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Commercially Important Crabs, Shrimps and Lobsters of the North Pacific Ocean

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1 Summary

Changes in the abundance of commercially important crustaceans in the North Pacific led PICES to form Working Group 12 in 1997. Objectives were to identify important North Pacific crustacean stocks, to describe historical changes in their abundance, to identify current research programs on them, and to clarify mechanisms that might account for their observed patterns of abundance. The PICES Region includes almost all of FAO Statistical Areas 61 and 67 and a small portion of Area 71. The Region in 1998 provided 48% of world crab landings and 45% of world shrimp landings, excluding data from North Korea.

The world-wide importance of the PICES Region with respect to crustaceans has been increasing over the last 15 years, with crab and shrimp landings increasing at an annual compound rate of 7.8% and 8.2%, respectively. Of the 48 crustacean species that have accounted for commercial fisheries landings in the PICES Region, 33, or 69%, are endemic to it.

Five FAO species groupings (16 species in four families) make up 79% of crab landings in the PICES Region. Four of these are brachyurans and the other is an anomuran (king crabs). The gazami crab (Portunidae, *Portunus trituburculatus*) fishery in the Yellow Sea area alone represented 39.5% of landings over this period. Harvested snow and Tanner crabs (Majidae, *Chionoecetes* spp.) include five species. Landings of king crabs (Lithodidae) include three species of *Paralithodes* and two species of *Lithodes*. 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. Hair crab (*Erimacrus isenbeckii*), rock crabs (*Cancer* spp.) and sheep crab (*Loxorynchus grandus*) provide small fisheries in the PICES Region, but except for hair crab, fisheries are poorly documented.

Three families of shrimps are commercially important in the PICES Region, and their landings have made up 93.8% of shrimp landings within the PICES Region over the last 15 years. Sergestidae includes the akiami paste shrimp (*Acetes chinensis* and *Acetes japonica*), that supports the largest shrimp fishery in the PICES Region, as well as the world. Penaeidae occur in the waters of China, Korea and southern Japan, and major fisheries exploit Kuruma shrimp/prawn (*Marsupenaeus japonicus*); the cocktail, or southern rough shrimp (*Trachysalambria curvirostrus*); fleshy prawn (*Fenneropenaeus chinensis*) and Shiba shrimp (*Metapenaeus joyneri*). The Pandalidae include the genera *Pandalus* and *Pandalopsis* and this family accounts for virtually all shrimp landings from northern Japan around the North Pacific rim to California. In terms of volume, the northern shrimp (*Pandalus borealis,* or *eos*) and the ocean shrimp (*Pandalus jordani*) have been most important economically, although six additional species have contributed substantially to the catch in various areas. There have been some recent attempts to exploit deepwater glass shrimps, Family Pasiphaeidae. Other species of shrimp such as many Crangonidae, which provide important commercial fisheries in the northeast Atlantic, are present in the PICES Region but are only harvested to a minor extent or as incidental catch.

Mantis shrimps, stomatopods (Squillidae) that are not closely related to the more familiar decapod shrimps, are briefly discussed for comprehensiveness, although the only species commercially exploited is *Oratosquilla oratoria* in the Bohai Sea. Mantis shrimps are widely distributed in Chinese waters and are also found around Korea and Japan, where they used to be historically more important. Spiny lobsters (Decapoda, Palinuridae) are exploited in Japan, South Korea, and China (*Palinurus japonicus*), and in California (*P. interruptus*).

2 Introduction

Interest in a working group was prompted by large changes in the abundance of commercially fished crabs and shrimps that occurred in various areas of the PICES Region. Working Group 12 (WG 12) was established by the Governing Council in October 1995 upon the recommendation of the Fisheries Science Committee (FIS). Many changes in crustacean abundance have been of considerable economic importance and affected large geographic areas. For example, red king crab (*Paralithodes camtschaticus*) was a mainstay of commercial fishing in the Gulf of Alaska (GOA) in the 1960s and 1970s, but almost all of the GOA has been closed to commercial fishing for red king crab from 1983 onward due to low stock abundance. At the same time red king crab abundance in the Sea of Okhotsk remained high and fishing continued unabated. This example illustrates that trends in stock abundance within species, and presumably mechanisms responsible for changes in abundance, are not homogeneous within the PICES Region. A major portion of WG 12's work was to assemble a first catalog of North Pacific crustacean stocks and their patterns of changing abundance, as part of an underlying effort to elucidate mechanisms of change in various species or species groups.

This report summarizes the results of four meetings that were held in Nanaimo, Canada (1996); Nemuro, Japan (1997); Fairbanks, USA (1998); and Qingdao, China (1999). Details of attendance and national representation are contained in Appendix 1 and 2.

2.1 Terms of Reference

The Governing Council established Working Group 12 upon the recommendation of the Fishery Science Committee using the following language:

"Because of recent changes in the abundance of crabs and shrimps and their economic consequences in the PICES region, the Working Group is established to:

- Identify the persons performing scientific work on the distribution, recruitment, larval transport, migration, population dynamics, and influences of environmental conditions for crabs and shrimp in the PICES region.

- Identify data that are available that would assist in the analyses of factors affecting abundance trends.

- Review current knowledge of factors affecting abundance and survival of crabs and shrimp and identify the key scientific questions relating to the understanding of the reasons for abundance fluctuations.

- Exchange data on the abundance of crabs and shrimp stocks in the PICES region."

Terms of reference evolved over the course of WG 12 deliberations because of:

- The vast number of crab and shrimp species in the North Pacific, and the resultant need to focus on a relatively few key species. These species provide an array of complex life histories and habitat requirements that provide contrasts when examining natural and/or anthropogenic causes of varying abundance.

- The large number of researchers involved to some extent with at least some of the identified species. WG 12 felt a need to restrict the scale of its mandate and identify researchers and institutions through citation. WG 12 effectively limited the terms "crabs" and "shrimps" to mean those species that were currently fished or which could be fished using conventional methods from other parts of the world. The very large group that study crabs and shrimps in general was hence reduced to those working with fishery related forms. This was, in part, necessary because trends in abundance are so seldom available for unfished species.

- Additionally, in 1997 we received information on the Japanese spiny lobster that indicated some importance in the PICES Region and further noted omission of the California spiny lobster. Both these species were recommended and accepted for inclusion in the terms of reference. This action effectively enlarged WG 12's mandate to include all harvested crustaceans in the PICES Region. The taxonomy of species contained in this report is reviewed in Appendix 3 and individual stocks are listed in Appendix 4.

