3 Major Species and Stocks of Crabs in the PICES Region

According to FAO statistics, five species or species groups of crabs within the PICES Region made up 78.5% of reported landings over the past 15 years (Table 3). Four of these are brachyurans and the other is an anomuran (king crabs). The gazami crab (Portunidae, *Portunus trituburculatus*) alone represented 39.5% of landings over this period. Snow, or Tanner, crabs (Majidae, *Chionoecetes* spp.) include five species. The Dungeness crab (*Cancer magister*) is the largest cancrid in the Pacific and supports an important eastern Pacific inshore fishery from the eastern Aleutian Islands south to California. Landings of king crabs (Lithodidae) include three species of *Paralithodes* and two species of *Lithodes*. "Other crabs" refers almost entirely to the portunid crab *Portunus pelagicus*. Portunid crabs dominate world crab landings and it is testimony to their high productivity that portunid landings also dominate the PICES Region, even though they inhabit only a small part of it.

Table 3 Summary of reported marine crab landings (10^3 t) from the PICES Region as approximated by member nation's landings in FAO Areas 61 (NW Pacific), 67 (NE Pacific) and 77 (E Central Pacific).

Year	Gazami Crab	Snow Crabs	Dungeness Crab	Other Crabs	King Crabs	Total
1984	30.3	29.0	12.5	93.9	38.4	204.1
1985	29.2	49.2	14.0	92.5	40.1	225.0
1986	36.2	63.5	11.5	86.1	49.8	247.1
1987	142.8	61.0	15.0	74.8	53.1	346.6
1988	134.5	74.1	23.1	72.1	54.6	358.4
1989	174.9	83.2	20.1	69.4	54.5	402.2
1990	148.2	101.6	16.4	94.7	57.9	419.0
1991	154.8	169.9	12.0	98.1	53.7	488.4
1992	176.1	165.4	22.2	90.4	49.5	503.7
1993	130.6	121.6	31.4	97.2	46.9	427.7
1994	297.1	79.3	26.9	118.7	44.0	565.9
1995	265.3	45.7	26.3	128.9	61.9	528.1
1996	303.2	34.2	34.5	187.5	44.1	603.5
1997	252.5	58.8	20.7	183.7	31.6	547.3
1998	284.0	118.9	18.5	156.4	43.6	621.3
Total	2559.7	1255.5	305.0	1644.1	723.7	6488.3
%	39.5	19.3	4.7	25.4	11.2	100.0

3.1 Gazami crab (*Portunus trituburculatus*, Portunidae, FAO: GAZ, Area 61)

The gazami crab (Plate 1) is the largest crab fishery in the PICES Region (Table 3) and is the largest single-species crab fishery in the world. It is frequently referred to as "blue crab", but we use the FAO common name here to avoid confusion with a similarly named, heavily exploited species (*Callinectes sapidus*) from eastern North America. Portunid crabs in general are also occasionally referred to as blue crabs, although the term swimming crabs is much preferred. The gazami crab is found in the Bohai Sea, Yellow Sea, and the East China Sea, as well as in certain Japanese waters within the PICES Region, but is also harvested in areas south of 24°N. Due to this southerly distribution, landings for China may include areas outside the PICES Region. This is the only crab of any great commercial importance in the Chinese portion of the PICES Region. Significant fisheries for this species are also prosecuted in Japan and South Korea (Table 4), and it is probably harvested in North Korea as well. While there are multinational fisheries for gazami crab in the Yellow and East China Seas, most fishing is in inshore waters and there is no international management of the resource. In Japan, considerable fishing takes place in the Inland Sea (Shiota 1993, Ariyama 1993) but gazami landing statistics are not well distinguished from that of other swimming crabs and the fishery is small relative to that in China or South Korea. Most crab fisheries in the PICES Region use pots and only exploit large males. By contrast, gazami crabs are usually fished with trawls or other types of nets over most of their range, and both males and females are harvested.

3.1.1 China

The gazami crab and several other portunid crabs are intensively cultured in some areas of China, including parts of the East China Sea coast, where separation of aquacultural production from wild harvests in landing statistics may not be complete. There are intensive Chinese fisheries for wild stocks of gazami crab in the Yellow and Bohai Seas (Table 5), where aquaculture is absent.

During the last decade, catches of gazami crab in China have increased year after year, and so far are being sustained. Based on landings from Zhejiang Province, China, yearly catches increased from 10-15 to 20-25 thousand tons between 1972-1977 and 1978-1982, respectively, due to increased fishing effort. For example, a landing in 1978 of 6,800 t was achieved by 300 fishing vessels of Wenzhou (one of the districts of Zhejiang Province), while 2,000 vessels realized a catch of 10,400 t in 1982. Other factors confirmed this catch–per-unit-effort (CPUE) decline. To sustain abundance, conservation measures need to be taken, appropriate to the gazami crab's biology. It was suggested that protecting spawners in the spring, young crab habitat in the summer, and conducting reasonable fishing in winter be considered (Zhaung and Deng 1999).

According to catch analyses (Zhaung and Deng 1999) in China from 1922-1981, individual body weight ranged from 15-650 g, with 70% ranging from 140-340 g. Carapace width (CW) ranged from 30-250 mm, and were dominated by 120-190 mm CW crab. During June to November, size composition fluctuates greatly due to rapid individual crab growth and intermittent recruitment to the fished population.

The spawning season extends from March to April. Females migrate to the spawning grounds prior to the males, and female crabs may make up 70% of the catch during this time. During July to November, male crabs typically exceed the number of females in the catch.

The mating period in China is from July to November, with peak activity from September to October. Mating occurs when the female is molting. Mated females store sperm and reach sexual maturity in the spring when extrusion, fertilization and the start of incubation occur. From February to July, egg-incubating females are found in the catch. Two broods may be incubated each year. A second incubation, when present, normally occurs 10-20 days after the first one is hatched. Fecundity is a function of body weight:

$$R_1 = -34.1 + 3.86\ W_1$$

$$R_2 = -41.4 + 5.41\ W_2$$

where, R_1 and R_2 are incubated egg numbers (10^3) in the first and second incubations, respectively; and W_1 and W_2 are corresponding body weights (g). A 100 g female thus produces about 350,000 eggs at first mating, while a 150 g female would produce about 770,000 eggs. The relationship between body weight (*W*) and carapace length (*CL*) is:

$$W = 0.000396\ CL^{3.06888}$$

Larvae are planktonic and have 6 larval stages. Incubation and larval development occur over 20-30 days.

Gazami crab may hibernate during the one-three winters of their life span. Age is estimated from size-frequency distributions, and growth is described with the von Bertalanffy model with the following parameters: L = 68.0 mm CL, K = 0.777 (month), t_0 = 0.558 (month), and W = 167.2 (g). Growth is fastest in the summer months and because there may be inflections in the growth curve, the above model is only approximate. Feeding is a nocturnal activity that occurs throughout the year. Principal prey items include benthic organisms and small fishes, but carrion, shrimps, squids and marine plants are also eaten.

3.1.2 South Korea

Almost all landings for swimming crabs in South Korea (Table 4) are gazami crab and these data are an accurate portrayal of trends in this fishery. The South Korean fishery was small and little known prior to 1970, but exceeded 10,000 t in 1974, 20,000 t 1981 and peaked at 32,000 t in 1988 due to increased fishing effort and the extension of fishing grounds as increased fishing developed. Thereafter, landings declined and were 10,400 t in 1998. Individual crab size was mainly 90-170 mm CW between 1988 to 1993 (Yeon 1997). The South Korean fishery depends on two groups of crabs that differ in their migrations and biological parameters (Kim *et al.* 1986, Yeon *et al.* 1992, Yeon *et al.* 1998, Yeon 1999). The two populations are the Korean western coast and East China Sea groups. The Korean western coast group occurs in the middle of the Yellow Sea during the winter and migrates to South Korean western coastal areas to spawn during late March-August. After spawning, it moves back to its wintering area around September, and crabs may hibernate by burying in the seafloor.

The East China Sea group spends winter in the southwestern area of Cheju Island where a branch of the Kuroshio Warm Current flows. These crab migrate to southern South Korean coastal areas to spawn, where they are present from March-August. After spawning, they move back to their wintering grounds, where they stay from September-November (Yeon 1997).

Table 4 Reported landings of gazami crabs from the PICES Region (t, FAO).

Year	China	Japan	South Korea	Total
1965	-	1,300	-	1,300
1966	-	2,400	-	2,400
1967	-	1,700	-	1,700
1968	-	1,000	-	1,000
1969	-	1,000	-	1,000
1970	-	1,000	2,700	3,700
1971	-	1,100	4,100	5,200
1972	-	1,500	5,700	7,200
1973	-	3,100	9,300	12,400
1974	-	3,496	10,487	13,983
1975	-	4,229	13,703	17,932
1976	-	3,104	11,176	14,280
1977	-	2,959	16,768	19,727
1978	-	3,501	16,691	20,192
1979	-	3,931	19,546	23,477
1980	-	2,807	19,734	22,541
1981	-	4,140	22,181	26,321
1982	-	4,714	19,393	24,107
1983	-	5,602	17,854	23,456
1984	-	4,638	25,643	30,281
1985	-	5,227	23,961	29,188
1986	-	5,328	30,897	36,225
1987	108,518	3,989	30,273	142,780
1988	99,138	3,412	31,968	134,518
1989	143,474	2,658	28,753	174,885
1990	120,701	4,105	23,415	148,221
1991	132,205	3,831	18,729	154,765
1992	155,548	3,270	17,317	176,135
1993	117,264	2,958	10,419	130,641
1994	272,102	3,564	21,483	297,149
1995	243,485	4,161	17,651	265,297
1996	283,394	4,022	15,754	303,170
1997	237,960	3,112	11,430	252,502
1998	266,630	3,528	13,813	283,971

Table 5 China's landings of gazami crab (t, Zhaung and Deng 1999).

Year	China's Seas	Yellow & Bohai Seas	Other Areas	Yellow & Bohai Seas Percentage
1987	104,535	27,906	76,629	26.7
1988	90,288	24,338	65,950	27.0
1989	132,560	20,961	111,599	15.8
1990	120,701	15,894	104,807	13.2
1991	132,205	27,949	104,256	21.1
1992	155,548	29,706	125,842	19.1
1993	132,264	27,826	104,438	21.0
1994	292,102	65,946	226,156	22.6
1995	243,485	25,301	218,184	10.4
1996	283,394	25,106	258,288	8.9
1997	237,960	34,214	203,746	14.4
Total	1,925,042	3,25,147	1,599,895	16.9

Fluctuations in landings of crabs from the Korean western coast group and the East China Sea group are similar. However, the regression slope decrease in landings from the East China Sea group was steeper than that of the Korean western coast group. Landings of the Korean western coast group were 18,000 t in the late 1980s and 10,000 t in 1998, but those for the East China Sea group were 14,000 t in the late 1980s and 3,000 in 1998 (Table 6). Fishing for these groups occurs during both the inshore (March-June) and offshore migrations (September-November).

The Korean western coast group spawns from May-August at a mean size of 126 mm CW. In the East China Sea group, the mean size at spawning is 103 mm CW. Mating takes place between June and November, with a peak activity from August to October. The size of male crabs at 50% maturity was estimated to be 100 mm CW. Individual female fecundity at first spawning ranges from 211,000 at 80 mm CW to 5,359,000 eggs at 170 mm, and increased exponentially with an increase in carapace width (Yeon 1999):

$$Fc = 854.673CW^{2.878}$$

Table 6 South Korean landings of gazami crab (t, Statistical Year Book, 1970-1999).

