIGURE 5.—Standard station pattern for NMFS eastern Bering Sea summer surveys, 1979-84. Actual stations occupied may have differed slightly from this pattern in any year.

Program (OCSEAP) cruise to the Pribilof Islands in May 1983. The seasons and durations of cruises are shown in Figure 6. Additional data concerning the NMFS summer cruises is contained in Otto et al. (1985, for the 1984 survey; similar documents are produced annually). Eastern otter trawl gear was used on all vessels throughout the 6-yr study period, except during the May 1983 OCSEAP cruise. On that cruise, either a 3.0 m beam trawl, 7.2 m try-net, or 1.2 m rock dredge were used to collect crabs, depending on bottom type determined from sediment samples taken with a Shipek bottom grab at each station. Fishing during both February cruises and the May 1983 cruise was conducted round-the-clock, whereas that during the summer surveys occurred only during daylight hours. Data collected during the February cruises and May 1983 cruise were not used in this report to determine distribution and abundance of hair crab in the EBS because of the limited area surveyed; only 1979-84 summer survey data were used for that purpose. Because different techniques were involved and no comparative fishing was conducted, catches of hair crab during the May 1983 cruise cannot be compared statistically with those from the summer surveys.

Tows were made in a systematic grid pattern with stations located 37 km (20 nmi) apart. During several years, extra tows were made in areas of higher hair crab abundance around the Pribilofs and in Bristol Bay, which increased the precision of population estimates during those years. Each tow lasted 0.5 hour and most were 2.2-3.3 km (1.2-1.8 nmi) long. Bottom temperatures were recorded with an expendable bathythermograph

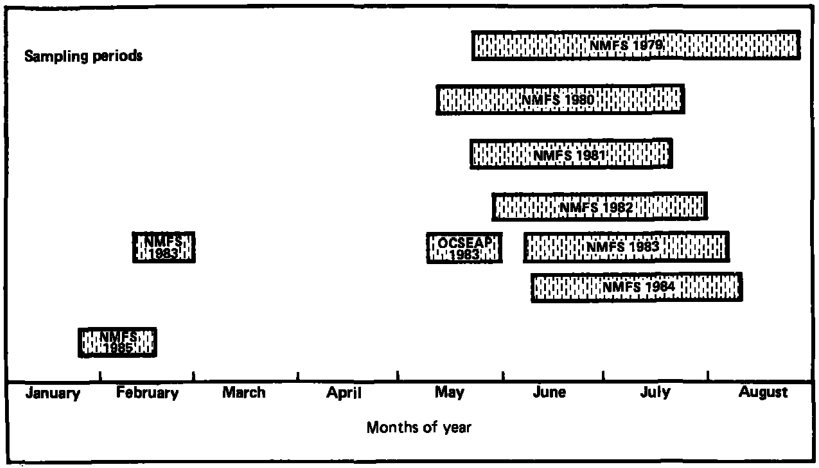


FIGURE 6.—Seasons and durations of sampling periods in the eastern Bering Sea, from 1979 through February 1985.

at as many stations as possible. After the catch was brought aboard, all species including hair crab were removed, counted, and weighed.

Carapace length of each crab was measured with steel vernier calipers to the nearest 1.0 mm from the rear of the right orbit to the middle of the posterior edge of the carapace (carapace length, CL). Carapace width (CW) was measured to the nearest 1.0 mm across the widest part of the carapace, excluding the lateral spines. Crabs were weighed on a triple-beam balance, and weights recorded to the nearest 1.0 g for crabs selected from a stratified size distribution. Shell condition was recorded as follows: molting (Drach's stages D_2 through E; Passano 1960), softshell (stages A_1 through B_1), new hard shell, old hard shell (probably skipped one annual molt), and very old hard shell (probably skipped several annual molts). Hard-shell conditions were graded subjectively according to the amount of epifauna on the carapace, color of carapace, and wear on the spines. A new hard-shelled crab carapace was relatively clean with no epifauna, reddish to yellowish brown, with sharp spines. A very old hard-shelled carapace, however, was usually darker brown in color and almost always had epifauna, and spines that were rounded or worn smooth. An old hard shell was intermediate between these two conditions, but in practice it was difficult to distinguish between new and old hard shell. The presence or absence of external embryos was recorded for all female crabs. Six ovigerous females caught by NMFS in the EBS, 1979-85, were preserved in 10% formalin and returned to the Kodiak NMFS laboratory for determination of fecundity. The entire clutch was removed from the crab, and the embryos dried, sieved to remove debris, and weighed to the nearest 0.1 mg. Three subsamples of embryos from each crab were weighed and counted. The total number of embryos was estimated by dividing the total clutch weight by the average embryo weight. For each of three crabs caught in 1980, diameters of 30 fixed embryos were measured to the nearest 0.1 mm under a stereomicroscope with an ocular micrometer, and average embryo diameters were calculated. Embryos were nearly spherical so no distinction was made between length and width. Other data were analyzed to determine distribution and abundance, sex composition, length frequency, molting periods, relative age according to shell condition, distribution by temperature and depth, and reproductive condition of females.

Population estimates were derived from trawl data using the area-swept technique (Alverson and Pereyra 1969) as described in Otto et al. (1985). The sampling variable was crab density, expressed as crabs caught per unit area swept, the latter equalling the product of net width and distance fished (determined with loran). High- and low-density strata were defined using the cumulative square root of frequencies method (Cochran 1963). Mean, total, and variance of crab density was determined within each stratum, and these combined for extrapolation to the survey area.

RESULTS

Distribution and Abundance

In the EBS, hair crab range from Bristol Bay west to about long. 174°00'W and north to St. Matthew Island at lat. 60°30'N (Fig. 7). Because so few juvenile and female hair crab were caught in NMFS surveys, the following information on distribution and abundance primarily concerns large males. Since fishery landings consist primarily of male crabs >89 mm CL, these are called "large", whereas "small" refers to male crabs <90 mm CL.

Within the survey area, the crabs are divided into eastern and western centers of abundance. The western group occurs primarily in the Pribilof District (Alaska Department of Fish and Game [ADF&G] statistical district; south of 58°39'N, and west of 168°00'W) and is most dense (>10 crabs/nmi trawled) immediately adjacent to the Pribilof Islands. Moderately dense concentrations (1-10 crabs/nmi trawled) surround the Pribilof high-density region, especially to the northeast and south. The eastern group occurs in the Bristol Bay District (south of 58°39'N and east of 168°00'W) and is centered along the northern shore of the Alaska Peninsula from western Unimak Island to about 160°00'W. This group is moderately dense, with areas of high density (10-100 crabs/nmi trawled) located near the western end of the Alaska Peninsula in 1979, and offshore of Unimak Island in 1981. Hair crab are scattered across the continental shelf between these two major population centers and in the Northern District (north of 58°39'N) in low densities (<1 crab/nmi trawled). As with large males, small males and females displayed distinct eastern and western concentrations, but very few were scattered between these two regions. Because of the more-or-less continuous distribution of hair crab across the EBS, we subsequently treat them as belonging to a single widespread population.