Accordingly the final terms of reference were:

- Consider those crabs, shrimps and lobsters that are utilized in commercial, subsistence or recreational fisheries. This may include introduced species if they are directly important or impact human utilization of any other marine species.
- Identify persons through citation from each country that are performing scientific work on the distribution, recruitment, larval transport, migration, population dynamics, and influences of environmental conditions for crabs and shrimps.
- Identify data that are available that would assist in the analyses of factors affecting abundance trends.
- Review and exchange current knowledge and data concerning factors affecting abundance and survival of crabs, shrimps and spiny lobsters and identify key scientific questions regarding reasons for abundance fluctuations.

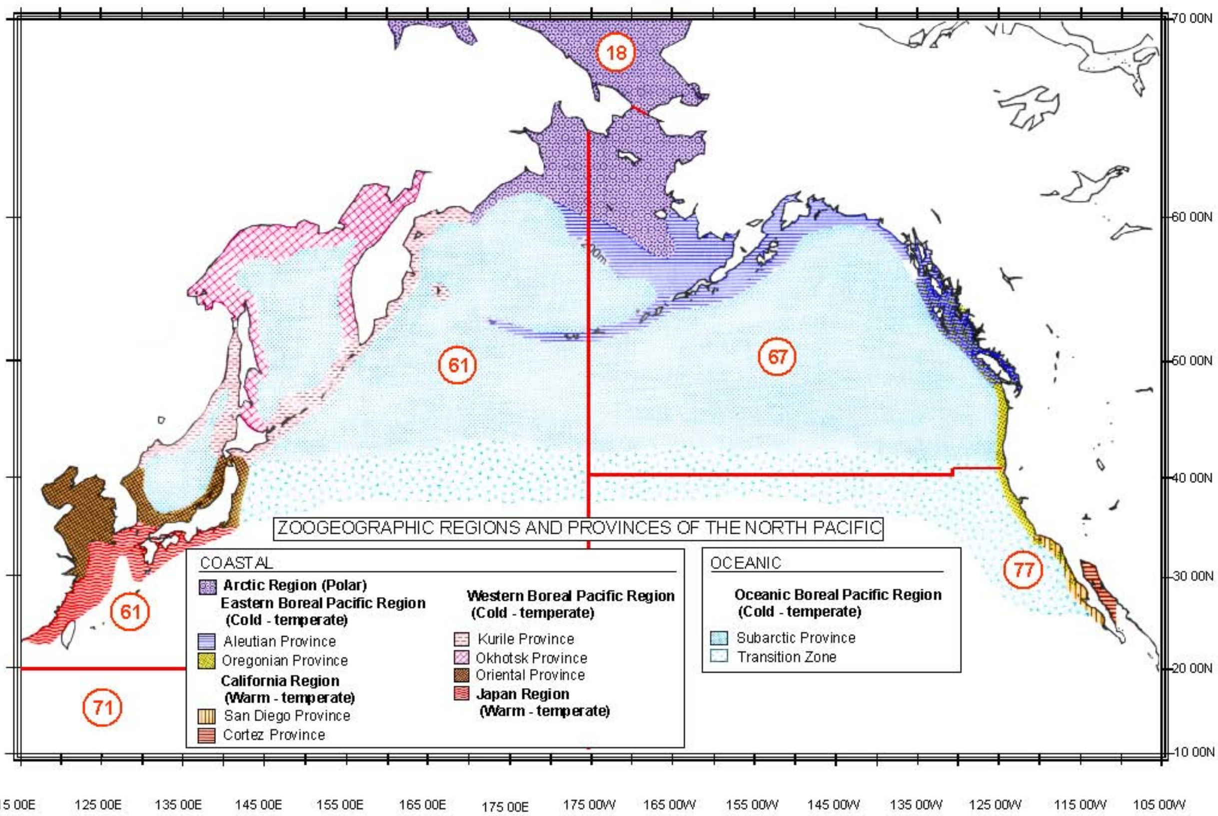


Fig. 1 Zoogeographic regions and provinces and FAO boundaries of the North Pacific. The PICES Region considered in this report is the East China Sea and the waters north of 24° in the North Pacific proper (redrawn from Allen and Smith (1988) and FAO).

2.2 An Overview of Crustaceans in the PICES Region

The PICES Region contains large proportions of the world's crab and shrimp resources. It is not always possible to precisely quantify landings of these resources from available statistics. At the meeting in Qingdao, it was decided that the East China Sea should be included and that 24°N would be an appropriate biologically-based southern boundary for crustaceans in Asia (Fig. 1). Unfortunately, fishery landing statistics have not always been available north and south of this latitude. The PICES Region (basically north of 30^{o}N) encompasses all of FAO Area 67 (Northeast Pacific), a small part of Area 77 (Eastern Central Pacific) and most of Area 61 (Northwest Pacific south to 20°N) (Fig. 1). As an approximation, landings from the PICES Region would include all landings in Area 67, only U.S. landings from Area 77, and summed landings from Chinese, Japanese, North Korean, South Korean and Russian marine waters from Area 61. There is no fixed boundary for the PICES Region, and so we referred to these FAO statistical areas as the PICES Region for the purposes of this document. With this caveat, in 1998 the PICES Region provided 48% of world crab landings (Table 1) and 45% of world shrimp landings (Table 2).

In all cases we tried to refer landings or other fisheries statistics to FAO or some other database available through the worldwide web or standard publications of various agencies. All FAO capture production (wild harvest) figures for 1984-1998 are from the FAO Fisheries Department, Fishery Information Data and Statistics Unit, and FISHSTAT Plus, universal software for statistical time series, Version 2.3 2000. This is accessed through www.fao.org/waicent/faoinfo/fishery/struct/fidi.asp. Earlier FAO statistics are from annual reports that may include some aquacultural production in FAO Area 67.

In both relative and absolute terms, the importance of the PICES Region has increased greatly over the past 15 years of record. Reported weight of crabs landed in the PICES Region (Fig. 2)

Table 1 World landing statistics for major stocks of crabs in the PICES Region (t, FAO).