Year	Total	South Korean western coast	East China Sea
1969	1,279	1,228	51
1970	2,700	2,567	133
1971	4,113	3,277	836
1972	5,701	4,907	794
1973	9,306	7,344	1,962
1974	10,487	7,932	2,555
1975	13,703	10,259	3,444
1976	11,176	9,422	1,754
1977	16,768	15,003	1,765
1978	16,691	12,029	4,662
1979	18,544	15,560	2,984
1980	19,734	13,595	6,139
1981	22,181	13,818	8,363
1982	19,393	11,945	7,448
1983	17,854	10,650	7,204
1984	25,643	15,753	9,890
1985	23,960	14,488	9,472
1986	30,897	19,400	11,497
1987	30,273	17,995	12,278
1988	31,968	17,519	14,449
1989	28,753	13,866	14,887
1990	23,415	15,373	8,042
1991	18,729	9,990	8,739
1992	17,317	10,648	6,669
1993	10,419	8,319	2,100
1994	21,483	9,479	12,004
1995	17,651	10,591	7,060
1996	15,754	12,043	3,711
1997	11,430	8,337	3,093
1998	13,813	10,471	3,342
Total	511,135	333,808	177,327

The relationship between carapace length (*CW*) and body weight (*W*) is:

$$W = 0.158CW^{2.877}$$

A change in this relationship occurs between May-October for females and between March-October for males. Growth in CW, notch-to-notch shows a seasonal pattern. Estimated seasonal growth equations were:

Female: $CW_t=18.7(1-e^{-\{0.668(t+0.730)+(0.912/2\pi)\sin2\pi(t-0.208)\}})$

Male: $CW_t=16.9(1-e^{-\{0.940(t+0.503)+(1.603/2\pi)\sin2\pi(t-0.168)\}})$

Growth of crabs was comparatively faster from August-October. Crabs grew little in the winter between January-March, i.e., about eight months after hatching (Yeon *et al.* 1998).

To manage this crab, various approaches have been utilised: reducing the number of fishing vessels, prohibition of fishing on the spawning grounds during the main spawning season (July to August), and improved monitoring of vessels in coastal area waters. In addition, larvae hatched in culture have been released and a legal size limit of 60 mm carapace length (CL), or 110 mm notch-to-notch CW exists.

In contrast to crabs from more northerly waters, gazami crab have a relatively short generation time, high fecundity, multiple broods and high growth rates, which means their population abundance and size composition can both change rapidly. Crabs hatched in the spring grow to commercial size by autumn, and can spawn the next spring.

3.2 Snow crabs (*Chionoecetes* spp, Majidae, FAO: PCR, Areas 61, 67)

Within the genus *Chionoecetes*, landings of snow crab (*Chionoecetes opilio,* Plate 1) have been historically most important, followed by Tanner crab (*Chionoecetes bairdi*, Plate 1) and most recently, fisheries for the red snow crab, or benizuwai gani (*Chionoecetes japonicus,* Plate 1) in the Japan/East Sea (Fig. 5). The EBS snow crab fisheries have been particularly significant over the past 15 years and have caused the large fluctuations in landings (Fig. 6, Table 8). The other two species, grooved Tanner crab (*Chionoecetes tanneri)* and angled Tanner crab (*Chionoecetes angulatus*), are deepwater species that resemble benizuwai gani. There have been exploratory efforts and only limited harvest of these two minor species in North America (Jamieson 1990**,** Jamieson *et al*. 1990, Philips and

Lauzier 1997, Boutillier *et al*. 1998). For the years 1997-1999 inclusive, Russian landings of angled Tanner crab amounted to 2,400 t and came mostly from the Sea of Okhotsk. Russian landings of grooved Tanner crab were 300 t, mostly from the Western Bering Sea during the same period.

Chionoecetes spp. are brachyurans and are capable of storing spermatophores from one mating to fertilise eggs at subsequent egg extrusions. Like the gazami crab or the hair crab (see below), snow crabs normally extrude and fertilise eggs shortly after the time of mating, but unlike the former crabs, they are also capable of fertilizing eggs in a subsequent annual egg extrusion period from stored spermataphores if no males are available to mate with and renew their carried spermatophores. It is generally agreed that female magid crabs go through a terminal molt when they assume their adult morphology. There is still controversy as to whether the male molt to morphometric maturity is always a final or terminal molt. Otto (1998) reviewed some of the consequences of this life history pattern relative to *Chionoecetes* fisheries in the EBS.

3.2.1 Snow and red snow crabs

Pacific snow crab have a broad distribution across several zoogeographic provinces, which provides comparative research opportunities similar to those for king crabs. Snow crab range in the Pacific from the Amundsen Gulf in the south-eastern Beaufort Sea (but not eastward in the Canadian arctic (Squires 1968)) to the Japan/East Sea. Snow crab are not found south of the Alaska Peninsula in North American Pacific waters. Snow crab occur to depths of about 700 m in Pacific North America but may be found even deeper in the Japan/East Sea. Snow crab also occur in the north-west Atlantic, where many detailed studies of their general biology have been carried out.

Fisheries for the snow crab have a long history in Japan but Japanese landings from Asian waters were relatively low prior to 1940. The recent history of the fishery is given in Figure 7. In the Japan/East Sea, there was a long fishery development period that continued until the early 1960s followed by a period of fluctuating landings, and then a slow decline in abundance that continues to the present. Landings in Hokkaido also came largely from the Japan/East Sea, and have followed the same declining trend, after developing rapidly in the late 1960s.

South Korean landings of snow crab (*Chionoecetes opilio*) are few, totalling less than 500 t annually. Most of the landed crabs are caught at 200-400 m depth by bottom gill nets from December through May. To enhance the stock, management tactics used are: a limit on mesh size (180 mm), a closed fishing season (June-October) and a prohibition on fishing all females, and small male crabs less than 90 mm CL.

Table 7 Reported landings (10^3 t) of snow crabs from the PICES Region. Data are based on FAO statistics and does not include the Russian landings, so that totals do not match in most years. Considerable landings of snow crab by South Korea (until 1992) and Russia are included with marine crab "nei" data, and are excluded here.

Year	N.W. Pacific		N.E. Pacific	
	Japan	South Korea	USA	Total
1984	6.900	-	22.120	29.020
1985	10.322	-	38.893	49.215
1986	13.586	-	49.896	63.482
1987	9.357	-	51.625	60.982
1988	7.741	-	66.373	74.114
1989	8.500	-	74.682	83.182
1990	4.799	-	96.795	101.594
1991	7.908	-	161.989	169.897
1992	6.595	-	158.777	165.372
1993	5.612	24.534	116.000	146.146
1994	6.919	31.134	72.382	110.435
1995	9.090	33.234	36.658	78.982
1996	3.447	37.495	30.785	71.727
1997	4.870	39.711	53.932	98.513
1998	4.677	33.605	114.230	152.512
Total	110.323	199.713	1145.137	1455.173
%	7.6	13.7	78.7	100.0

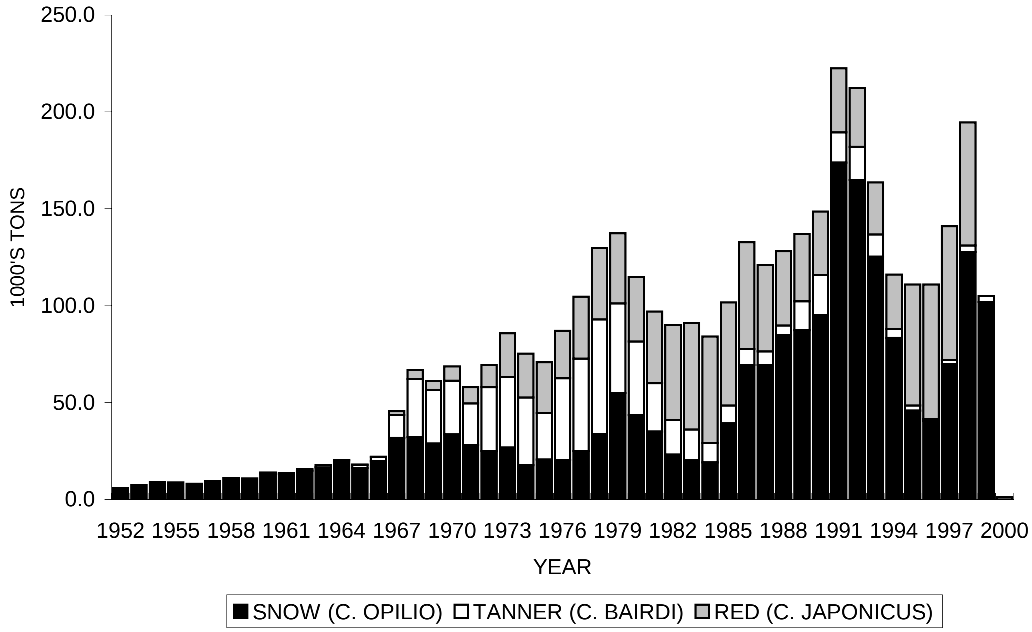


Fig. 5 Composition by species of North Pacific catches (10^3 t), 1952-2000, of snow or tanner crabs. *Chionoecetes opilio* = snow crab which are amphi-Pacific; tanner crab = *C. bairdi* which are North American; and red snow crab or benizuwai gani, = *C. japonicus* which are mostly from the Sea of Japan. Very small experimental or exploratory fisheries for two other deepwater species (*C. tanneri, C. angulatus*) are ignored. Landings in Russian waters by foreign fleets are not included prior to 1986.

Japan had extensive distant water crab fleets that used to fish in what are now U.S. and Russian 200 nautical mile exclusive zones. The complete history of landings from Russian waters was not available, which accounts for the shortness of the Russian data series in Fig. 6, but the combined U.S. and Japanese fisheries in the EBS were well documented through statistical series and research conducted under the auspices of the International North Pacific Fisheries Commission. In the EBS, there have been three periods of high snow crab abundance (Fig. 6), the first of which may not have been completely captured by the developing fisheries in the 1970s. Fluctuations since 1975 have been extensive.

3.2.2 Tanner crab

Tanner crab are found from the Japan/East Sea (Kon 1996) around the North Pacific Rim to Oregon (Hosie and Gaumer 1974). In areas of the Bering Sea north of the Pribilof Islands, Tanner crab are generally restricted to the outer continental shelf and slope where waters are warmed by upwellings and the Bering shelf current (Stabeno *et al.* 1999). In more southerly areas, they may occur from the intertidal to depths of about 700 m.

Fisheries for the Tanner crab are mostly in North American waters (Fig. 8) and it is probable that most catches in Asia are taken incidentally in the pursuit of other species. Tanner crab fisheries in the GOA were developed as king crab fisheries declined in the late 1960s. Tanner crab had long been taken as bycatch in king crab fisheries and the switch involved little by way of modifying vessels and gear. Following fishery development, GOA Tanner crab fisheries experienced a decade of moderately fluctuating landings, followed by a long period of gradual decline until most fisheries were closed in the late 1990s (Fig. 8). However, in the EBS the fishery pattern was quite different, and there were three periods of peak abundance that seemed to be unrelated to abundance patterns in the GOA. The first period of abundance may not have been entirely reflected by the developing Japanese distant water Tanner crab fishery, displaced from the EBS king crab fishery by the U.S. crab fleet. The second peak was fished by both Japanese and U.S. fishermen, while the third was solely a U.S. fishery. Tanner crab landed by both nations were generally larger than 1.0 kg I, while snow crab were about 0.5 kg, which explains, in part, why the EBS Tanner crab fishery developed before the snow crab fishery, even though snow crab are most numerous. Rosenkranz *et al.* (1998) explained some of the fluctuations in Tanner crab recruitment through wind direction and velocity, and their probable influence on larval drift patterns. Peaks in snow and Tanner crab abundance coincided in the late 1970s and early 1990s but not in the late 1990s (Figs. 6 and 8).

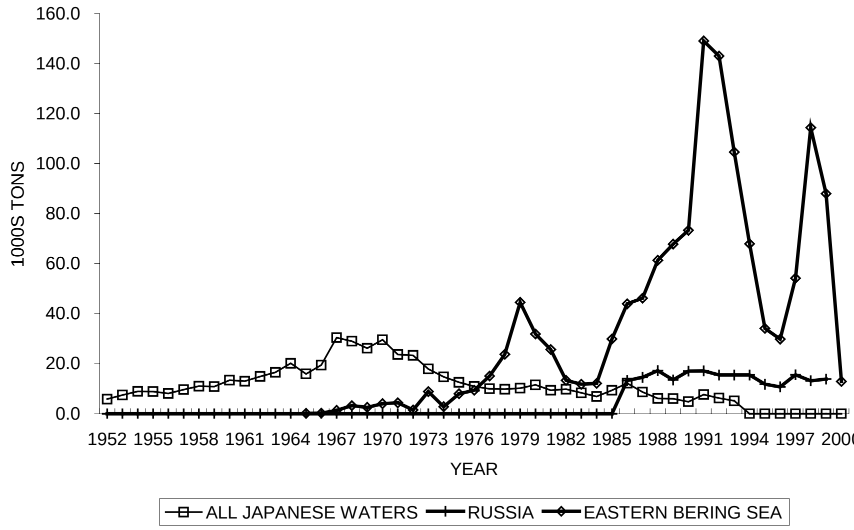


Fig. 6 Landings (10^3 t) of snow crabs by major fishing areas from 1952-2000. Landings are dominated by the eastern Bering Sea stock that was fished by the United States and Japan until 1980, and by the United States thereafter. There were three periods of abundance in the EBS. Stocks are combined for Japanese and Russian fisheries but do not show strong peaks of relative abundance singly or in aggregate.