Population estimates have been made for hair crab only since 1979 (Table 2), and as previously mentioned, these reflect primarily the abundance of large males. From 1979 to 1981, the estimated population of EBS hair crab remained fairly stable between 22 and 24 million crabs. The population dropped 60% between 1981 and 1982, 35% from 1982 to 1983, and 30% more from 1983 to 1984, to a low of only 4.4 million crabs. (*Note added in proof*: Hair crab abundance has continued to decline to a total of 2.5 million crabs in 1986.) From 1979 to 1984, an average of 67% of the EBS hair crab occurred in the Pribilof District, 27% in the Bristol Bay District, and 6% in the Northern District. Although the total population size did not vary greatly from 1979 to 1981, the proportion of the population in the Pribilof District increased from 51 to 81%, while it decreased from 40 to 18% in the Bristol Bay District, and from 9 to 1% in the Northern District. By 1984, the population distribution was again similar to that of 1979. The population was very densely concentrated around the Pribilofs in 1981; however, since that time, the densities and range of hair crab in the EBS have declined greatly.

Females comprised only 8% (248) of the total catch of about 3,091 hair crab during the 1979-84 NMFS summer surveys. In contrast, females accounted for 40% (48) of the 120 hair crabs >40 mm CL caught during the survey conducted in the Pribilof Islands in May 1983, when fishing was conducted both day and night around the Pribilof Islands, with dredge, try-net and beam trawl.

Habitat

Male *E. isenbeckii* collected during the summer

TABLE 2.—Population estimates for *Erimacrus isenbeckii*, in the eastern Bering Sea, and proportions of the total population present in each statistical district. See text and Figure 7 for description of districts. Numbers are millions of crabs[1]. M = Male, F = Female.

Year	Pribilofs				Bristol Bay				Northern				Totals				Grand total
	M	F	All	%	M	F	All	%	M	F	All	%	M	±%[2]	F	±%	
1979	11.9	0.3	12.2	51	8.8	0.9	9.7	40	1.8	0.4	2.2	9	22.5	29	1.6	35	24.1
1980	15.1	2.3	17 4	77	3.6	0.7	4.3	19	0.8	0.1	0.9	4	19.5	47	3.1	138	22.6
1981	18.1	0.3	18.4	81	3.7	0.5	4.2	18	0.2	0.0	0.2	1	22.0	19	0.8	42	22.8
1982	6.3	0.1	6.4	67	2.3	0.2	2.5	26	0.5	0.1	0.6	6	9.1	22	0.4	56	9.5
1983	2.8	0.3	3.1	48	1.9	0.5	2.4	39	0.7	0.1	0.8	13	5.4	15	0.9	38	6.3
1984	2.3	0.2	2.5	57	1.2	0.1	1.3	30	0.5	0.1	0.6	13	4.0	16	0.4	48	4.4

[1]Numbers represent only crabs within the survey area and those large enough to be retained by the trawl, i.e. mostly large males (>89 mm CL).
[2]Two standard errors expressed as a percentage of the mean.

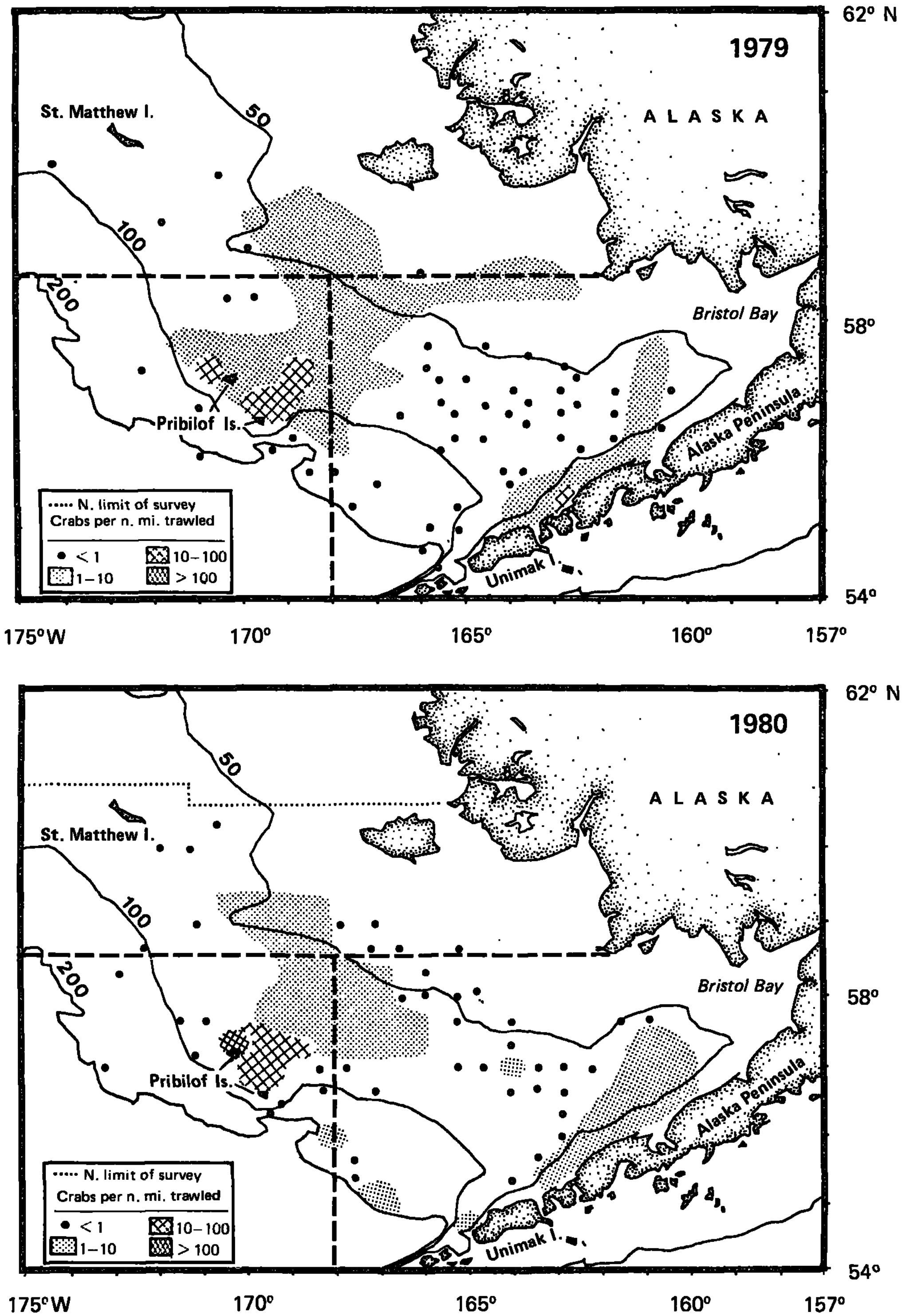


FIGURE 7.—Relative abundance of *Erimacrus isenbeckii* in the eastern Bering Sea, 1979-84. Depth contours are shown at 50, 100, and 200 m. Dotted line indicates the northern limit of the survey in each year. Dashed lines demarcate the Bristol Bay (south of lat. 58°39'N, east of long. 168°00'W), Pribilof (south of lat. 58°39'N, west of long.