Year	World	PICES	% PICES
1984	518,573	204,063	39.4
1985	546,711	224,959	41.1
1986	589,595	247,097	41.9
1987	715,807	346,642	48.4
1988	782,848	358,415	45.8
1989	827,889	402,159	48.6
1990	847,976	418,970	49.4
1991	957,599	488,387	51.0
1992	987,959	503,691	50.0
1993	984,500	427,736	43.4
1994	1,169,165	565,940	48.4
1995	1,159,324	528,092	45.6
1996	1,212,021	603,505	49.8
1997	1,203,428	547,346	45.5
1998	1,284,838	620,721	48.3
Total	13,788,233	6,488,284	47.1

Table 2 World landing statistics for major stocks of shrimps in the PICES Region (t, FAO).

Year	World	PICES	% PICES
1984	1,770,176	347,837	19.6
1985	1,957,344	446,232	22.8
1986	1,977,460	479,087	24.2
1987	1,940,911	553,043	28.5
1988	1,998,856	636,011	31.8
1989	1,960,169	603,115	30.8
1990	1,967,500	614,834	31.2
1991	2,054,824	616,566	30.0
1992	2,112,607	678,104	32.1
1993	2,081,805	653,598	31.4
1994	2,287,289	955,760	41.8
1995	2,336,835	960,219	41.1
1996	2,454,989	1,093,628	44.5
1997	2,600,256	1,103,126	42.4
1998	2,713,450	1,232,634	45.4
Total	32,214,471	10,973,794	36.1

increased at an annual compound rate of 7.8% (R^2 = 0.87) from 1984 to 1998 as compared to world increases at a 6.8% (R^2 = 0.95) compound rate over the same period. Reported weight of shrimps in the PICES Region (Fig. 3) increased at a compound rate of 8.2% (R^2 = 0.93) while world landings were more stable, increasing at 2.6% (R^2 = 0.87). Most growth in crab fisheries took place in China, which accounted for 37.5% of PICES Region crab landings over the past 15 years of record. Unfortunately, large amounts of Chinese landings have been listed as "crabs nei" (nei = not elsewhere included) or "crustaceans nei", and the true magnitude of China's crab landings remains unknown and speculative. Some apparent increases in crab landings are due to improved reporting whereby a species is now listed individually rather than grouped in some large taxonomic bin.

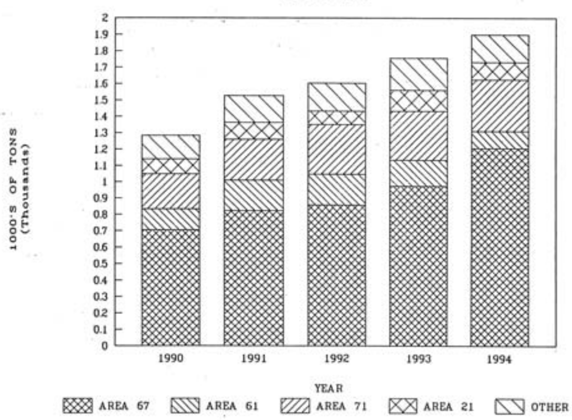


Fig. 2 World crab landings for selected FAO areas from 1990-1994.

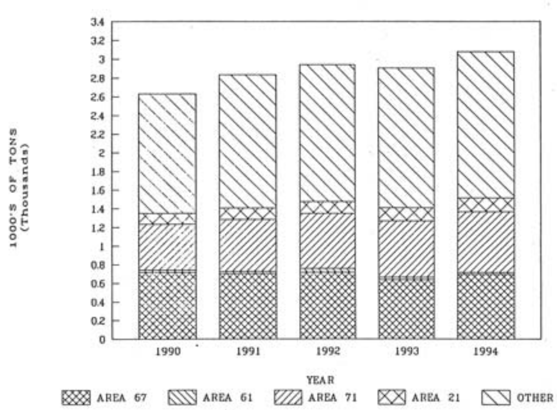


Fig. 3 World shrimp landings for selected FAO areas from 1990-1994

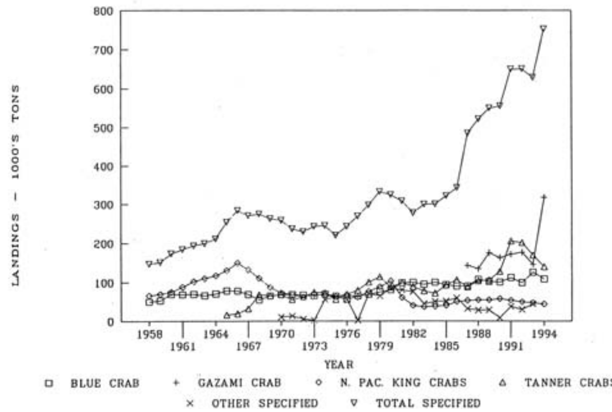


Fig. 4 FAO crab landings for selected species areas from 1958-1994.

Many crab and shrimp landings are included only as unspecified crustaceans (Fig. 4). For example, UN/FAO statistics list only "unspecified crustaceans" for North Korea. By consequence, our knowledge of stocks or stock structure in transboundary areas such as the Yellow Sea (China-North Korea-South Korea) and the Japan/East Sea (Japan-North Korea-South Korea-Russia) is incomplete. Only about 60% by weight of the total marine crustaceans landed in the PICES Region over the years 1984 - 1998 are identified by species or narrowly defined species group (e.g. king crabs). This percentage has ranged from 48% (1984) to 67% (1967) and has been fairly static. In general, shrimp fisheries (92% identified to species or group) were better defined than crab fisheries (79% identified). A large portion of crustacean landings in the PICES Region (35%) was identified only as miscellaneous crustaceans. Incomplete or lacking fishery statistics (even at the level of landings by species or species group over broad areas) frequently hampered WG 12 efforts to define stocks or elucidate patterns of changing abundance. Nevertheless, fishery statistics were found to be the only useful series for evaluating stock abundance in many areas.

A list of exploited and potentially exploited species (Appendix 3) was compiled at the first meeting and has been updated during subsequent meetings. This list served as a basis of discussion because little published literature was available on abundance trends for species of little commercial importance or potential, even though their ecological importance may be well established (e.g., Lang 1992; Livingston 1988, 1989, 1991; Livingston and Goiney 1983; Livingston and deRaynier 1996; Livingston *et al.* 1993; Wakabayashi 1986). As a matter of preference, we agreed to use taxonomic nomenclature published by the American Fisheries Society (Williams *et al*. 1989) first and that used by FAO second. Occasionally we have used other names for species that are not named in either of these two sources. WG 12 also noted that the taxonomic diversity included in the terms "crabs and shrimps" is daunting. For example, The American Fisheries Society (Williams *et al*. 1989) lists 186 species of shrimps in 19 families that occur on the Pacific Coasts of the United States and Canada. Of these, four families are landed in commercial fisheries in aggregate, but specific statistical data are available for only 15 species, of which eight are Pandalidae (see below). Here we also note that the northern shrimp in the Pacific Ocean is frequently referred to as *Pandalus eos*, but also as *Pandalus borealis* in the Atlantic and Pacific Oceans. WG 12 recognizes that there is some controversy here and that on-going DNA studies will likely resolve the matter. Similarly, there are about 51 species of penaeid shrimps and about 40 species of swimming crabs (Portunidae) in the East China Sea, but we discussed only three penaeids and one portunid in our meetings due to the lack of data for most species.