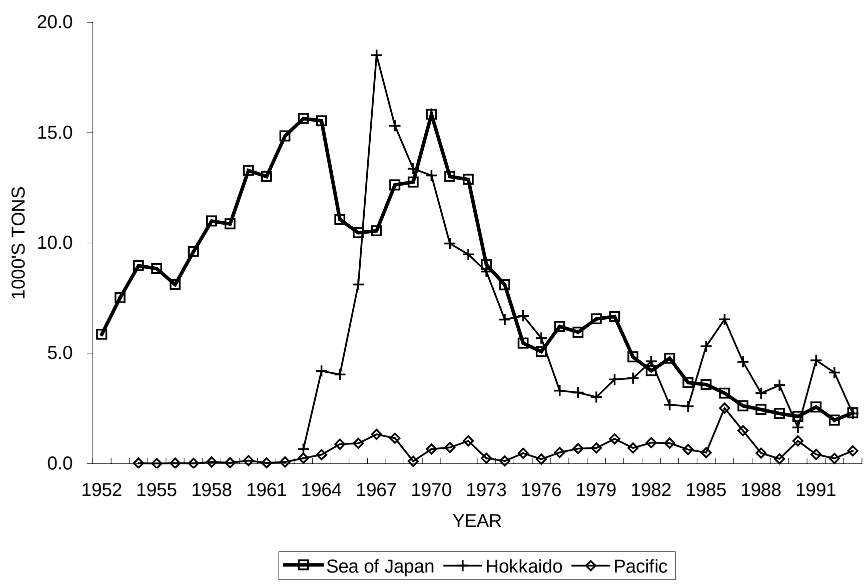


Fig. 7 Historical landings (10^3 t) of the Japanese snow crab (*Chionoecetes opilio*) fishery in Asian waters. Traditional fisheries in the Japan/East Sea were equalled by those from Hokkaido following the latter's rapid development in the early 1960's. Japan's distant water landings are not shown.

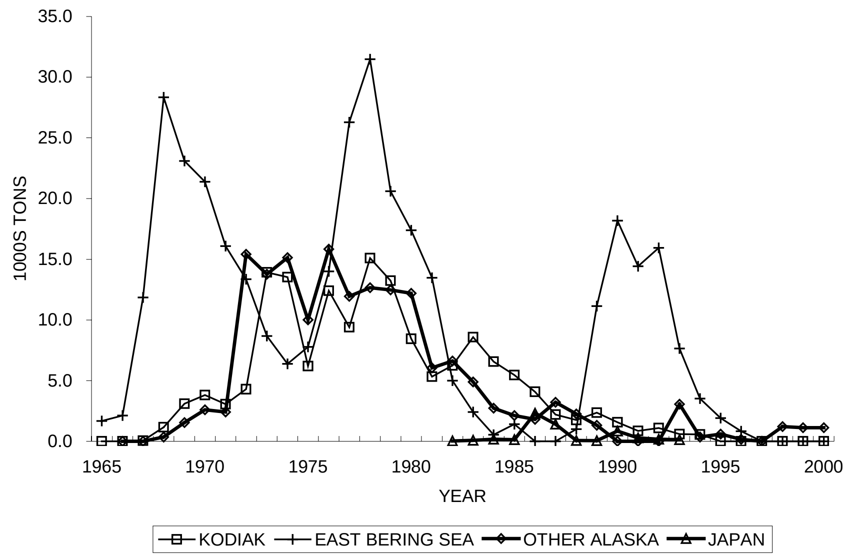


Fig. 8 Historical landings (10^3 t) in selected Tanner crab (*Chionoecetes bairdi*) fisheries, 1965-2000. Their three apparent peaks in abundance of the Eastern Bering Sea stock are different than the pattern observed in the Gulf of Alaska (Other Alaska). The Bering Sea stock peaked first under exploitation by Japanese distant water mothership fleets, secondly when jointly exploited by the United States and Japan, and thirdly during only American exploitation. The last two peaks in Bering Sea Tanner crab abundance coincided with the first two peaks in snow crab abundance. The Gulf of Alaska fishery had a period of rapid expansion in the early 1970s following the decline of the king crab fishery, followed by a period of fluctuating abundance until the early 1980s and a gradual decline thereafter.

The red snow crab is fished in Japanese, South Korean, Russian and possibly North Korean waters (Fig. 9). South Korean fishing for the crab has developed since the late 1980s. South Korean fishing had increased to 39,000 t in 1997, but decreased to 33,000 t in 1998. Most landings from the Japan/East Sea are caught by baited crab traps at 700-1,500 m depth, as in the Japanese fishery. Catches are dominated by crabs of 75-105 mm CL (Gong *et al.* 1978). In order to promote a sustainable yield, landings of females and the use of trap mesh less than 150 mm are prohibited by law.

In Japan, landings of females and male crabs less than 90 mm CW are prohibited by law. The main Japanese fishing area is at a depth of 1,000–2,000 m. In the mid-1980's, landings of this crab reached 50,000 t, but have since decreased. The recent landing of 69,300 t from the Japan/East Sea for both countries combined are at a peak, making this fishery the world's largest for a deepwater (>500 m) crab species. Fluctuations in landings until recently were from the development of new grounds in the Japan/East Sea, It now appears that all grounds may be developed and that overexploitation may be occurring.

Tanner and snow crabs spatial distributions are less patchy and form fewer apparent stocks than do king crabs. Females of both species tend to be more densely concentrated than males. Near Kodiak, recent studies of Tanner crab reproduction have shown different spawning behaviours between primiparous and multiparous females (Stevens *et al.* 1993; Stevens *et al.* 1994, 1999; Stevens *et al.* 1996). Primiparous females spawn singly while multiparous females form dense aggregations of mounded females, that apparently facilitates larval release. Mounding of females seems to be timed to release larvae during the highest spring tides of the year, as this behaviour has not been found at other times of the year. Spawning aggregations of other species of *Chionoecetes* are undocumented, but survey data in the EBS suggest that significant aggregations of female snow crab occurs. The positioning of such aggregations relative to prevailing current or wind transport may be important in determining recruitment patterns.

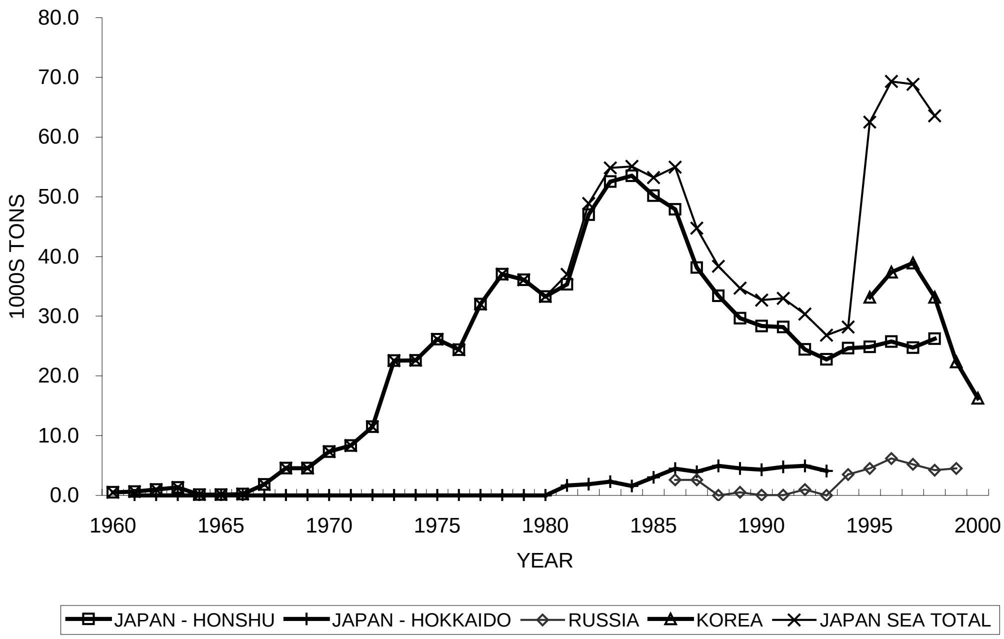


Fig. 9 Historical landings (10^3 t) of the Japan/East Sea fishery for the red snow crab, or benizuwai gani (*Chionoecetes japonicus*), 1960-2000. The traditional fishery off Honshu reached a pear in the early 1980s and declined through the early 1990s. The sharp peak in production is due to the rapid development of South Korean fisheries in the western basin of the Japan/East Sea.

3.3 Dungeness crab (*Cancer magister*, Cancridae, FAO: DUN, Areas 67, 77)

Dungeness crab (Plate 1) are commercially exploited from central California to Unalaska Island in the eastern Aleutian Islands by the United States and Canada (Table 8, Fig. 10). Only hard-shell males about 4+ years old (> 165 mm CW spine-to-spine; 155 mm CW notch-to-notch) are legal in the commercial pot fishery. Most exploitation in the US occurs from winter through spring, while in Canada, its during the spring and summer. Populations regularly cycle in abundance south of British Columbia, with peaks and troughs every 8-10 years (Table 9, Fig. 11). The central California stock declined in the late 1950s in accord with the entire U.S Dungeness fishery, but did not rebuild and has apparently collapsed.

Eastern Pacific landings from 1970-1996 ranged from a minimum 5,000 t (1974) to a maximum of 26,000 t (1977). For a complete summary of annual landings across eastern Pacific fishing areas, see the Pacific States Marine Fisheries Commission website, www.psmfc.org for tables and figures on crab, as well as pandalid shrimp. British Columbia landings are smaller, have been more consistent from year to year, and do not display the cyclic patterns observed in the California to Washington fisheries. However, major differences in recruitment patterns have been observed in British Columbian waters (Fig. 12), with the most recent being a major recruitment of Dungeness crab in the waters around the Queen Charlotte Islands. Alaskan landings are not in synchrony with either the southern U.S. states or with Canada, and landings there may have been market driven over portions of the historical landing series. In several regions of Alaska, there have been historic fish-downs of Dungeness crab stocks that may indicate both inherently slower growth and a more episodic recruitment. Orensanz *et al.* (1998) described the virtual collapse of Dungeness crab and other decapod fisheries in Prince William Sound in advance of the Exxon Valdez oil spill in 1989, and elsewhere more broadly across the south-east Gulf of Alaska. Since patterns of abundance differ between zoogeographic provinces, comparative studies within populations of this species may provide insight into mechanisms influencing crab population sizes.

Table 8 NW Pacific landings of Dungeness (10^3 t, FAO).

	Canada	USA	Total
1984	1.155	11.321	12.476
1985	1.165	12.829	13.994
1986	1.321	10.165	11.486
1987	1.631	13.363	14.994
1988	1.532	21.519	23.051
1989	1.522	18.591	20.113
1990	2.168	14.248	16.416
1991	1.887	10.122	12.009
1992	3.334	18.908	22.242
1993	6.225	25.153	31.378
1994	5.995	20.868	26.863
1995	4.586	21.696	26.282
1996	5.025	29.478	34.503
1997	3.396	17.328	20.724
1998	2.968	15.519	18.487
Total	43.910	261.108	305.018
%	14.4	85.6	100.0

Hypothesised environmental and ecological effects that have been evaluated in efforts to explain the cyclical pattern of abundance of California-Washington Dungeness crab include elevated temperatures (Wild *et al.* 1983), nemertean worm predation on incubating eggs (Wickham 1979), salmon predation on larvae (Thomas 1985), and various cyclic phenomena (cannibalism, upwelling, wind stress, geostrophic flow, fishing effort; see reviews by Botsford *et al.* 1989, Jamieson *et al.* 1989, McConnaughey *et al.* 1994, Orensanz *et al.* 1998). Habitat and fishing impacts that effect stocks include dredging to maintain navigation channels and for landfills (Wainwright *et al.* 1992), use of pesticides in estuaries to benefit oyster culture (Feldman *et al.* 2000), and ghost pot fishing and fishery handling of sublegal males and females (Smith and Jamieson 1989). Current fishery regulations select for the largest males, and it has been hypothesised that regulations could be selecting genetically for smaller males, since it is these males that end up doing most of the mating in fully-exploited populations (Fig. 13, Jamieson *et al.* 1998). The relative absence of large males may in turn decrease the mating opportunities for larger females, which might negatively influence the probability of their moulting and so their population size structure as well.