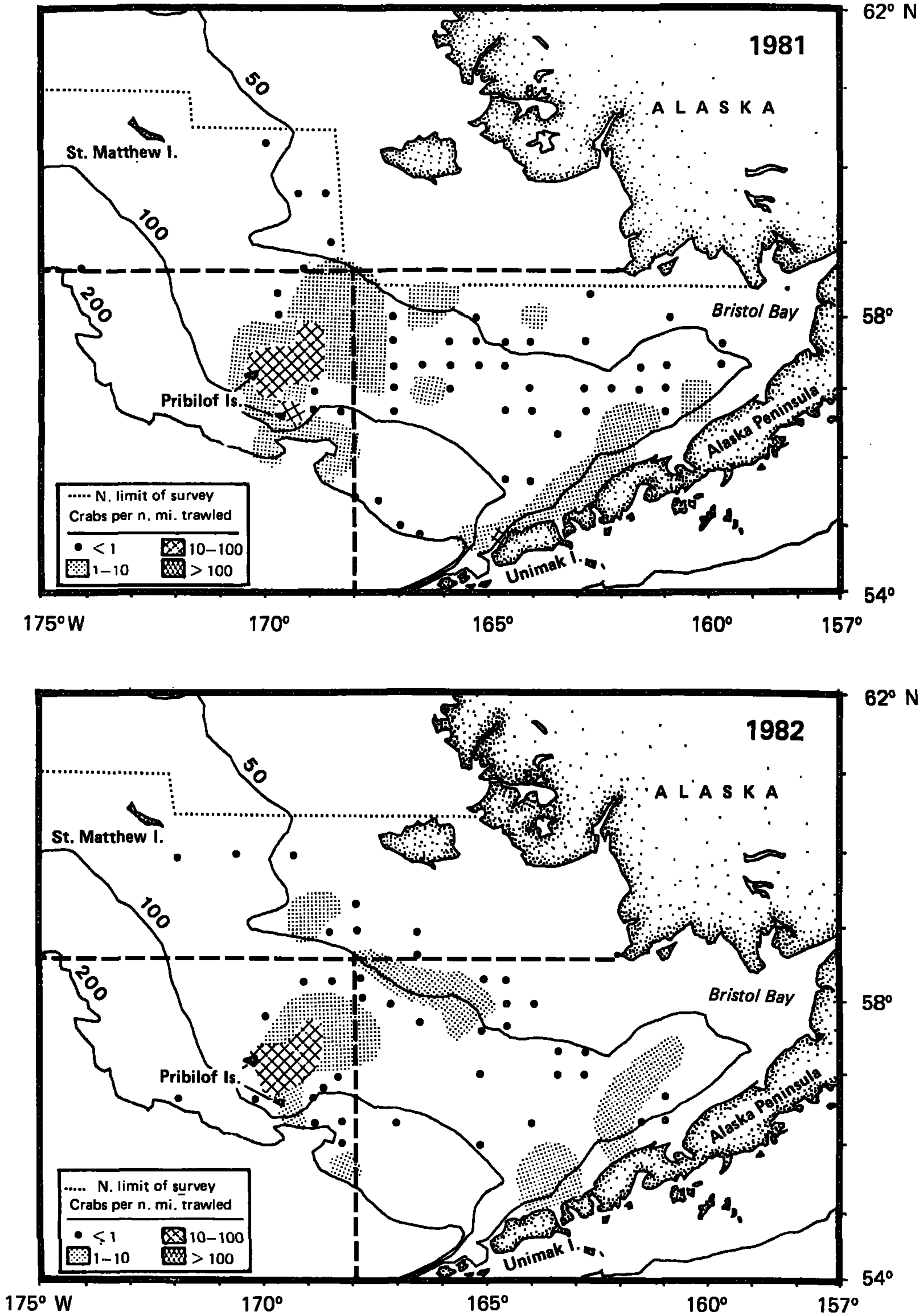
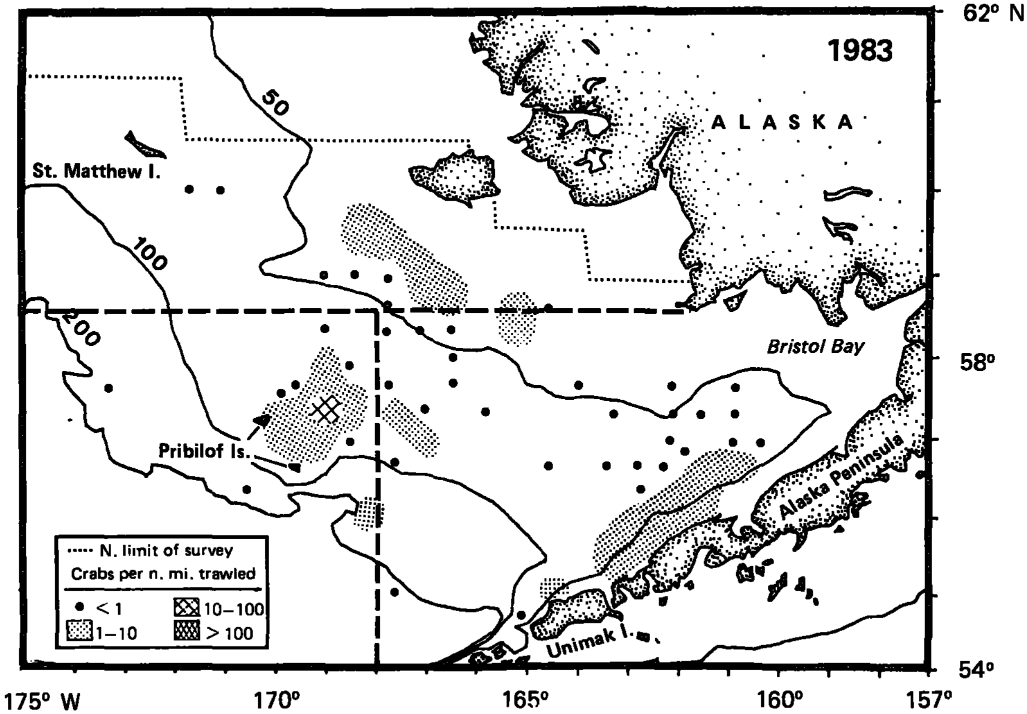


FIGURE 7.—*Continued*—168°00'W), and Northern (north of lat. 58°39'N) statistical districts. Densities expressed as crab per nautical mile trawled.