Commercially important stocks, or those with reasonable fishery potential, were grouped by species and geographic area (Appendix 4). These were then classified as to their fishery size (or long-term fishery potential), trends in abundance, type of fishery development and degree of development. Conventionally fished crab and shrimp stocks in North America and Asia ranging from the Japan/East Sea northward are at or near full exploitation, with the possible exception of a few shrimp stocks in the Russian Far East. Crabs and shrimps in the Bohai and Yellow Seas are fully exploited, while those in the East China Sea may still have some potential for fishery expansion. We chose species or stocks for in-depth discussion based on population exploitation, unique management approach, differences in patterns of abundance, known population fluctuations, and quality or quantity of data. A commentary on every species or species population in Appendix 4 could not be presented. Emphasis was given to those populations or stocks that showed contrasts and best illustrated patterns of abundance in various geographic areas.

There were many possible between-area comparisons of population fluctuations that we identified but did not have the resources to pursue. For example, the Yellow Sea to the west of Korea is relatively unique within the PICES Region. This part of the Yellow Sea has a tropical fauna with several well-described, exploited crustacean populations that could be contrasted with those of nearby temperate or boreal species found in the Japan/East Sea just to the east of Korea. The two faunal groups are separated only by a short distance at the tip of the Korean Peninsula and hence potentially provide a unique opportunity to study the comparative effects of large-scale climatic variables. Unfortunately, data available to us for these temperate-boreal species complexes are much less than complete, in part, because data are lacking from North Korea.

North Pacific zoological provinces (Fig. 1) described in Allen and Smith (1988) for finfish were used by WG 12 to structure many of its discussions. This classification applies only to shelf and mesobenthyal (200 - 500 m) slope waters though, and zoogeographic provinces in deeper waters are not necessarily the same. Never the less, we found Allen and Smith's classification useful and recommend it highly. Their zoogeographic provinces follow from those of earlier workers studying various taxa (summarized by Ekman 1953 and Briggs 1974) and are compatible with recent work on American decapod crustaceans (Boschi 2000). All authors recognize an Arctic Zoogeographic Region (AR) that is of recent geologic origin and has served to separate the Eastern Boreal Pacific Region (EBPR, at Cape Olyutorskiy) from the Western Boreal Pacific Region (WBPR, at Nunivak Island). To the south it is convenient to recognize a Western Pacific Southern Region (WPSR), divided at approximately the latitude of the Strait of Korea, and an Eastern Pacific Southern Region (EPSR), divided at approximately Point Conception. There are transitional zones, faunal overlaps and various defined provinces within these regions.

From the simplified perspective of these five regions within the overall PICES Region and considering the 48 species listed in Appendix 3, we note that 33 species, or 69%, are endemic to the PICES Region. For example, endemic species include all king crabs, all the Tanner crabs except snow crab (*Chionoecetes opilio*), all the rock crabs and all the northern shrimps (Pandalidae) except possibly *Pandalus borealis/eos*. In the boreal regions (EPBR, WPBR), 19 species are amphi-Pacific, of which 14 are endemic to the PICES Region, while in the southern regions, no species are amphi-Pacific and only two are endemic. Taken individually, the AR and SEPR have no endemic species, the SWPR has 2 endemic species (17%), WPBR has 4 endemic species (16%) and the EPBR has 8 endemic species (27%). The southern regions owe their affinities to widespread tropical faunas while endemism is concentrated in temperate to boreal areas.

While there is an intractably large body of literature on North Pacific crustaceans, recent symposia, workshop proceedings, and published bibliographies provide a wealth of readily available sources. Those noted in particular are the University of Alaska's Lowell Wakefield Symposium series that has included: pandalid shrimps in 1979 (Frady 1981), "the genus *Chionoecetes*" in 1982 (Anonymous 1982), king crab in 1985 (Anonymous 1985a), Dungeness crab in 1985 (Anonymous 1985b), king and Tanner crabs in 1989 (Anonymous 1990), and, "high latitude crabs" in 1995 (Anonymous 1996). In 2001 and still unpublished, there was a symposium on "crabs in cold water regions" that will become part of this series. Some of these Proceedings are available on line (www.uaf.edu/seagrant/Conferences/symposia.html).

The 1996 symposium also resulted in an extensive bibliography on snow crab (Paul 2000), which follows a tradition of Lowell Wakefield symposia leading to bibliographies, such as those on king and Tanner crabs (Bowerman *et al.* 1983), the genus *Chionoecetes* (Bowerman and Melteff 1984) and world king crabs (Dawson and Yaldwyn 1985, Dawson 1989). Fisheries and Oceans Canada sponsored several meetings of particular interest: an invertebrate assessment and management workshop in 1984 (Jamieson and Bourne 1986), an international workshop on snow crab biology in 1987 (Jamieson and McKone 1988), and a second invertebrate assessment and management symposium in 1995 (Jamieson and Campbell 1998). These proceedings contain much useful information on North Pacific crustaceans, as well as other invertebrate fisheries, and the 1987 workshop is particularly relevant to the issue of terminal molting of male snow and tanner crabs in the genus *Chionoecetes*.

The California Department of Fish and Game published a review of Dungeness crab biology that is very useful, particularly regarding the southern limits of this crab's range (Wild and Tasto 1983). Orensanz *et al*. (1998) provides an extensive bibliography in their review of crustacean fisheries in the Gulf of Alaska (GOA). Abe (1992) provided a summary of literature on the crab resources of Hokkaido. Bergström (2000) and Komai (1999) provided recent and comprehensive literature reviews of the genus ***Pandalus*.** The Symposium "*Pandalid Shrimp Fisheries - Science and Management at the Millennium*", was held in, Dartmouth, Nova Scotia in September, 1999, and was sponsored by NAFO, ICES and PICES, with 96 participants from 15 countries (Koeller *et al*. 2000).