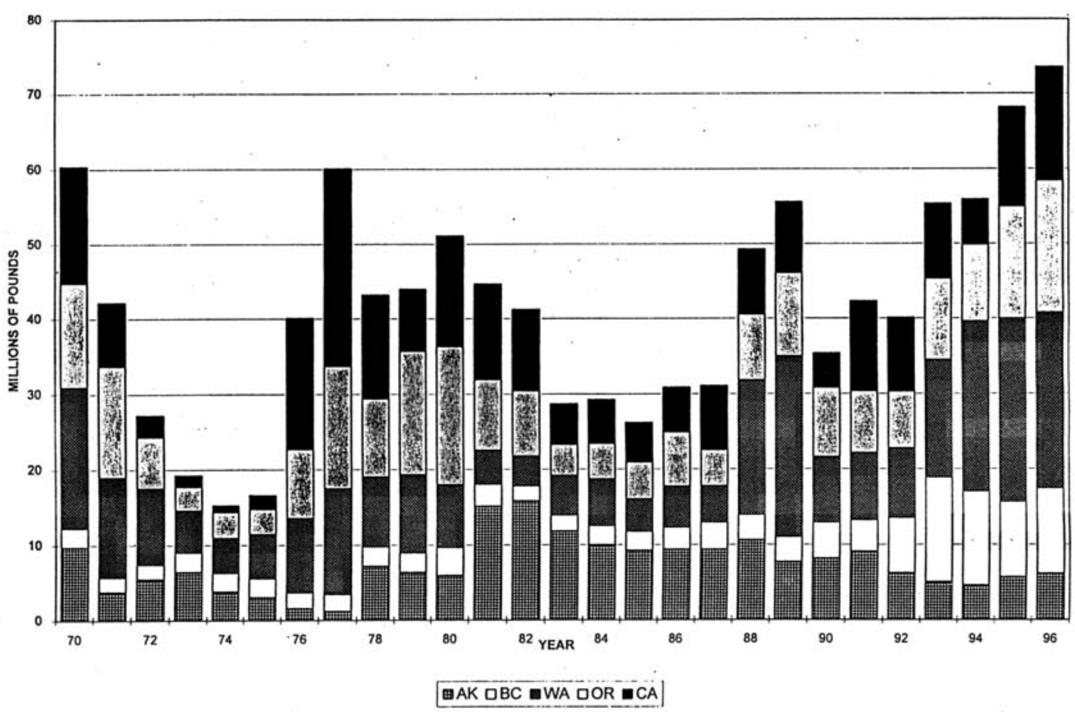


Fig. 10 Landings of Dungeness crab by jurisdiction from California to Alaska, 1970-1996.

Table 9 Commercial landings (10^3 t) of Dungeness crab from the Pacific coast of North America (PACFIN, Pacific States Marine Fisheries Commission). Alaska and British Columbia landings are annual for the last year in column 1, the remainder are for fishing seasons that start in the first year indicated and end in the last (e.g., April to March). W-O-C = sum of Washington, Oregon and California.

Year or Season	Alaska	British Columbia	Washington	Oregon	California	W-O-C Sub-total	Grand Total
1969-70	4.398	1.156	8.471	6.282	7.060	21.813	27.366
70-71	1.701	0.890	5.992	6.684	3.856	16.532	19.123
71-72	2.471	0.896	4.579	3.075	1.304	8.959	12.326
72-73	2.913	1.170	2.532	1.426	0.680	4.638	8.722
73-74	1.732	1.134	2.088	1.570	0.399	4.058	6.924
74-75	1.377	1.140	2.674	1.513	0.824	5.011	7.528
75-76	0.701	0.962	4.484	4.127	7.897	16.508	18.171
76-77	0.527	1.029	6.361	7.348	11.977	25.686	27.242
77-78	3.252	1.176	4.190	4.706	6.260	15.156	19.583
78-79	2.873	1.179	4.700	7.417	3.765	15.882	19.934
1979-80	2.682	1.701	3.774	8.29	6.737	18.802	23.184
80-81	6.853	1.315	2.038	4.277	5.768	12.084	20.252
81-82	7.172	0.998	1.782	3.946	4.892	10.621	18.791
82-83	5.353	0.957	2.375	1.86	2.455	6.691	13.001
83-84	4.521	1.156	2.797	2.132	2.655	7.584	13.261
84-85	4.164	1.164	1.935	2.223	2.380	6.538	11.866
85-86	4.245	1.320	2.463	3.253	2.717	8.433	13.997
86-87	4.239	1.631	2.180	2.153	3.900	8.233	14.103
87-88	4.795	1.508	8.100	3.939	3.971	16.011	22.313
88-89	3.478	1.519	10.839	5.059	4.333	20.231	25.228
1989-90	3.695	2.129	3.914	4.189	2.063	10.166	15.99
90-91	4.110	1.858	4.023	3.741	5.424	13.188	19.157
91-92	2.817	3.333	4.156	3.430	4.448	12.034	18.184
92-93	2.275	6.289	7.045	4.932	4.569	16.546	25.11
93-94	2.075	5.995	10.220	4.645	2.926	17.791	25.861
94-95	2.572	4.539	11.001	6.823	6.001	23.825	30.936
95-96	2.781	4.931	10.561	8.031	6.902	25.494	33.206
96-97	2.243	3.943	6.499	3.199	1.816	11.514	17.699
97-98	1.315	2.955	6.658	3.212	5.136	15.006	19.277
Total	93.330	59.971	148.435	123.485	123.115	395.034	548.336
%	17.0	10.9	27.1	22.5	22.5	72.0	100.0

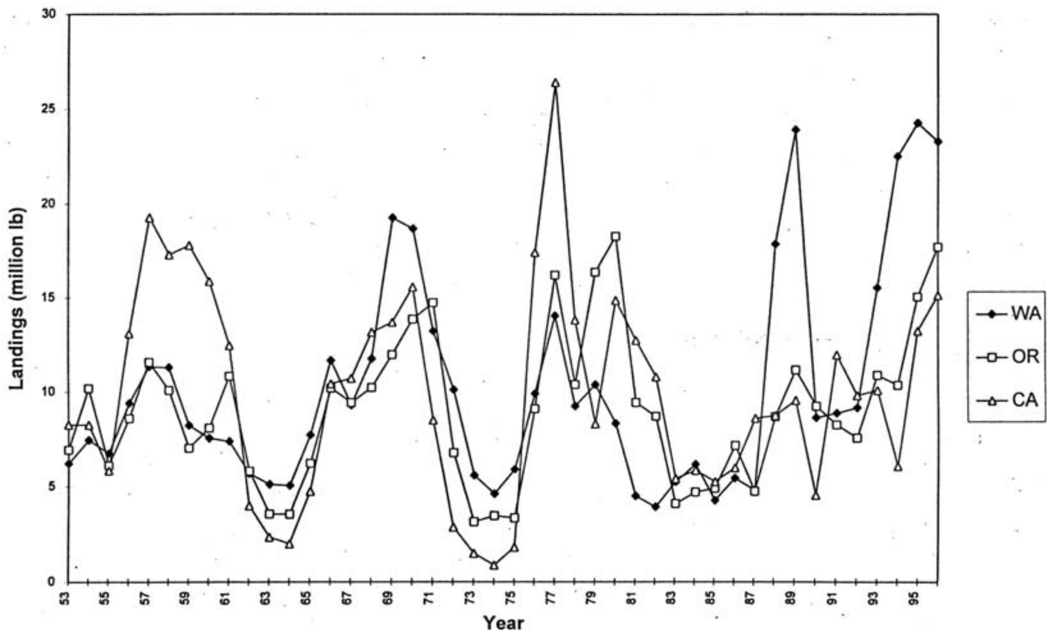


Fig. 11 Landings of Dungeness crab by jurisdiction from California to Washington,1953-1996.

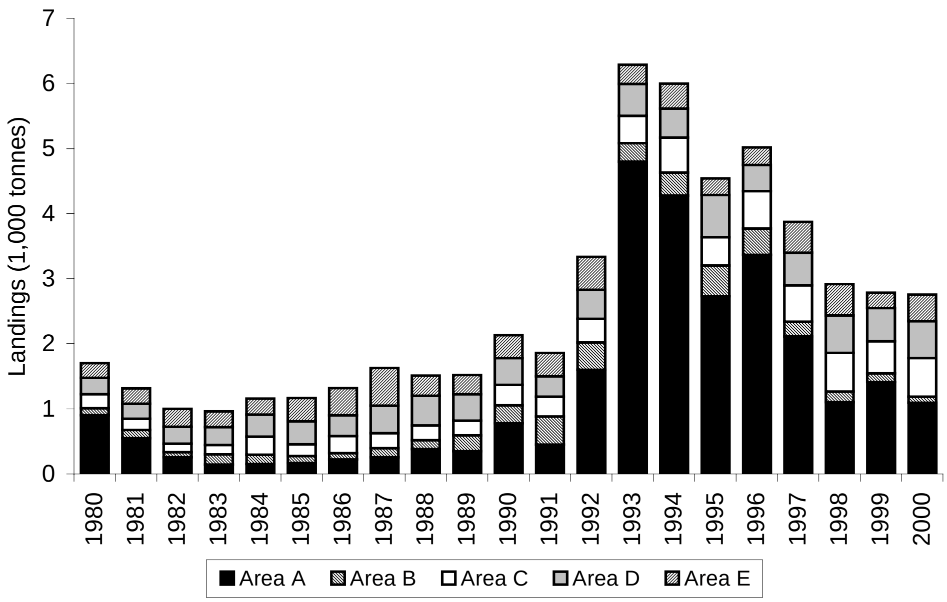


Fig. 12 British Columbian landings (10^3 t) of Dungeness crab by Crab Fishing area, 1980-2000. Area A = Queen Charlotte Islands, Area B = North Coast and central mainland, Area C = Strait of Georgia and Johnstone Strait, Area D = Fraser River area, and Area E = west coast of Vancouver Island.

Foreign species introductions have had actual or perceived negative impacts on local Dungeness populations. The European green crab, *Carcinus maenus*, is considered a potential competitor and juvenile crab predator of Dungeness crab (Jamieson *et al.* 1998), although evidence to the contrary indicates cancrid populations may substantially restrict *Carcinus* in the eastern Pacific (McDonald *et al.* 2001). The exotic cord grass, *Spartina alterniflora*, encroaches across estuarine tideflats and may reduce available habitat for small juvenile crab that otherwise use eelgrass (*Zostera marina*) and shell (see Fernandez *et al.* 1993, McMillan *et al.* 1995). However, one potentially beneficial consequence of an exotic introduction is that of the eastern soft-shell clam, *Mya arenaria*, to estuaries of the eastern Pacific in the late 19th century. Shell deposits of adult clams accumulate and provide excellent refuges for small instars of Dungeness (Palacios *et al.* 2000), which has been used as a basis of intertidal habitat mitigation programs in which oyster shell (*Crassostrea gigas*) is spread over large tideflats to promote crab survival (Dumbauld *et al.* 1993, 2000).