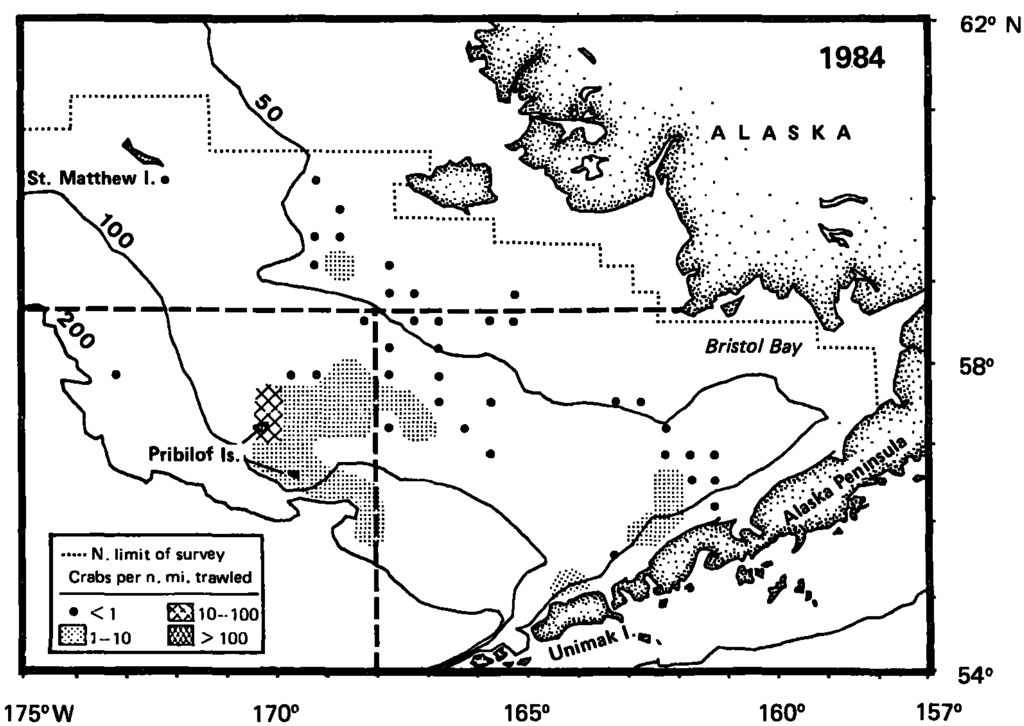


FIGURE 7.—*Continued.*

surveys occurred at a mean temperature (weighted by crab abundance) of 3.4°C and depth of 65.6 m, although they ranged from −0.9° to 10.1°C and from 22 to 249 m depth. One male hair crab was found outside this range, at 401 m. The mean values for females were 2.4°C (range −0.9°-7.3°C) and 63.8 m depth (range 26-243 m). Results of a 2-sample t-test with unequal variances (Minitab "Twosample T" test; Ryan et al. 1976) indicated there was no significant difference ($t = 1.52$, df = 213, $P = 0.13$) between mean depths at which male and female hair crab were found; however, there was a significant difference ($t = 5.82$, df = 219, $P < 0.01$) between mean temperatures.

Data from the Pribilof Island study of May 1983 indicate that hair crab appear to prefer a heterogenous substrate as early juveniles, switching to sandy bottoms with increasing age. Among 120 juveniles <20 mm CL, 41% were on a substrate of gravel (less than about 1 cm diameter), polychaete tubes, and shell fragments, and small numbers were found in areas of large rocks, mud, or large shells. A substrate of medium or fine sand (usually containing shell fragments) was occupied by 58% of crabs in the size range <20 mm CL, 70% of 10 crabs in the range 20-40 mm CL, 94% of 73 males >40 mm CL, and all 48 females >40 mm CL.

Reproduction

The scarcity of juvenile and female hair crabs in NMFS collections prevented a thorough study of reproductive characteristics of the EBS population; only eight ovigerous females were caught from 1979 to 1985. The size at maturity of these crabs in the EBS is unknown, however, the smallest mature female caught by NMFS was 38 mm CL and had spermathecae filled with a viscous liquid, indicating it had been mated. The smallest female with empty egg cases caught by NMFS was a 42 mm CL old hard-shell crab. We follow Abe (1977) in assuming that the mean size at maturity for female hair crab is above 55 mm RL (50 mm CL).

Some female hair crabs collected during NMFS summer surveys were found with hard, proteinaceous plugs in the gonopores. The plugs were rootlike in appearance and formed a large, whitish, irregular-shaped protuberance outside the aperture (Fig. 8a). Each plug had a white, tapered stem that extended inward to the spermatheca (Fig. 8b). Some gonopores without plugs were closed by a flexible, swollen membrane (Fig. 8c) similar to the arthrodial membrane and continuous with the lining of the canal leading to the spermatheca. Some gonopores were open (Fig. 8d), owing to the flexible membrane having become flaccid.

Although the presence of closed pores was not associated with any particular shell condition of the female, plugs and open pores were. Plugs were present only in recently molted soft-shell crabs, while most females with open pores (28 of 30, or 93%) were new or old hard-shell crabs. Some females had only one plug, and 96% of these also had the other pore closed. During the May 1983 OCSEAP cruise, 40% (19) of the 48 large females (>40 mm CL) caught had plugged gonopores, 1 had new uneyed embryos, 4 carried eyed embryos that were in the process of hatching, and 11 carried empty egg cases. Of the 19 females with plugged gonopores, 89% (17) were new hard-shell crabs and 2 were newly molted soft-shell crabs.

Most female hair crabs caught carried no external embryos (Table 3A). Although few crabs with

TABLE 3.—Seasonality of egg bearing and molting in *Erimacrus isenbeckii* from the eastern Bering Sea. A) Percent of female crabs (actual number in parentheses) with embryos in each of 4 developmental stages. B) Percent of molting or soft-shelled crabs for each sex (total number of males or females caught shown in parentheses).

	February surveys		Summer surveys, 1979-1984, years combined			
	1983	1985	May	June	July	August
A. Condition of external embryos						
None	86(26)	93(14)	89(16)	88(109)	73(54)	38(12)
Uneyed	0	7(1)	0	0	1(1)	3(1)
Eyed	7(2)	0	11(2)	1(1)	0	0
Hatched	7(2)	0	0	11(14)	26(19)	59(19)
B. Frequency of molting or soft-shell crab						
Male	20.0(136)	0.0(56)	1.3(234)	2.0(1240)	3.1(1215)	0.0(154)
Female	30.0(30)	6.7(15)	0.0(18)	5.6(124)	18.9(74)	3.1(32)