With the advent of computerized internet literature searches, huge amounts of published information are now readily available. We found the Cambridge Scientific Internet database (www.csa.com/csa/about/about-csa.shtml) very useful. Other pertinent sites include: Pacific States Marine Fisheries Commission for landings and status (www.psmfc.org/pacfin/6-1.html), the North Pacific Fishery Management Council (www.fakr.noaa.gov/npfmc/default.htm), Information Center, Chinese Academy of Fishery Sciences (www.lib.noaa.gov/china/chinafp.htm), Fisheries and Oceans Canada (www.dfo-mpo.gc.ca/index.htm).

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

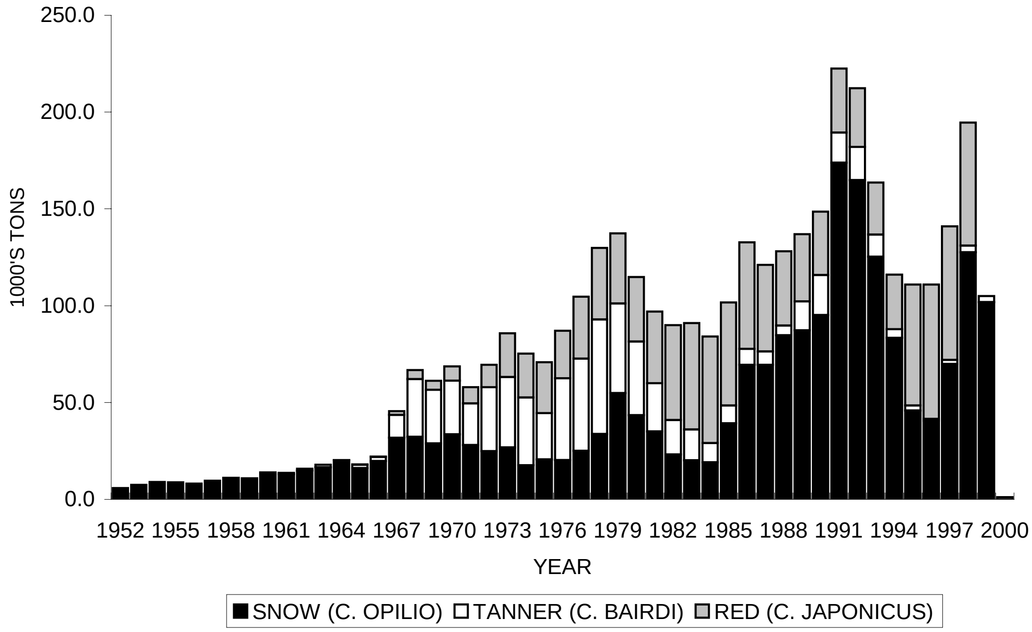


Fig. 5 Composition by species of North Pacific catches (10^3 t), 1952-2000, of snow or tanner crabs. *Chionoecetes opilio* = snow crab which are amphi-Pacific; tanner crab = *C. bairdi* which are North American; and red snow crab or benizuwai gani, = *C. japonicus* which are mostly from the Sea of Japan. 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).

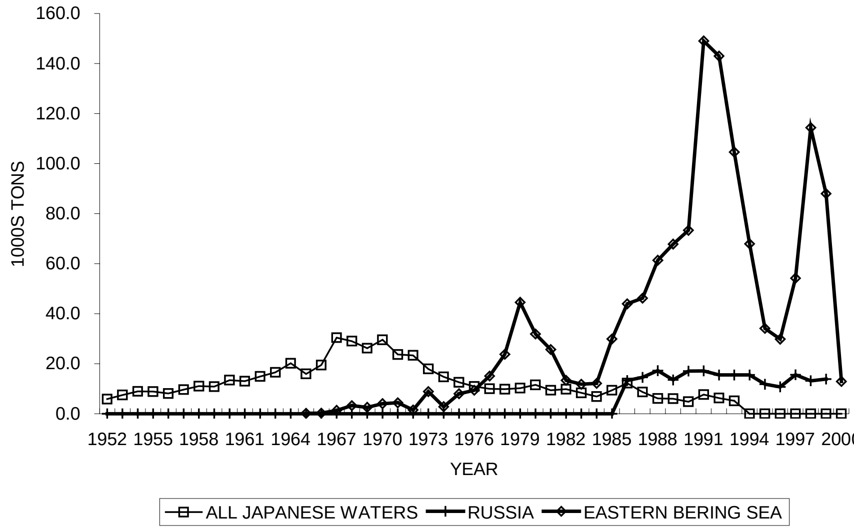


Fig. 6 Landings (10^3 t) of snow crabs by major fishing areas from 1952-2000. Landings are dominated by the eastern Bering Sea stock that was fished by the United States and Japan until 1980, and by the United States thereafter. There were three periods of abundance in the EBS. Stocks are combined for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

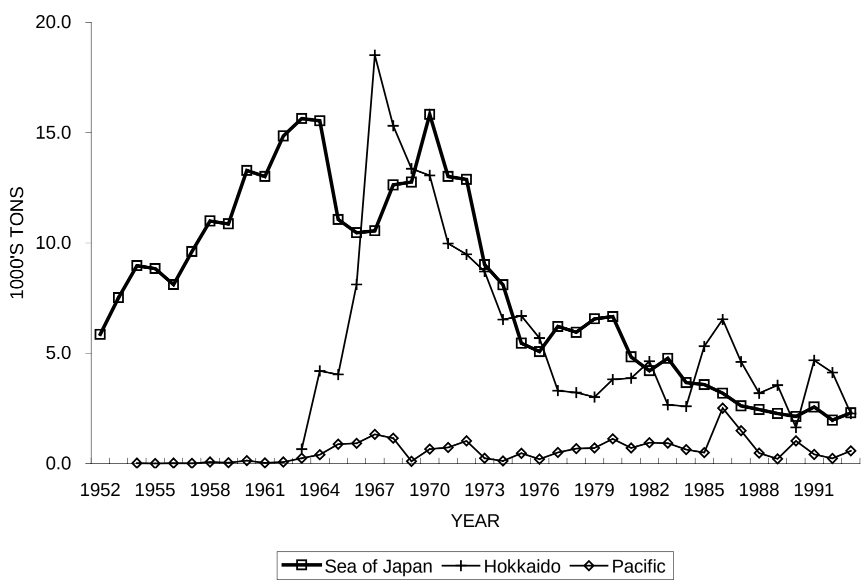


Fig. 7 Historical landings (10^3 t) of the Japanese snow crab (*Chionoecetes opilio*) fishery in Asian waters. Traditional fisheries in the Japan/East Sea were equalled by those from Hokkaido following the latter's rapid development in the early 1960's. Japan's distant water landings are not shown.