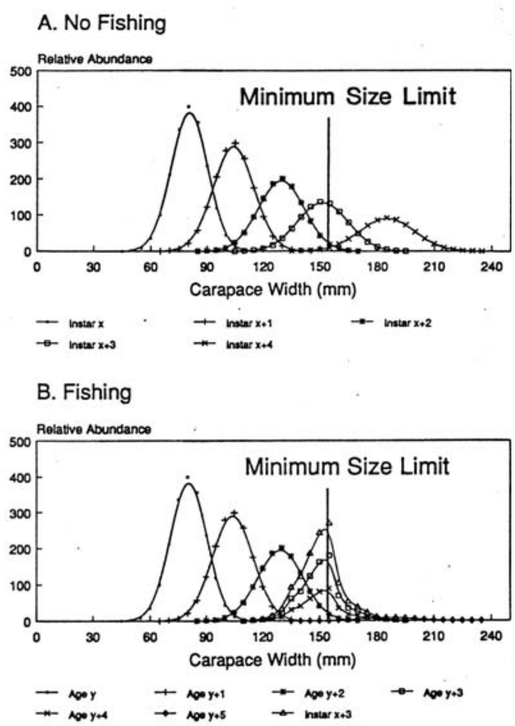


Fig. 13 Estimated Dungeness crab size frequency distributions (mm, notch-to-notch CW) by A. instar and B. age for male Dungeness crab. (Note: instar absolute abundances are arbitrary, and increments in age refer to moults, which may not always be on an annual basis) Ages y+3 and y+4 (the latter assumed to be 50% of y+3) are summed to give a size frequency distribution for instar x+3, with attenuation of abundance at size above the legal size of 155 mm CW (the vertical bar) because of fishing. Most prerecruit instar x+3 crabs appear to have a 2-tear intermoult period, at least when the population is fished, and relatively few (here shown as 10% of age y+4) crabs appear to survive to age y+5 (instar x+4).

The list of factors evaluated to explain changes in Dungeness crab populations is a sampling of factors that are thought to control crab populations in general. Predation on adult crab, parasitism and epizootic diseases are all known to be important factors population abundance determination in a number of king and Tanner crab populations.

Even through thoroughly studied, there has been no general agreement as to the mechanisms responsible for the cyclic trends in Dungeness crab abundance observed from northern California through Washington. Larval sampling has shown that megalopae offshore from the coasts of California, Oregon and Washington are dispersed long-shore and off-shore by wind driven currents. These currents reverse seasonally before eventual shoreward transport, but the nature and degree of wind-current dispersal of larvae relative to nursery habitat is still being debated (see hypotheses proposed by Botsford 1986, Johnson *et al.* 1986, McConnaughey *et al.* 1992, Wing *et al.* 1998). Such mechanisms do not predetermine settlement location. Off Vancouver Island, megalopae appear to be concentrated in boundary areas between near shore surface currents moving in opposing directions, and this may impede their necessary movement to shallow water (Jamieson *et al.* 1989), where survival after settlement is maximised. The preference of outer coast megalopae to the upper 25 m of the water column is a behaviour that apparently fosters beneficial transport. By contrast, larvae from Dungeness crab populations within the Strait of Georgia occur in an estuarine circulation pattern, where surface water (<100 m) flows outward through the Strait of Juan de Fuca and is replaced by an influx of saltier water at depth. Strait of Georgia larvae make daily vertical migrations (surface at night, at depth during daylight) of about 160 m, and with the long day length, are thereby effectively retained within the Strait of Georgia oceanographic system. Outer coast megalopae cannot easily enter the Strait because they continuously reside in the out-flowing surface waters. This is an example of very different larval behaviours resulting in transport favorable for each population, despite the close geographic proximity of the two populations (Jamieson and Phillips 1993). Hypothetically, such behaviours probably evolved relatively rapidly, perhaps within a few thousand years at most, as the Strait of Georgia did not exist about 10,000 years ago, as it was glaciated. It therefore seems quite plausible that different crab and/or shrimp populations of other species may also have population-specific behaviours that help spatially structured adult populations persist. Care must therefore be taken in suggesting common dispersal patterns for species as a whole and for even specific populations, unless dispersal patterns from those populations have been directly studied.

3.4 Other crabs

Hair Crab (*Erimacrus Isenbeckii*), Rock Crabs (*Cancer productus, Cancer anthonyii*), and sheep crab (*Loxorynchus grandus*) provide small fisheries in the PICES Region, but except for hair crab, these fisheries are poorly documented. Hair crab are of considerable importance in Hokkaido (see Fig. 25) and sometimes are landed in the EBS (Fig. 14). In the EBS, most landings occur near the Pribilof Islands, although the species has a widerdistribution (www.AFSC.NOAA.GOV/ Kodiak)

The biology of the species in the Bering Sea has been summarized by Armetta and Stevens (1986) and several publications by Abe (1973,1977,1982 and 1992) provide much information for Japanese waters. Factors affecting recruitment in this species have not been investigated.

3.5 King crabs (*Lithodes* and *Paralithodes* spp., Lithodidae, FAO: KCS, Areas 61, 67)

Landings of king crabs (Plate 2) in the PICES Region have ranged from 38,400 t (1984) to 61,900 t (1995) over the past 15 years of record (Table 10), and landings have been much more stable in Asian than in North American waters. Landing data (Table 10) show the recent history of this fishery by FAO Areas and nation. In actuality, these figures belie the economic importance of king crabs, which are generally sold at the highest prices of any crabs in the PICES Region. Due to their economic importance and significance in international trade, king crab fisheries have been a key negotiating point in the development of international fisheries arrangements throughout northerly portions of the PICES Region.

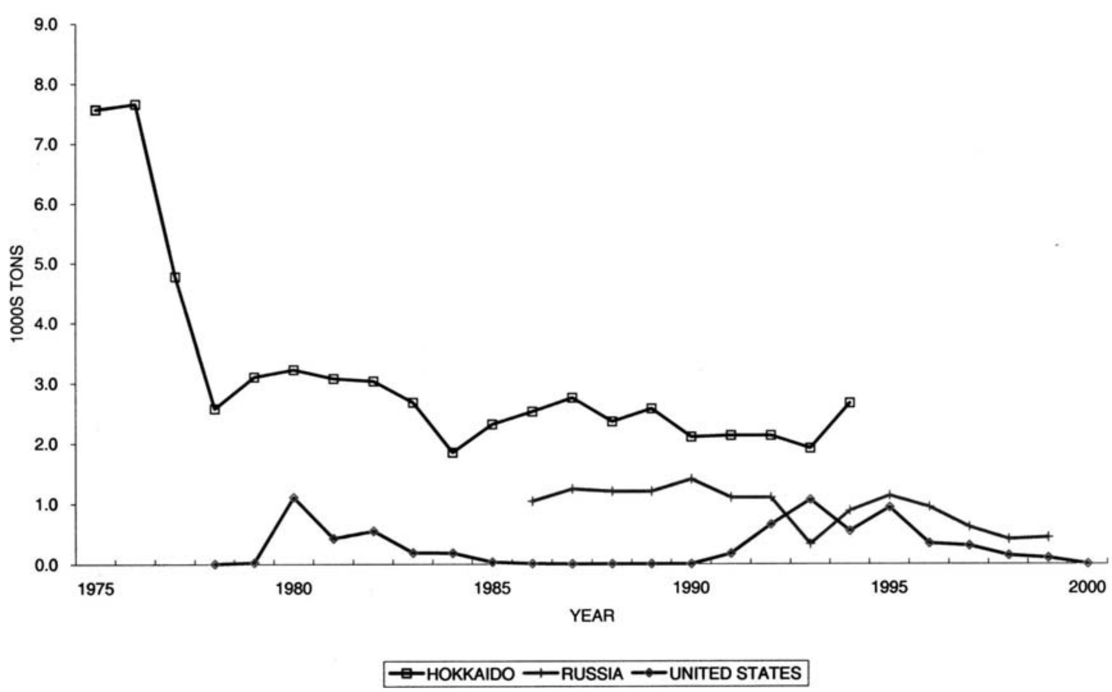


Fig. 14 Reported landings (10^3 t) of Japanese, Russian and American hair crab, 1975-2000.

Red king crab (*Paralithodes camtschaticus,* Plate 2) fisheries of the Sea of Okhotsk and the eastern Bering Sea (EBS) have been most important, followed by blue king crab (*Paralithodes platypus,* Plate 2) in the Sea of Okhotsk, off the Koryak Coast, and in the EBS. Golden king crab (*Lithodes aequispina,* Plate 2) in the Aleutian Islands and the Sea of Okhotsk are next in importance. The Hanasaki gani, or brown king crab (*Paralithodes brevipes,* Plate 2), is a shallow water (< 100 m) species that is confined to Asiatic waters, and is particularly important in Japan. Hanasaki gani are smaller crab than the other three king crab species listed above and rarely exceed 2.5 kg in weight. Fisheries for the scarlet king crab (*Lithodes couesi*) have been largely experimental; this crab occurs at depths usually exceeding 700 m.

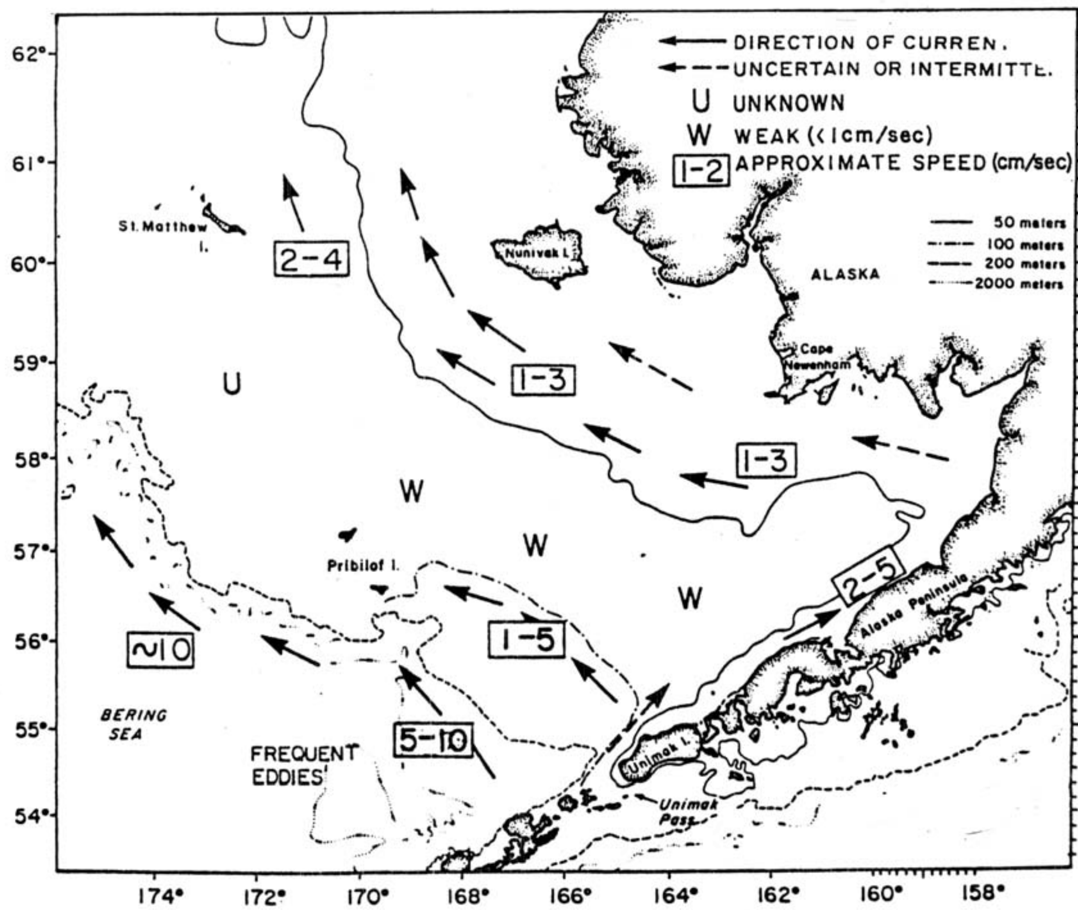
Four species of king crabs thus support major fisheries in the PICES Region. They differ in their life history characteristics and because many species' populations co-occur, comparative study of the effects of life history characteristics on population stability may be possible. For example, red king crab and blue king crab both inhabit the Pribilof Islands area and some areas of the Sea of Okhotsk, where their comparative dynamics may be explored.