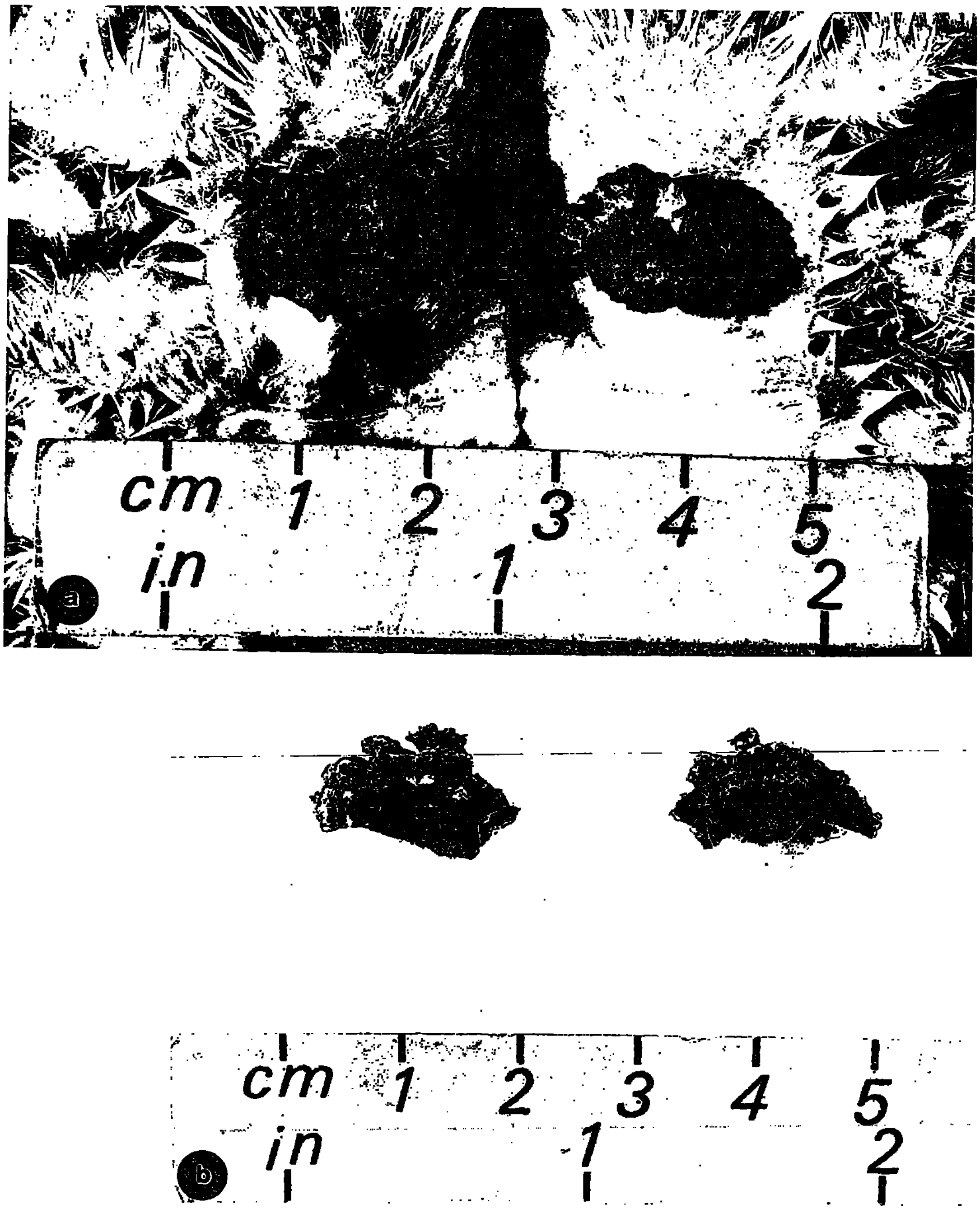
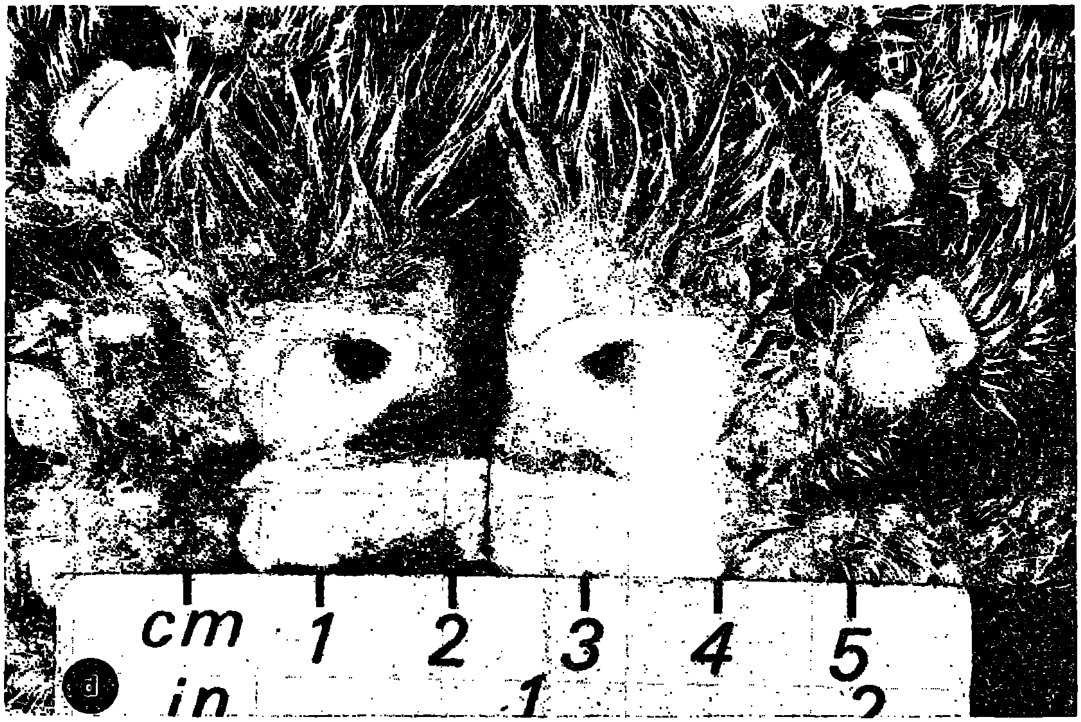


FIGURE 8.—Spermathecal plugs in formalin preserved female *Erimacrus isenbeckii*. a, ventral view of third thoracic sternite, with anterior towards the top of page, showing both gonopores with plugs; b, plugs removed from female crab; c, both pores closed (no plugs); d, both pores open. Plugs in live animals were whitish in color.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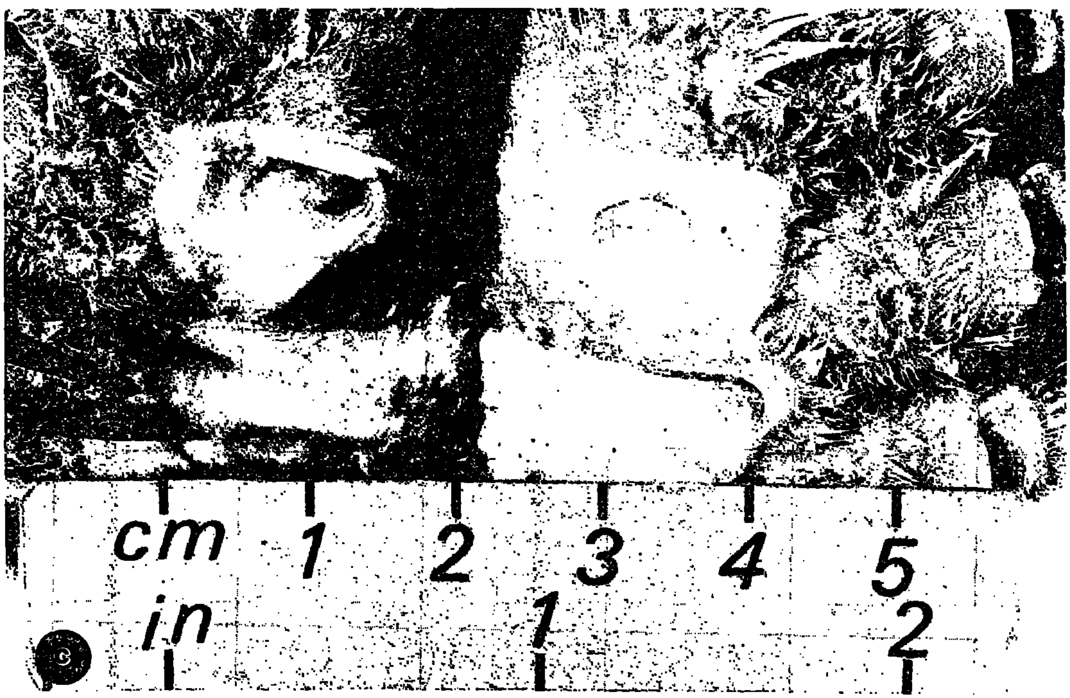
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embryos were caught, the highest proportions occurred in February and May. Empty egg cases became proportionately more abundant from June through August. The eight ovigerous females caught ranged from 56 to 87 mm CL. Fecundity estimates for six ovigerous females ranged from 34,000 to 160,400 embryos, averaging 0.9 mm in diameter (Table 4). Uneyed embryos were orange in color, whereas eyed embryos were dark brown.