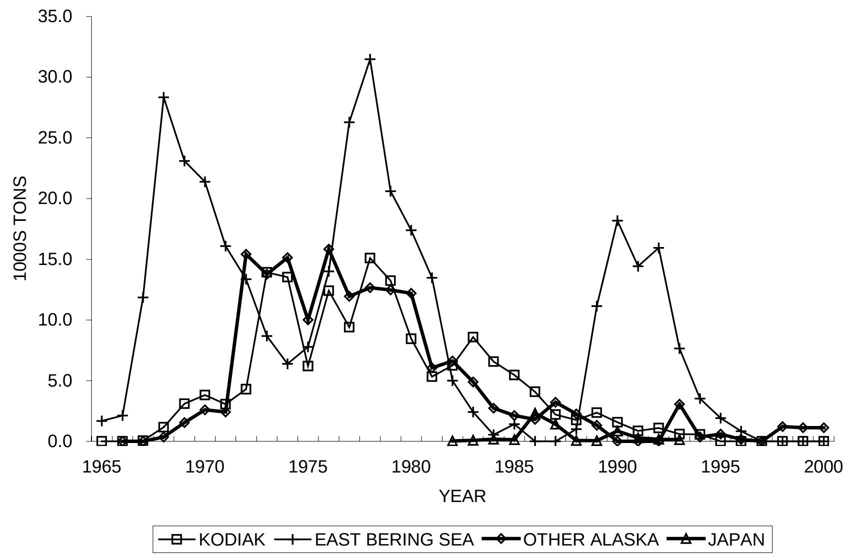


Fig. 8 Historical landings (10^3 t) in selected Tanner crab (*Chionoecetes bairdi*) fisheries, 1965-2000. Their three apparent peaks in abundance of the Eastern Bering Sea stock are different than the pattern observed in the Gulf of Alaska (Other Alaska). The Bering Sea stock peaked first under exploitation 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.

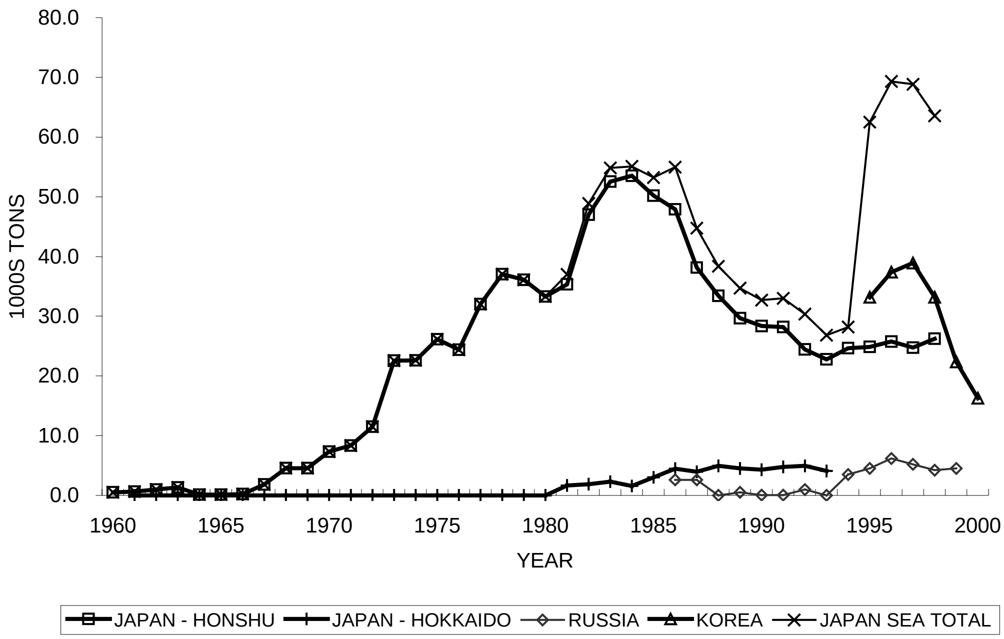


Fig. 9 Historical landings (10^3 t) of the Japan/East Sea fishery for the red snow crab, or benizuwai gani (*Chionoecetes japonicus*), 1960-2000. The traditional fishery off Honshu reached a pear in the early 1980s and declined through the early 1990s. The sharp peak in production is due to the rapid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

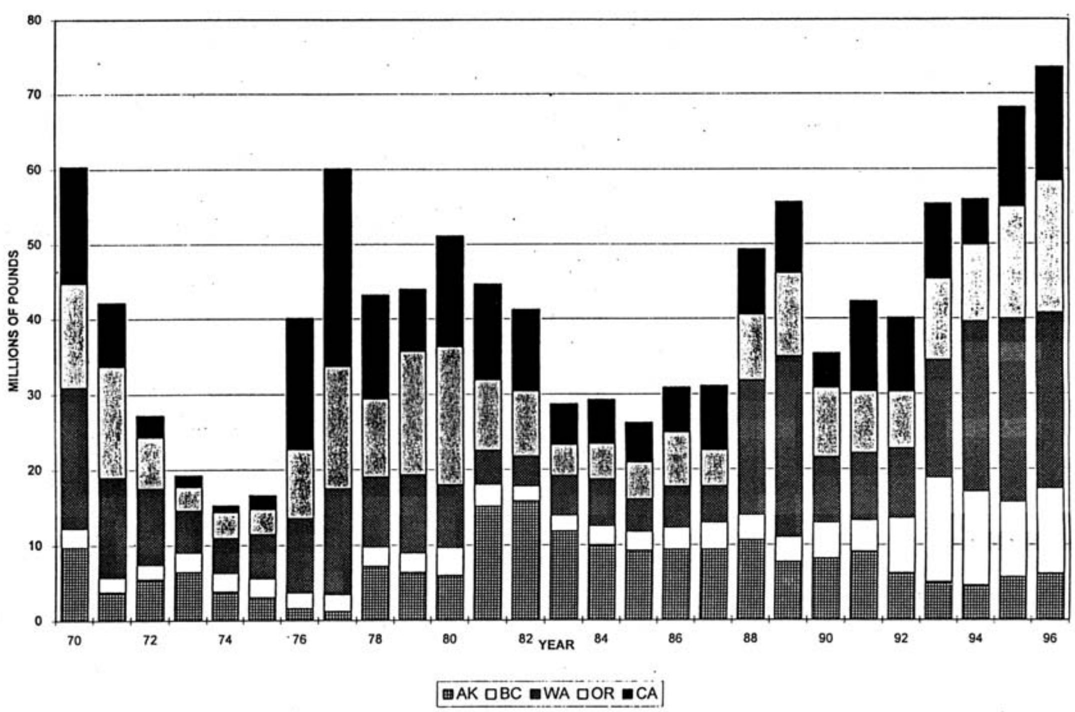


Fig. 10 Landings of Dungeness crab by jurisdiction from California to Alaska, 1970-1996.