3.5.1 Blue king crab

Blue king crab are similar to red king crab, but usually are biennial spawners with lesser fecundity and somewhat larger sized (*ca.* 1.2 mm) eggs (Somerton and Macintosh 1983, Jensen and Armstrong 1989, Selin and Fedotov 1996). By comparison, the more common red king crab are annual spawners with relatively higher fecundity and smaller sized (*ca.* 1.0 mm) eggs. Ecologically the two species apparently are very similar. The lower reproductive potential of blue king crab is interesting from an oceanographic perspective (Fig. 15), since blue king crab populations form concentrations around offshore islands in the EBS (Fig. 16). Presumably, either localized transport mechanisms or demersal larval behavior might be involved in maintaining these populations of blue king crab. Oceanographic data from these near-shore, island areas has been insufficiently described and larval surveys, mostly for relative abundance within a specific survey design, have been sporadic.

Table 10 Reported landings (t) of king crabs from the PICES Region (FAO). [1] = Russian landings for 1984-1987 from FAO Vol.72.

	N. W. Pacific				N. E. Pacific	
Year	Japan	South Korea	Russia[1]	SubTotal	United States	Grand Total
1984	137	6	3,459	3,602	7,804	38,406
1985	351	14	32,720	33,085	6,969	40,054
1986	123	5	37,943	38,071	11,752	49,823
1987	207	4	39,707	39,918	13,184	53,102
1988	329	10	44,762	45,101	9,513	54,614
1989	623	3	41,940	42,566	11,971	54,537
1990	824	3	41,733	42,560	15,385	57,945
1991	1,122	2	39,763	40,887	12,764	53,651
1992	2,058	11	38,830	40,899	8,644	49,543
1993	313	9	35,330	35,652	11,218	46,870
1994	472	0	38,068	38,540	5,425	43,965
1995	261	0	54,986	55,247	6,656	61,903
1996	322	0	34,300	34,622	9,526	44,148
1997	154	0	23,262	23,416	8,177	31,593
1998	132	0	32,486	32,618	1 941	43,559
Total	7,428	67	566,289	573,784	149,929	723,713
%	1.0	0.0	78.2	79.3	20.7	100.0



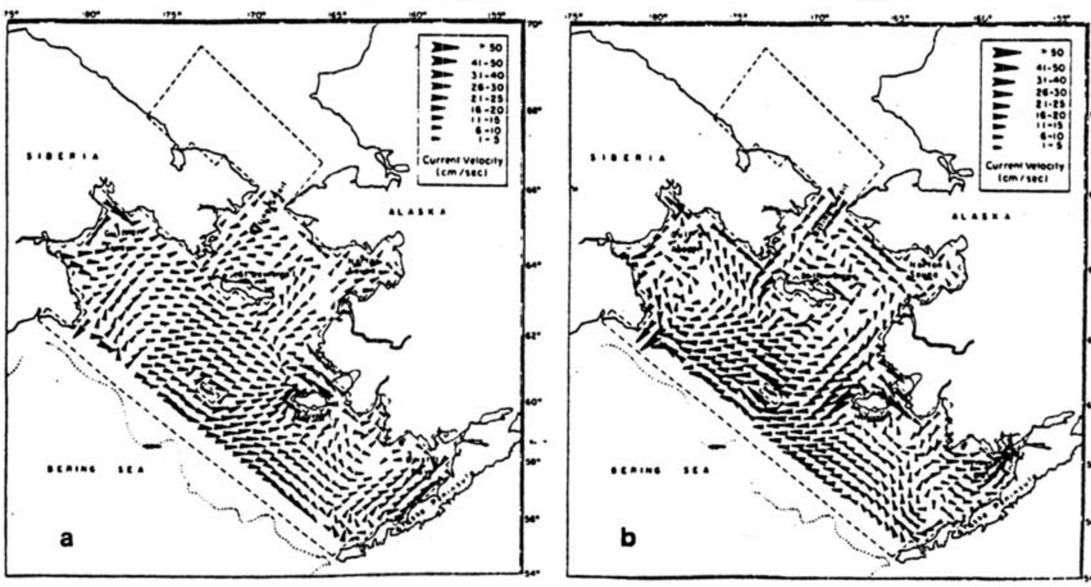


Fig. 15 Tidal currents (cm sec^{-1}) calculated from a numerical tidal model for (a) four hours before high tide, and (b) four hours before low tide at the eastern boundary (from Hastings 1975).

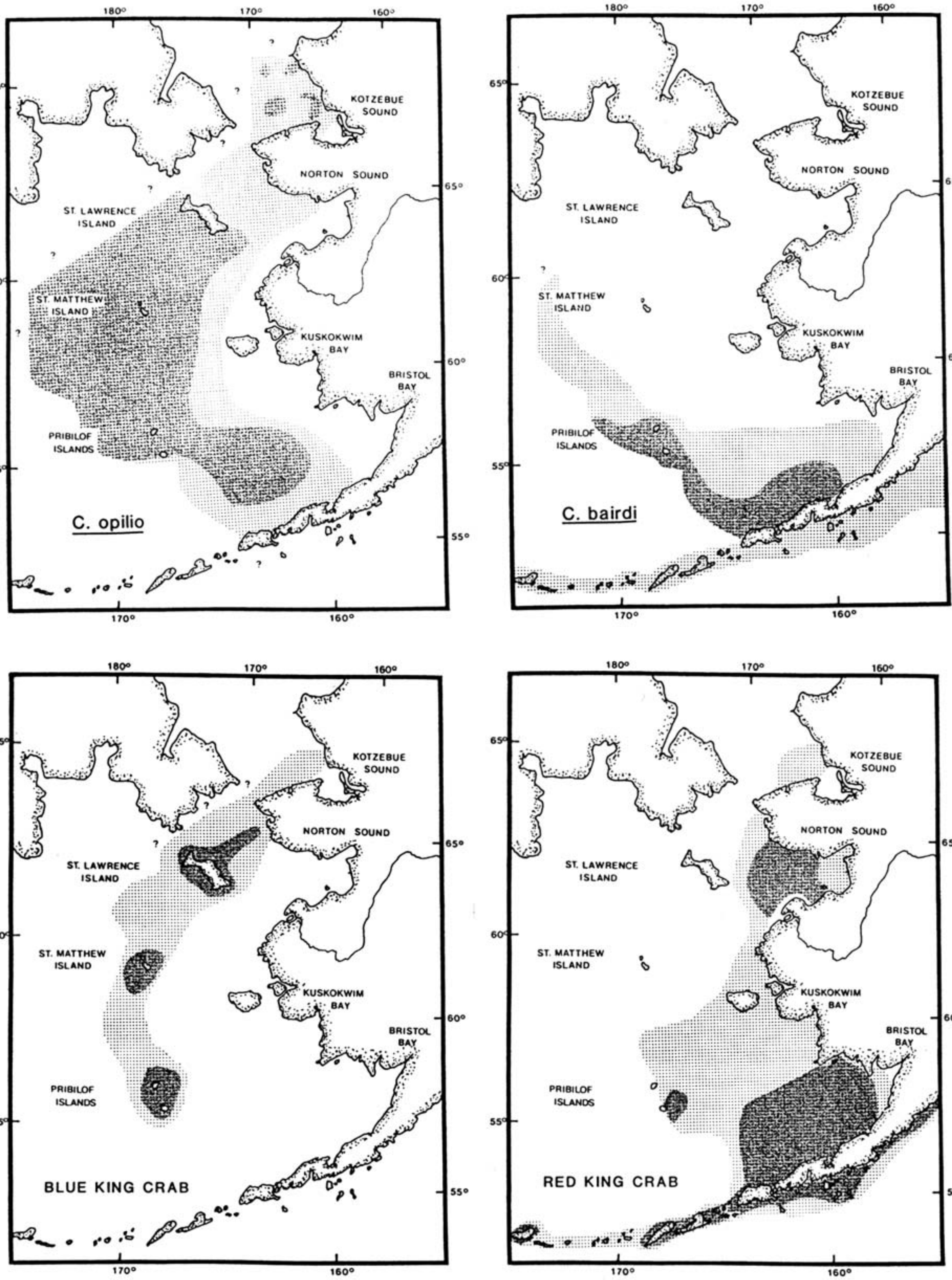


Fig. 16 *Chionoecetes* spp., blue king and red king crab stock distributions in the EBS (Otto 1981).

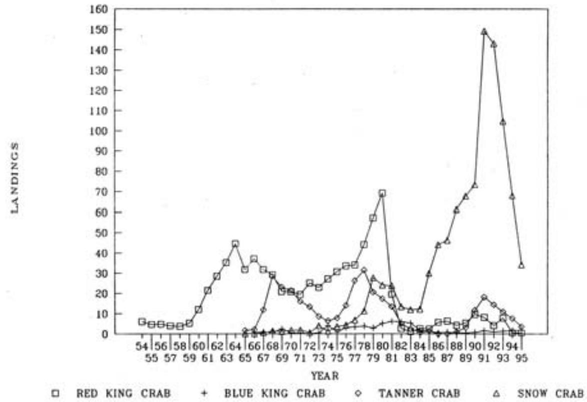


Fig. 17 *Chionoecetes* spp., blue king and red king crab landings from the eastern Bering Sea (from the Alaska Department of Fish and Game and Otto 1981).

Little stock specific assessment information is available for most Asian stocks, which tend to be located near continental coasts rather than islands. North American stocks are surveyed annually and managed in a manner similar to the EBS red king crab (see below).

In general, blue king crab stocks are small and localized (Fig. 16) and support small fisheries. For example, combined landings from the Pribilof and St. Matthew Island areas have seldom exceeded 5,000 t (Fig. 17). The Pribilof Islands stock has been fished since 1966 when Japanese fishermen began exploratory efforts. The fishery produced an average of 1,300 t during the 1960s, which rose to 1,850 t in the 1970s. The Pribilof fishery reached a peak of 4,980 t in 1980, but soon declined precipitously to 120 t in 1986. The fishery was closed by the State of Alaska in 1988 and only four fishing seasons have been allowed since. The fishery has averaged 370 t during the four fishing seasons allowed during the 1990s. Pribilof Islands blue king crab are among the largest in the world and the average size of landed crab has exceeded 3.5 kg in many years. Blue king crab in the St. Matthew Island area are smaller and fishery average weight seldom exceeds 2.2 kg. The St. Matthew fishery is smaller and began in 1977. For the years 1977-1999, the fishery averaged 1,350 t; it has ranged from 90 t in 1979 to 4,290 t in 1983. The fishery declined severely after 1998, following the near average catch of 1,300 t in 1998, the 1999 survey indicated an 80-90 % decrease in abundance, that lead to closure of this fishery (see http://www.afsc.noaa.gov/kodiak/) for details concerning EBS stocks.

Other stocks of blue king crab occur in scattered locations in the GOA and the EBS, but they are much smaller, rarely fished and have mostly been unsurveyed. Their scattered locations and frequent occurrence in fjord-like waters poses interesting zoogeographic and ecological questions.

Russian stocks in the Western Bering Sea (WBS), particularly along the Koryak coast, have yielded an average 1,800 t in recent (1996-1999) years. However, the Sea of Okhotsk, where several stocks occur, is more important. Sea of Okhotsk landings averaged 3,720 t between 1986-1999 and peaked at 7,580 t in 1997. Over the past 5 years, the Sea of Okhotsk produced 29% of Russian landings. Total landings from Russian waters have averaged 7,200 t in recent years. The higher and steadier production of blue king crab in the WBS and Sea of Okhotsk may reflect more constant and colder conditions caused by a southerly current and proximity to a large continental land mass to the west.

3.5.2 Golden king crab

Golden, or brown, king crab occur from the Japan/East Sea to the northern Bering Sea, around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia. They are typically found on the continental slope at depths of 300-900 m. Their fisheries are relatively recent developments in most areas and frequently have developed (e.g., Figs. 18, 19) after shallower-water king crab fisheries became fully developed or had declined (Somerton and Otto 1986, Orensanz *et al.* 1998). Golden king crab have much larger eggs (*ca*. 2.3 mm) than those of blue or red king crabs (Otto and Cummiskey 1985, Somerton and Otto 1986) and also tend to spawn throughout the year rather than in the late winter and spring (Hiramoto 1985, Hiramoto and Sato 1970, Otto and Cummiskey 1985, Klitin *et al.* 1999, Somerton and Otto 1986). Golden king crab eggs have about 12 times the volume of red king crab eggs. Large eggs tend to be characteristic of the genus *Lithodes,* and scarlet king crab also have relatively large eggs. A seasonal spawning occurs because larvae in this species are capable of lecithotrophic development (Shirley and Zhou 1997). There are few records of golden king crab larvae in upper water plankton tows and it is possible that these larvae are demersal. In southeastern Alaska and British Columbia, isolated golden king crab populations are frequently found in deep-water fjords or other long narrow sounds (Jewett *et al*. 1985). Populations in some of these confined areas seem to show an elevated incidence of parasitism (Sloan 1984, Sloan *et al*. 1984). In many areas of the GOA and northern British Columbian coastal waters, populations of golden king crab may spend their entire life span in such bays or fjords.