Molting and Growth

Seasonality

Molting periodicity of hair crabs in the EBS is not well understood, owing to the lack of seasonal data. Summer cruises during 1979-84 turned up only three molting male crabs. Molting and soft-shell crabs comprised only 2.2% of males (65 crabs) and 8.9% of females (22 crabs) (Table 3B). Molting females were more abundant in July samples, but males showed no particular pattern.

Molting was much more apparent during the February 1983 cruise. Thirty percent (9 of 30) of female crabs were soft shell. Among the 136 males captured, 9% (12) were soft shell and 11% (15) were undergoing ecdysis. In contrast to the 1983 results, almost no molting was observed in February 1985. All 56 males captured were new hard shell or older, and only 1 (6.7%) of 15 females was soft shell.

In the EBS, based on the percentage of crab that we classified as new hard shell each year, an average of 79% of the large males (>89 mm CL), 95% of the small males (<90 mm CL), and 84% of the females appeared to have molted by the time the summer survey occurred.

Size Range

During the period 1979-84, 3,091 specimens of *E. isenbeckii* were captured in NMFS summer surveys, of which only 248 were females (Table 5). The average size of males caught was 96.1 mm CL

TABLE 4.—Estimated egg number and condition for six ovigerous female *Erimacrus isenbeckii* caught in the eastern Bering Sea from 1979 to 1985. Hyphens indicate no data taken.

Length (mm)	Date caught	Total[1] eggs	Egg condition	Egg color	Mean diameter[2] (mm)
65	9/82	107,900	—	—	—
69	5/80	103,400	uneyed	orange	0.86
74	9/81	113,600	eyed	—	—
79	7/85	160,400	uneyed	orange	—
82	5/80	99,800	eyed	dark brown	0.94
87	5/80	33,500	uneyed	orange	0.88

[1]Estimated from total dry weight of clutch (see methods).
[2]No obvious difference between length and width.

TABLE 5.—Descriptive statistics of *Erimacrus isenbeckii* caught during NMFS surveys, 1979-84, in the eastern Bering Sea. Carapace lengths were measured from the right orbit.

	Mean		*s*	Range	Number measured
Males					
length (mm)	96.1		12.7	17-145	2,810
width (mm)	93.5		17.0	18-133	1,089
weight (g)	714.3		339.5	3-1574	703
Total males caught		2,843			
Females					
length (mm)	65.5		16.2	14-111	246
width (mm)	67.2		16.5	14-109	232
weight (g)	197.1		137.1	4-623	179
Total females caught		248			
Total caught		3,091			

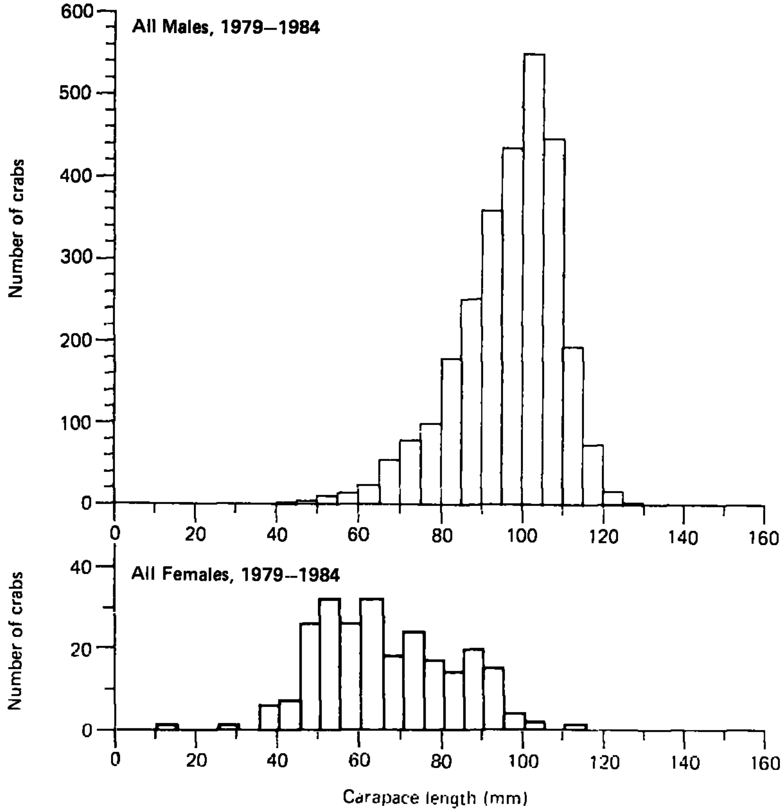

FIGURE 9.—Carapace length frequencies of *Erimacrus isenbeckii* collected during NMFS summer surveys in the eastern Bering Sea, 1979-84. Data for all 6 years were combined. Note scarcity of specimens below about 45 mm CL.

(range 17-145 mm); females averaged 65.5 mm CL (range 14-111 mm). Median values were 98 mm CL for males and 63 mm CL for females. The combined length-frequency distributions of male and female hair crab, 1979-84, are shown in Figure 9. In order to facilitate conversion between different methods of measurement, we calculated regression relationships between length, width, and weight (Table 6).

DISCUSSION

Distribution and Abundance

The decline of the EBS hair crab population occurred during the same time period (1980-84) in which substantial declines of red and blue king crabs (*Paralithodes camtschatica* and *P. platypus*, respectively), as well as two species of snow (Tan-

TABLE 6.—Regression relationships for length, weight, and width of *Erimacrus isenbeckii*, from the eastern Bering Sea. Length is carapace length from orbit.

	R^2	n
Males		
length (mm) = 2.28 + 0.974 width (mm)	0.945	1,087
L_n weight (g) = −7.24 + 3.02 L_n length (mm)	0.926	703
Females		
length (mm) = 1.87 + 0.938 width (mm)	0.969	231
L_n weight (g) = −6.73 + 2.86 L_n length (mm)	0.946	178

ner) crab (*Chionoecetes bairdi* and *C. opilio*) also occurred in the EBS (Stevens and MacIntosh 1985[9]). These events may be responses to common causes such as changes in the oceanographic environment of the Bering Sea, increased predation, or increased incidence of disease. A. K. Sparks[10] indicated that a presumptive viral infection was present in 13 of 20 hair crabs collected opportunistically in 1983, and in 2 of 3 examined from 1984 collections in the EBS. Although damage to the antennal gland in these infections suggest that the disease is fatal, this has not been proven. Fishery removals have ranged from <1% (before 1980) to a high of 11% (1983) of the estimated population of large males, which is probably underestimated (see Tables 1 and 2). Thus fishing pressure does not seem to have played a significant role in the population decline. A more plausible explanation of the decline in the hair crab population (and perhaps other EBS crab species as well) is that very large year classes may have been produced in the EBS in the late 1960's or early 1970's, recruited to the fisheries in the period 1977-80, and then declined to lower levels as these crabs succumbed to mortality. Historical data support this hypothesis for red king crab, and it may be applicable to hair crab as well as other species of crab.