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

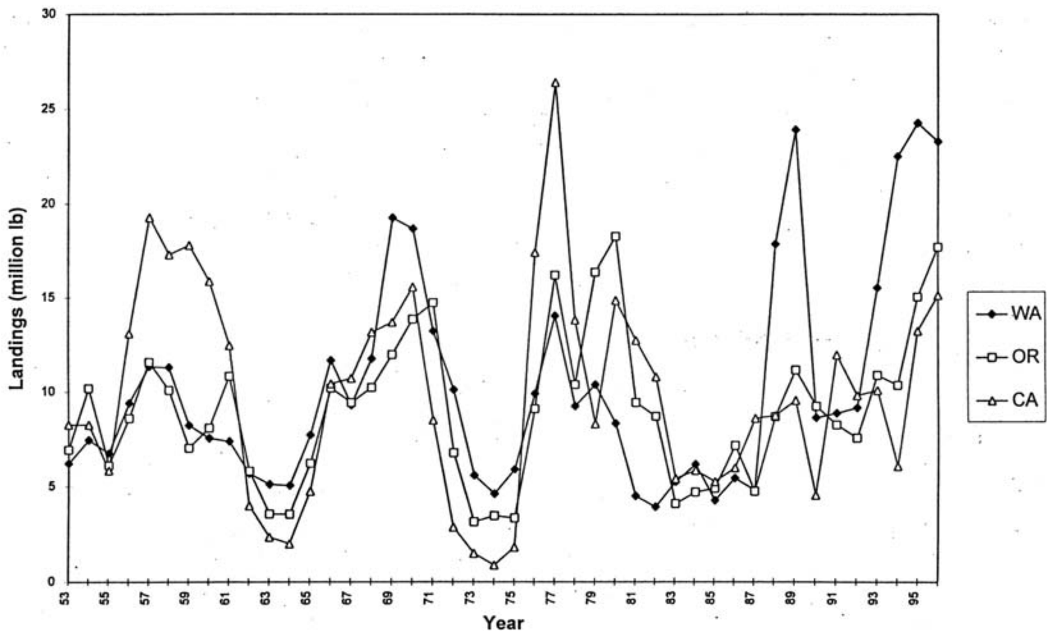


Fig. 11 Landings of Dungeness crab by jurisdiction from California to Washington,1953-1996.

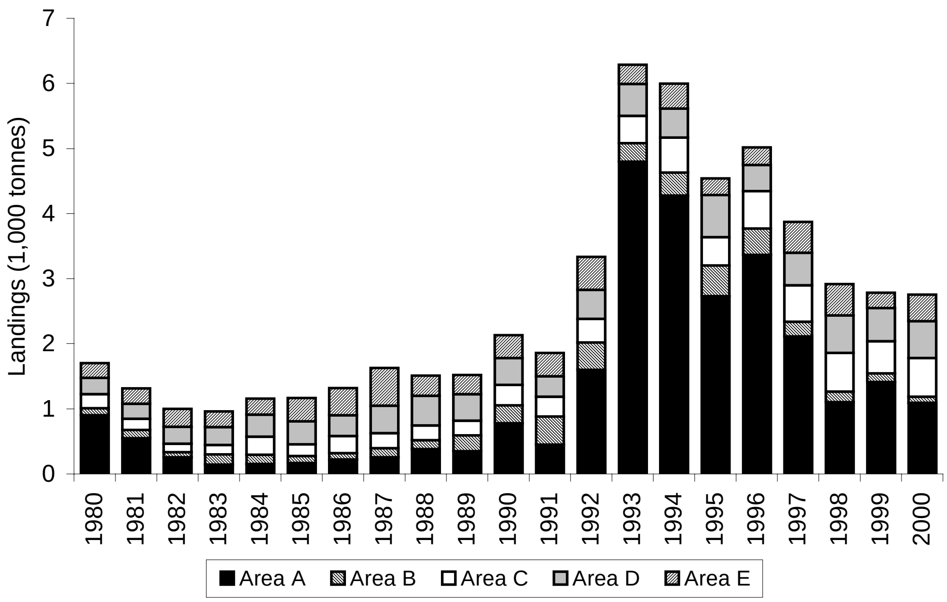


Fig. 12 British Columbian landings (10^3 t) of Dungeness crab by Crab Fishing area, 1980-2000. Area A = Queen Charlotte Islands, Area B = North Coast and central mainland, Area C = Strait of Georgia and Johnstone Strait, Area D = Fraser River area, and Area E = west coast of Vancouver Island.

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).

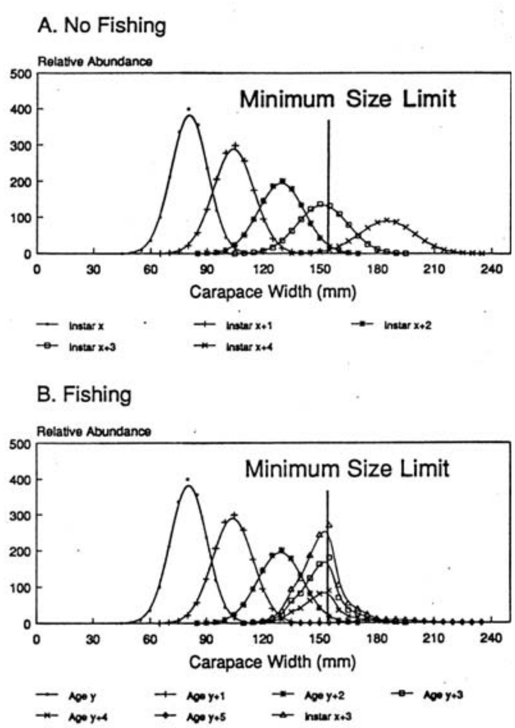


Fig. 13 Estimated Dungeness crab size frequency distributions (mm, notch-to-notch CW) by A. instar and B. age for male Dungeness crab. (Note: instar absolute abundances are arbitrary, and increments in age refer to moults, which may not always be on an annual basis) Ages y+3 and y+4 (the latter assumed 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.