The most important golden king crab fisheries are found in the Sea of Okhotsk and the Aleutian Islands (Fig. 20). These fisheries tend to be recent in origin (since 1980). From 1986 to 1999, golden king crab fisheries in the Russian Far East produced an average landing of 2,500 t. From 1994–1999, annual landings have been more than twice those of previous years but have been declining. In the Aleutian Islands, golden king crab were taken incidentally to red king crab until 1981, when a directed fishery was first established. Landings from 1975 to 1979 averaged 10 t per year, while those from 1981 to 1999 averaged 3,600 t, with a peak landings of 6,650 t in 1986.

3.5.3 Red king crab

Red king crab are economically the most important of the king crabs. Commercial fisheries for them were pioneered by the Japanese in the early 1900s and fishing for this species soon developed into a major commercial enterprise. Cahn (1948) reviewed the development of the Japanese fishery. The economic importance of red king crab coupled with an ongoing interest in marine biology displayed by the Japanese royal family lead to a number of classic crab studies, such as that of Marukawa (1933), and later to interest in Alaskan resources.

Red king crab canned production data were converted to number of crab landed using data from Cahn (1948) to show trends in the Japanese pre–1940 fishery for various areas (Fig. 21). The earliest developments were in Hokkaido, Karafuto (modern day Sakhalin Island), and the southern Kuril Islands. These fisheries lead to shore-based processing in the Northern Kuril Islands and major fisheries in western Kamchatka, which is today the world's most important red king crab fishery. Use of floating processors ("floaters" in Fig. 21) lead to further developments, including exploratory fishing in the EBS and the Koryak Coast during the 1930s. Most of the "floaters" (Fig. 21) and their catcher boat fleets, however, exploited waters of the Sea of Okhotsk, and their landings generally reflected abundance in that region.

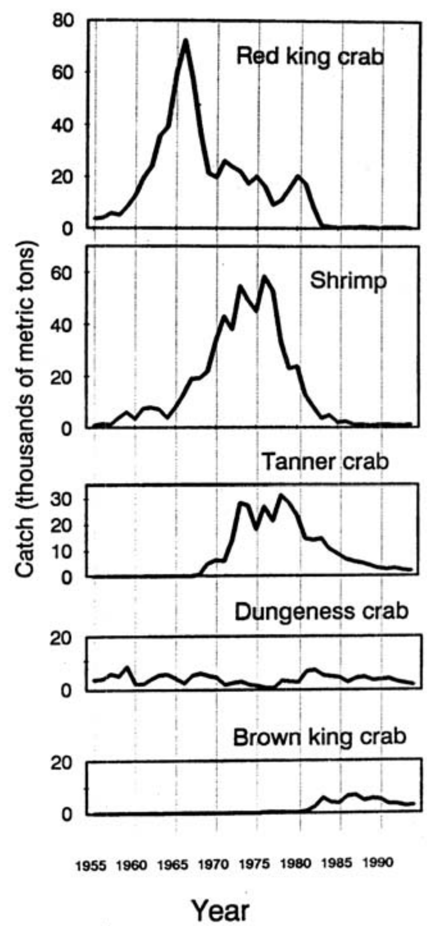


Fig. 18 Crustacean landings by species in the greater Gulf of Alaska (Orensanz *et al.* 1998).

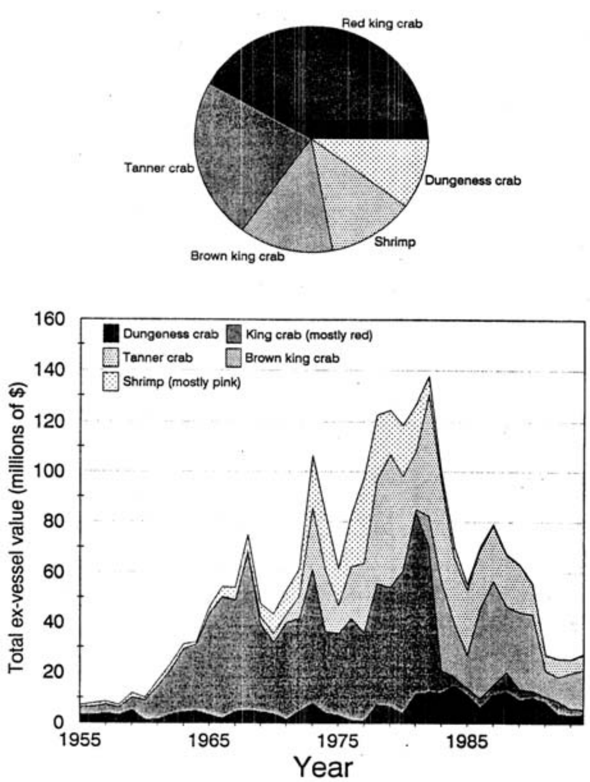


Fig. 19 Top: Relative aggregated values of the historical landings (1955-1994) for major crustacean fisheries in the greater GOA. Bottom: Values (standardized to 1983 US$) of crab landings by species in the greater GOA (Orensanz *et al.* 1998).

All major Asian stocks were apparently fully exploited by 1930. The Hokkaido fishery enjoyed a long period of stability, showing only one major peak (1933) and decline in the pre-war era. Stocks in the Japan/East Sea (principally near Sakhalin Island) showed several peaks (1917, 1930) and more variability than those around Hokkaido. The West Kamtchatka fishery peaked in 1927 and again about 1940, before fisheries were curtailed during the war years.

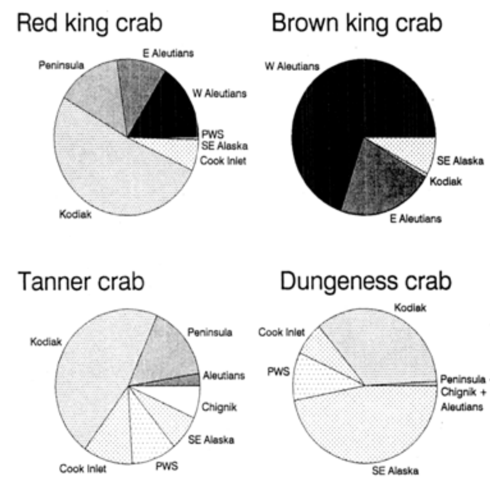


Fig. 20 Alaskan crab landings proportions for the period 1945-1995 (Bering Sea excluded) for the four most commercially valuable crab species in Alaska (Orensanz *et al.* 1998). PWS = Prince William Sound.

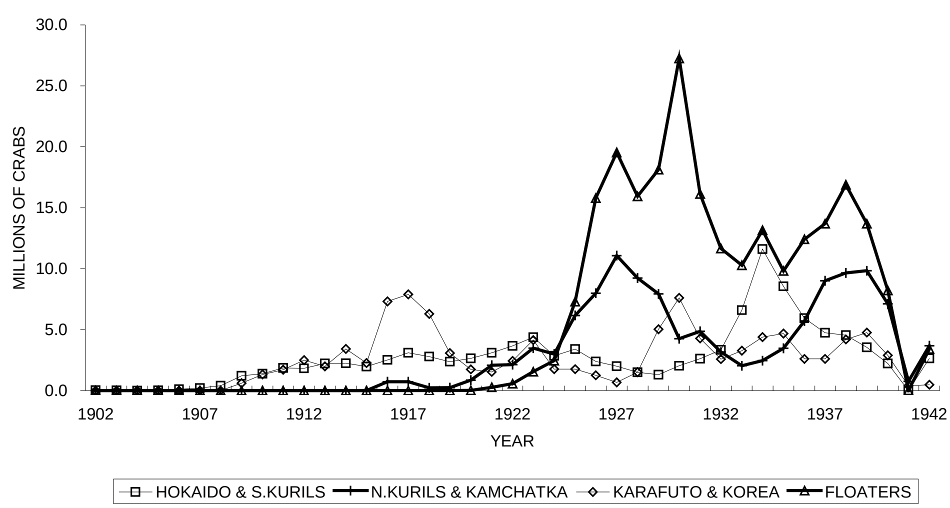


Fig. 21 Development of major pre-1940 Japanese red king crab fisheries based on records from the canned crab industry (from Cahn 1948).

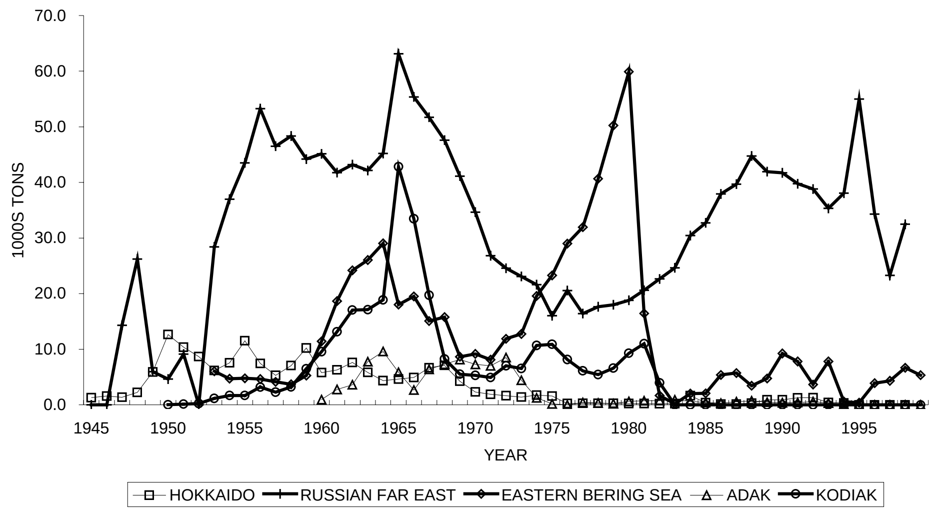


Fig. 22 Historical landings of red king crab in major fisheries since 1945.

After 1945, (Fig. 22), all of these fisheries were reestablished except for those in the Japan/East Sea. The Hokkaido fishery resumed at a similar level, if an average landed weight of about 2.5 kg is assumed (note change of scale between Figs. 21 and 22).

The West Kamchatcan fishery was prosecuted both by Japan and the Soviet Union, leading to record catches and a period of stability from 1955-1965. This lead to a decade-long gradual decline in landings. In the late 1950s and early 1960s, the Japanese in Bristol bay and the Americans in the Gulf of Alaska developed Alaskan king crab fisheries as far west as the Adak area of the Aleutian Islands. Trends in the Gulf of Alaska fishery are represented in Figure 22 by Kodiak landings, but it should be noted there were simultaneous fisheries developed in Cook Inlet, along the southern Alaska Peninsula, and in the eastern Aleutians (Fig. 23). The EBS red king crab fishery (Fig. 24) first began in the 1930s when Japanese fishermen began to exploit this stock with tangle nets (Cahn 1948). There was some U.S. trawl fishing during the 1940s, but effort and catch were small. During this time, the needs of the developing U.S. king crab industry were largely met in the GOA, and this continued until the late 1960s. Japanese fishing began again in 1953 (Nyahara 1954), when the modern fishery began. Otto (1981) reviewed the history of the multinational king and Tanner crab fisheries in the EBS from 1953 to 1979. Except for minor exploratory efforts by Japanese and Russian fleets in the 1960s, fishing in the GOA and Aleutian Islands has always been entirely an U.S. industry. A special study of red king crab in Alaska was conducted in 1940-1941, and this was both instrumental in stimulating fishery development and provided initial detailed biological information (Wallace *et al.* 1949, Harrison *et al.* 1942).