Changes in the proportions of the hair crab population in various districts of the EBS (Table 2) may indicate that many crabs shifted from the Bristol Bay and Northern Districts into the Pribilof District and back again over the 6 survey years, or more likely, that the eastern and northern segments of the population began to decline several years before the Pribilof population, which may have been increasing until 1982. Bottom temperature did not seem to be an important factor in determining distribution of hair crab since there was no narrow range of temperature consistently associated with high catch rates.

The low percentage of female hair crab caught in the annual NMFS summer trawl surveys, compared with the relatively high percentage caught in the May 1983 survey, might be a result of gear selectivity, and possibly indicates that females were more abundant in shallow (<25 m) water or nearshore habitats that were not heavily sampled during the summer surveys. Low proportions of female hair crabs have also been captured during surveys around Hokkaido, where females comprised only 1-12% of the total catch (Kawakami 1934; Hirano 1935; Matui 1970). Hirano (1935) felt that the low numbers could be attributed to the small size of females in relation to mesh size of the net used for sampling, a preference by females for different habitats, or perhaps frequent burrowing. In a laboratory experiment, Hirano noted that females burrowed as deep as 13-15 cm for up to 4 days, whereas males burrowed for relatively short periods of time and usually so shallowly that the carapace protruded at the surface. Most (90%) of the adult females collected in the May 1983 survey were caught by trawl or try-net between the hours of 1900 and 0600. Abe (1973), however, found very little difference in the trawl catches of females between night (two 1-h tows at 2100 and 0330; 11 caught) and day (two 1-h tows at 0900 and 1500; 9 caught), although he did find that females were significantly more vulnerable to crab pots during the day (281 crabs/118 pots) than at night (46 crabs/115 pots). It is possible that increased activity of females during the day resulted in the higher pot-catch. During Abe's survey, females comprised 35% (347) of the total catch of 996 hair crab.

Depth, temperature, and substrate preferences appear to be similar for EBS and Japanese populations of hair crab, although maximum annual bottom temperatures in the EBS rarely exceed 12°C.

Compared with the distribution of juvenile and adult hair crab in the EBS, hair crab larvae were distributed primarily north and northwest of Unimak Island (Fig. 10) and concentrated in the upper 40 m of the water column, during surveys in the spring and summer of 1976-81 (Armstrong et al. fn. 4). Highest concentrations (over 5,000 larvae/100 m^2) occurred from Unimak Island north to about 55°30'N, mostly along the 50 m isobath. Low numbers (1-1,000/100 m^2) were scattered broadly over shelf and slope areas, but were more abundant along the 100 and 200 m isobaths. Sparse sampling occurred in the Pribilof Islands area during those surveys, but extensive sampling was conducted there in May 1983 (Arm-

[9]Stevens, B. G., and R. A. MacIntosh. 1985. Report to industry on the 1985 eastern Bering Sea crab survey. NWAFC Processed Rep. 85-20, 48 p. Kodiak Facility, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 1638, Kodiak, AK 99615.

[10] A. K. Sparks, Fisheries Research Biologist, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115, pers. commun. May 1985.

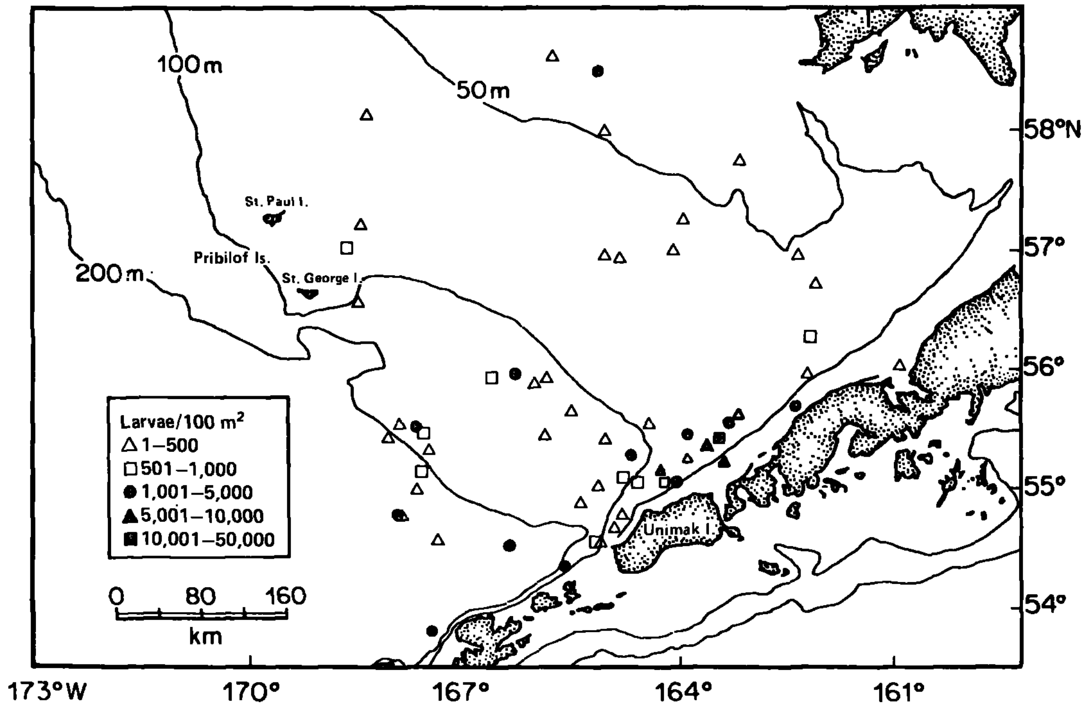

FIGURE 10.—Locations and densities of *Erimacrus isenbeckii* larvae collected in the southeastern Bering Sea, 1976-81. Locations where no larvae were found are omitted. With permission, from Armstrong et al. 1983 (see text footnote 4).

strong et al. 1984[11]). Highest concentrations (over 20,000 larvae/100 m^2 at one station) were found in waters 40-80 m deep, within about 24 km of St. Paul Island. Very few larvae were found near St. George Island.

Reproduction

The gonopore plugs found in female hair crab collected by NMFS resembled those described by Yoshida (1940) as having a "distal end that swells into an irregular form outside the aperture" and were of male origin (Morado[12]). The proximal tip of the plug extends to the spermatheca, as noted also by both Yoshida and Hirano (1935). The flexible, swollen membrane (Fig. 8c) that closed the aperture of some females is apparently not an exogenous plug, but a part of the female crab's body. The purpose of gonopore plugs is not known, but Hirano (1935) has conjectured that they serve to prevent copulation with other males during the period between the completion of copulation and spawning. They may also prevent degradation of the sperm from contact with seawater. Hartnoll (1969) reported that similar plugs have been observed in *Cancer irroratus, C. pagurus, Callinectes sapidus*, and *Carcinus maenas* and surmised that they prevent loss of sperm from female crabs which mated while still soft, or that they are a vestigial remnant of a hard sperm-case applied externally by more primitive ancestral brachyurans.