The mid 1960s was a period if high red king crab landings in Asia as well as North America, but there were signs that stock exploitations were at or approaching their limits. For example, Bristol Bay data in the Bering Sea showed that CPUE peaked in 1960 and that increased catch was being maintained by increases in the number of tangle nets being fished and in the average time that nets were soaked. Following peak catches in 1964, the Bristol Bay stock began to decline. The Kodiak and other GOA stocks also declined sharply, and this lead to both more stringent management measures and renewed interest by US fishermen in the Adak area and the Bering Sea. The Kodiak and other GOA stocks supported smaller but more stable fisheries in the late 1960's and through the 1970's, only to decline sharply, leading to many fishery closures in 1982 and 1983. Only small fisheries in the eastern GOA have been allowed since. The Adak fishery declined in the early 1970s and has never fully recovered, although small (*ca.* 500 t) fisheries have been allowed in most recent years.

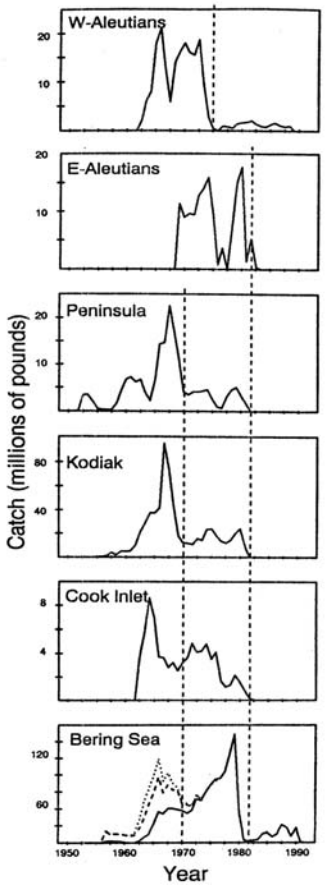


Fig. 23 Red king crab catches (10^6 pounds) during the period 1959-1995 in several management areas, including the Bering Sea (dashed and dotted lines indicate the contribution from the Japanese and Russian fleets, respectively, added on top of the catch by the American fleet, solid line). Vertical dashed lines indicate the timing and geographic spread of major stock declines (from Orensanz *et al*. 1998).

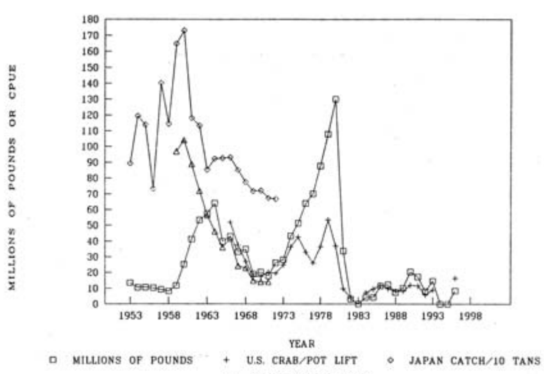


Fig. 24 Commercial landings and CPUE of Bristol Bay red king crab, 1953-1996.

In the remainder of this time period, red king crab abundance in the EBS and the Russian Far East became clearly out of phase with each other. Hokkaido and Adak fisheries had some similarities, and both have done poorly in recent years. In Hokkaido, red king crab fisheries have recently been supplanted by Hanasake gani and hair crab (Fig. 25). One wonders if the abundance of hair crab indicated a change in ecological conditions. Almost all GOA red king crab fisheries have been at extremely low levels since the early 1980's and fishery independent surveys show virtually no sign of recovery. The decline of GOA red king crab has been attributed to over fishing (serial depletion of Orensanz *et al*. 1998, Fig. 26) and changing ecological conditions. The lack of discernible recovery despite fishery closure from 1982 to present suggests a fundamental change in the habitat or a broad scale climatic phenomenon.

The American National Marine Fisheries Service (NMFS) has conducted annual trawl surveys of the EBS to collect data on abundance, distribution and biology on five species of crabs and over ten species of groundfish. The area surveyed encompasses the adult distributions of most commercial species, but frequently does not cover an entire species' range. For example, immature king crab, less than three years, are typically found inshore on rocky grounds or other untrawled shallow areas. The EBS survey takes place annually during late May, June, July and August to avoid the spring crab molting periods. Over the period 1979-1994, the area covered, sampling density and timing of the survey have been similar. The habitat of Bristol Bay red king crab has been well covered since 1968, and there are some data available from the 1950s. Areal abundance indices are calculated by an area-swept technique (Alverson and Pereyra 1969, Hoopes and Greenough 1970), assuming a catchability of 1.0. Abundance indices are relative rather than absolute since there are very little data on catchability of juvenile crabs in the trawl or their actual availability to the survey. For management purposes, it is usually assumed that virtually all commercial-sized crab in the trawl's path are captured. Smaller males and females are probably less vulnerable than commercial-sized males. A detailed report (e.g., Stevens *et al*. 2000) is published each year and is also available on line (http: //www.afsc.noaa.gov/ kodiak/). Survey data are primarily used in stock assessment models (e.g., Zheng *et al*. 1998, Zheng and Kruse 1995).

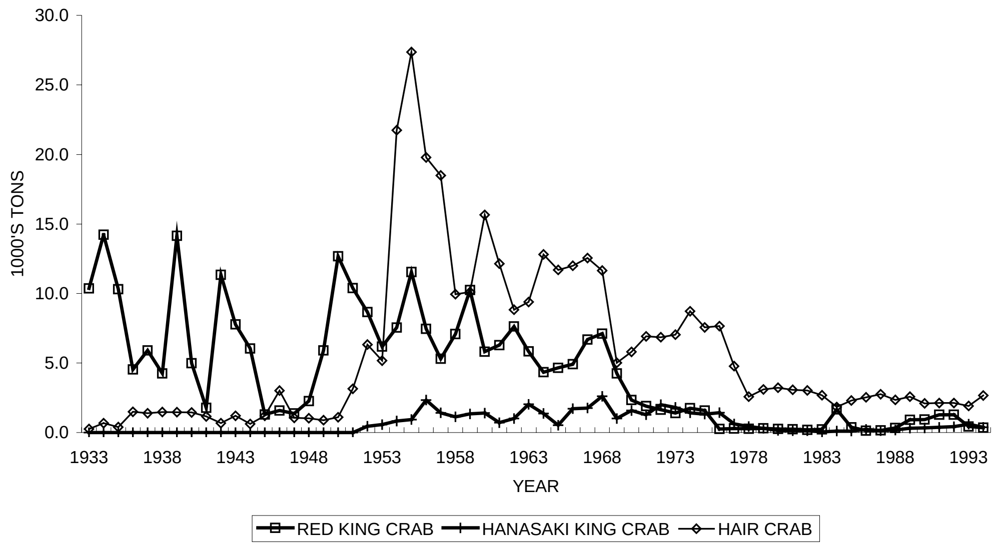


Fig. 25 Hair crab and king crab landings in Hokkaido crab fisheries.

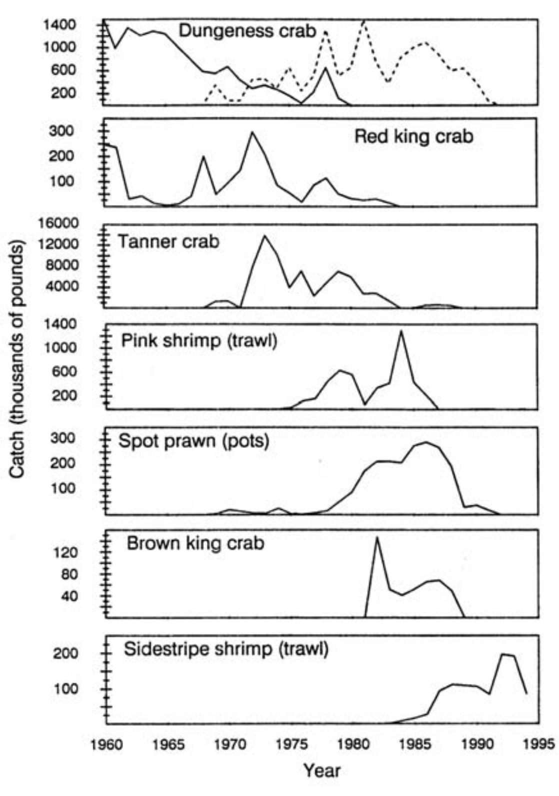


Fig. 26 Time trends in commercial landings of major crustacean resources from the Prince William Sound Management Area. For Dungeness crab, the solid and dashed lines correspond to the Orca Inlet and Copper River fisheries, respectively (from Orensanz *et al*. 1998).

The West Kamchatka stock of red king crabs seems to follow a basic denatent-contranatent life history pattern (Fig. 27), where adults occur up current from juvenile nursery grounds and show a contranatent ontogenetic migration to the adult habitat (Rodin 1985**,** 1990). Sub-population units of adults have their own seasonal pattern of offshore-onshore migration that is apparently mediated by temperature. This life history pattern is similar to those described by Jones (1968) for a wide variety of marine fishes. Positioning of females at the time of egg hatching relative to long-shore currents appears important for king crabs. The life history pattern of Bristol Bay red king crab appears similar to that of the West Kamchatkan stock, except that there is currently only one area or sub-population of adults (Rodin 1990). In both populations, the spatial structure of adults appears to be important and the critical juvenile habitat appears to be limited in area. Searching benthic habitat by megalopae (= glaucothoe) appears to be an important mechanism whereby larval settling on an appropriate substrate is insured (Stevens and Kittaka 1999).

Throughout most of the GOA and eastern Aleutians, red king crab populations declined from the late 1970s until the fisheries were closed in 1983 (Fig. 26). Populations have been at low levels and fisheries closed since 1983.

Populations declined soon after the now recognized regime shift (Anderson *et al*. 1997, Anderson and Piatt 1999) of the late 1970's, and this offers an opportunity for both retrospective study and comparative study with Asian populations that have differing patterns of abundance over time. Comparative study of Bristol Bay and West Kamchatkan populations may be particularly instructive. Over the past 20-30 years it appears that southern stocks of red king crab (Hokkaido, Adak, GOA) have not fared as well as more northerly stocks (EBS, West Kamchatka).

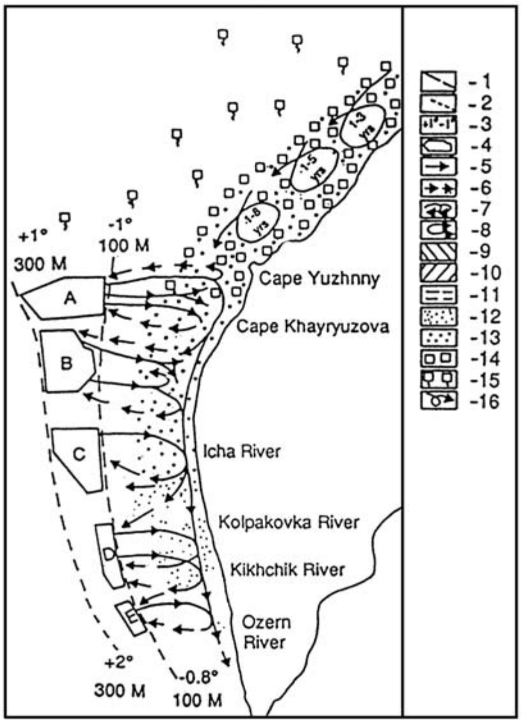


Fig. 27 Diagram of the distributional structure and ontogenetic migrations in the West Kamchatka red king crab population. 1. Isobaths; 2. Currents (not shown here); 3. Bottom water temperature; 4. Overwintering area of subpopulations: A and B – Khayryuzovskiy independent; C – Ichinskiy semi-dependent; D – Kolpakovskiy and Kikhchiskiy dependent; E – Ozernovskiy pseudopopulation; 5. spring spawning migration; 6. autumn migration to winter habitat; 7. Migration connections between sub-populations; 8. concentrations of adult males; 9. summer distribution of adult males (not shown here); 10. females with external eggs (not shown here); 11. small males (not shown here); 12. occasional detection of planktonic larvae; 13. Stage I and II zoea; 14. Stage III and IV zoea; 15. gloucothoe settling area; 16. Ontogenetic migration of year classes (from Rodin 1990).