The following sequence of events is suggested by the observed associations between shell condition of female crabs and the presence or absence of gonopore plugs. After mating, the plugs loosen and slough off, either by mechanical abrasion (Yoshida 1940) or by dissolution from within as

[11]Armstrong, D. A., J. L. Armstrong, G. Jensen, R. Palacios, and G. Williams. 1984. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. Interim Rep. OCSEAP/OMPA contract No. 83-ABC-00066. Office of Marine Pollution Assessment, Alaska Office RD/MPF24, P.O. Box 1808, Juneau, AK 99802.

[12]J. F. Morado, Fisheries Research Biologist, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115, pers. commun. May 1982.

the female's ovaries mature (Hirano 1935), leaving the swollen membrane in place. The membrane eventually becomes flaccid, perhaps to allow egg extrusion. As the spawning period approaches, the spermatophores gradually break up and release spermatozoa. Fertilization occurs, either as the eggs are extruded (Kawakami 1934; Yoshida 1940) or afterwards, perhaps by contraction of the sperm sac and expulsion of the spermatozoa over the eggs (Sakurai et al. 1972). Our estimates of the number of external embryos carried by EBS hair crabs are in accordance with Sakurai et al. (1972, see Literature Review).

Molting and Growth

Molting frequency varies with age and sex of the crab. Because the percentage of recently molted male crabs declined with increasing size, the NMFS data appears to support Yamamoto (1971), who indicated that molting frequency of males decreases as size increases. Yoshida (1941) claimed that female hair crab molt every other year. Our data neither support nor refute this. However, old and new shell conditions are difficult to distinguish in hair crab, because shell discolorations and epibiota are uncommon. Thus, it is difficult to determine when a particular crab last molted. A higher frequency of molting in February (based on the 1983 data, Table 3B) for EBS hair crab tends to support the conclusions of Abe (1984[13]) and Sakurai et al.(1972) (Fig. 3) that hair crab molt and mate in winter, although the 1985 data did not. The second period of molting exhibited by female crabs in July tends to support the contention by Sakurai et al. that multiparous females molt and breed from August to November; however, females exhibited a low frequency of molting in August. Crabs of all sizes molted in both periods.

The effect of temperature on molting periodicity of hair crab is unknown. Mean bottom temperatures that were 2.5°C warmer in February 1985 than February 1983 for stations sampled for hair crab in both those years could have affected the onset of molting in 1985. Whereas in 1983, 22% of the hair crab caught were molting or in soft-shell condition, in 1985 only 1% were.

Abe (1982) determined the mean carapace length of 14 male and 13 female hair crab postlarval instars (Table 7) through length-frequency analysis of 10,547 individuals. For the first 9 instars, there was no difference in mean carapace length between males and females. However, after sexual maturity (i.e., sizes greater than about 55 mm RL or 50 mm CL) females showed less growth per molt than males, although growth increments decreased with age for both sexes. Abe plotted postmolt carapace lengths (L_{n+1})

[13]Abe, K. 1984. Reproductive cycle of hair crab. Unpubl. manuscr. Chief, Fisheries Resources Division, Hokkaido Wakkanai Fisheries Experimental Station, 5-4 Horai, 4-chome, Wakkanai, Hokkaido, 097, Japan. Presented at the hair crab conference, Yoichicho, Japan, January 31, 1984.

TABLE 7.—Mean carapace length (mm RL) for each postlarval instar of male and female hair crab, *Erimacrus isenbeckii*, (from Abe 1982), and calculated mean growth increment for the next molt.

Instar number	Mean length[1] (mm) male	Mean length[1] (mm) female	Percent increase male	Percent increase female	Calculated Orbit length (male)
C1	5.2		35		
C2	7.0		24		
C3	8.7		44		
C4	12.5		25		
C5	15.6		31		
C6	20.4		34		
C7	27.4		22		
C8	33.5		38		
C9	46.4		27	20	41.9
C10	59.1	55.9	24	18	53.6
C11	73.3	65.8	20	13	66.7
C12	88.2	74.1	17	13	80.4
C13	103.5	84.0	14		94.5
C14	117.5				107.4

[1]Lengths of females were same as males for instars 1-9.

against premolt carapace lengths (L_n) and derived the following equations (not converted to CL):

Both sexes (<50 mm RL)	$L_{n+1} = -0.40 + 1.336\ (L_n)$
Males (>50 mm RL)	$L_{n+1} = 11.68 + 1.036\ (L_n)$
Females (>50 mm RL)	$L_{n+1} = 9.49 + 0.998\ (L_n)$

Abe (1982) plotted the regression of percent growth per molt on length, and estimated maximum lengths to be 125 mm RL (116 mm CL) for females and 177 mm RL (162 mm CL) for males. The largest hair crabs observed by NMFS in the EBS (Table 5) were smaller than these projections, as were those caught near Hokkaido by Abe (1982), who reported maximum lengths of 152 mm RL (139 mm CL) for males and 105 mm RL (97 mm CL) for females. Reportedly, female hair crabs from Hokkaido rarely reach a carapace length >80 mm RL (73 mm CL) (Sakurai et al. 1972). In contrast, over 20% of the females caught in the EBS were >80 mm CL. However, NMFS trawl gear caught few hair crab <40-50 mm CL, and juvenile and female crabs may occupy rocky nearshore habitat which cannot be adequately sampled by such gear.

The mean age of hair crab in the fishable population can be estimated from available data. Abe (1982) concluded that male crabs mature in their 10th postlarval instar, about 33 months after hatching, at about 60 mm RL (54 mm CL; Fig. 3). According to Yamamoto (1971), they would require one more annual molt to reach stage C11 in their fourth year. At this size, crabs may molt annually or biennially. Male crabs landed in the EBS fishery averaged 106 mm CL (116 mm RL) in 1984, or about stage C14 (Tables 1, 7). To attain this size would require 3 molts from C11, and these crabs would range in age from 7 to 10 years depending upon whether their last 3 molts were annual or biennial. If any failed to molt more than 1 year in a row, they would be age 11 at this size. Abe (fn. 13) (Fig. 3) indicated that male hair crab in Hokkaido waters reach similar sizes at the age of 6 years (assuming none skip molted).

Resource Potential and Management

Because of the great declines in abundance of the Bering Sea populations of *E. isenbeckii* from 1979 to 1984, this fishery will probably not be of great economic importance in the near future. If abundance increases in the future and prices remain adequate, this fishery might become lucrative, albeit on a small scale relative to other Bering Sea crab fisheries. The species could then probably support a small boat fishery in the Pribilof Islands. Hair crab are still in high demand in Japan.

The EBS hair crab fishery is not intensively managed. Fishing may occur year-round and is not limited by quotas. However, only males may be landed and gear is restricted to crab pots. There is no minimum size limit since the marketable size is large relative to the probable size of male maturity (about 54 mm CL), although the latter has not been adequately determined.

As a result of distribution and habitat differences as well as gear selectivity, the size-frequency distributions of NMFS collections have been largely unimodal with few juveniles and females in the catch. Thus, a thorough study of EBS hair crab reproduction and recruitment has not been feasible. Much useful information could probably be gained by systematic, year-round sampling of rocky heterogeneous habitats around the Pribilof Islands with appropriate gear such as rock dredges and beam trawls. Some data of this sort have already been collected by Armstrong et al. (fn. 11) and during other NMFS surveys, but are too limited to allow an improved understanding of growth rates, or the seasonality of molting and spawning of hair crab in the EBS. Further information on maturity, growth, and mortality is critical for informed management and will be necessary if this fishery gains importance.

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