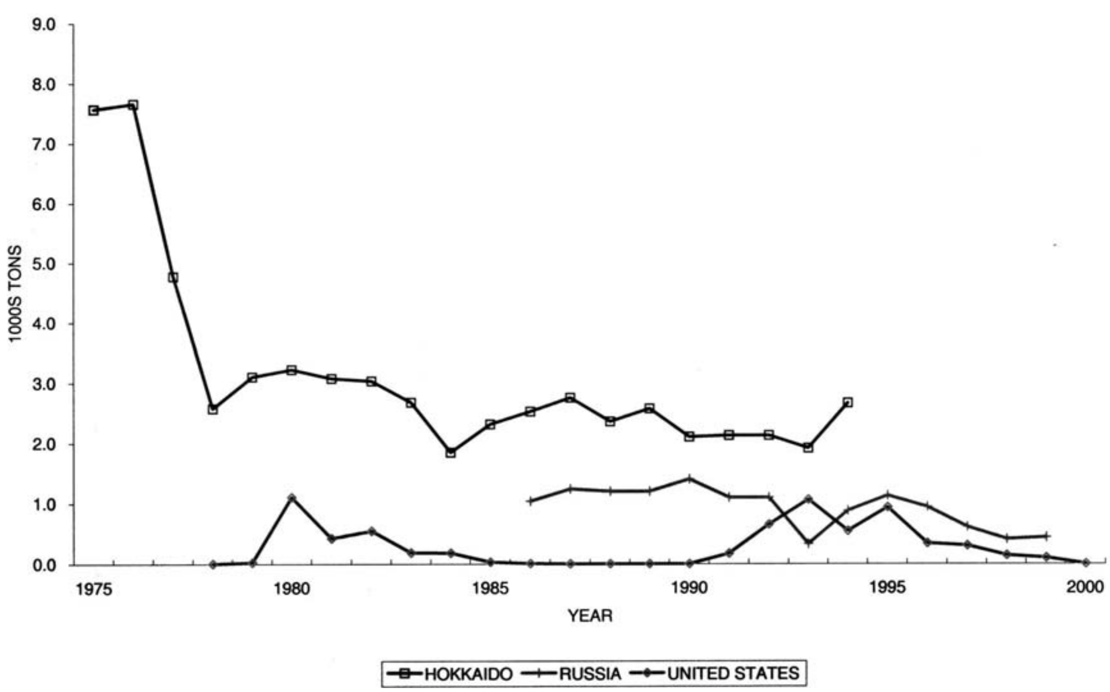


Fig. 14 Reported landings (10^3 t) of Japanese, Russian and American hair crab, 1975-2000.

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.

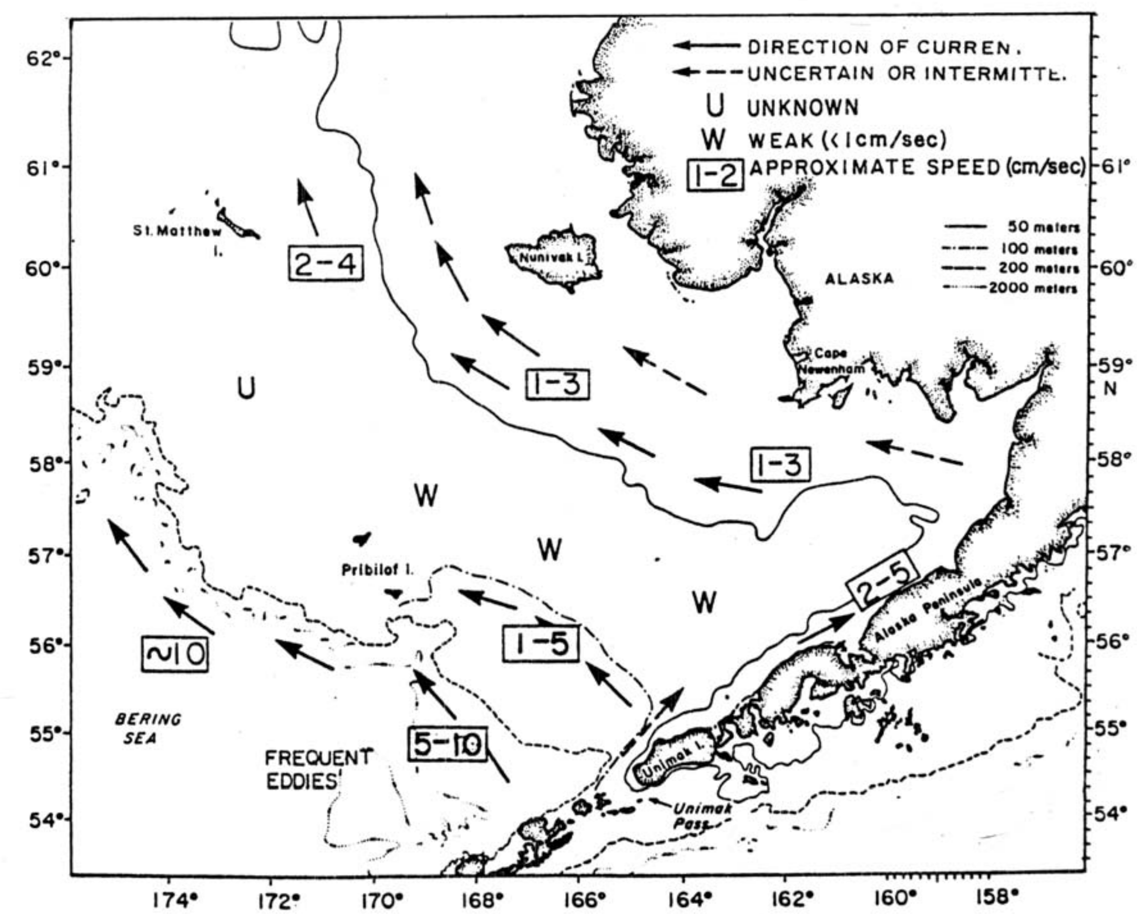
Four species of king crabs thus support major fisheries in the PICES Region. They differ in their life history characteristics and because many species' populations co-occur, comparative study of the effects of life history characteristics on population stability may be possible. For example, red king 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



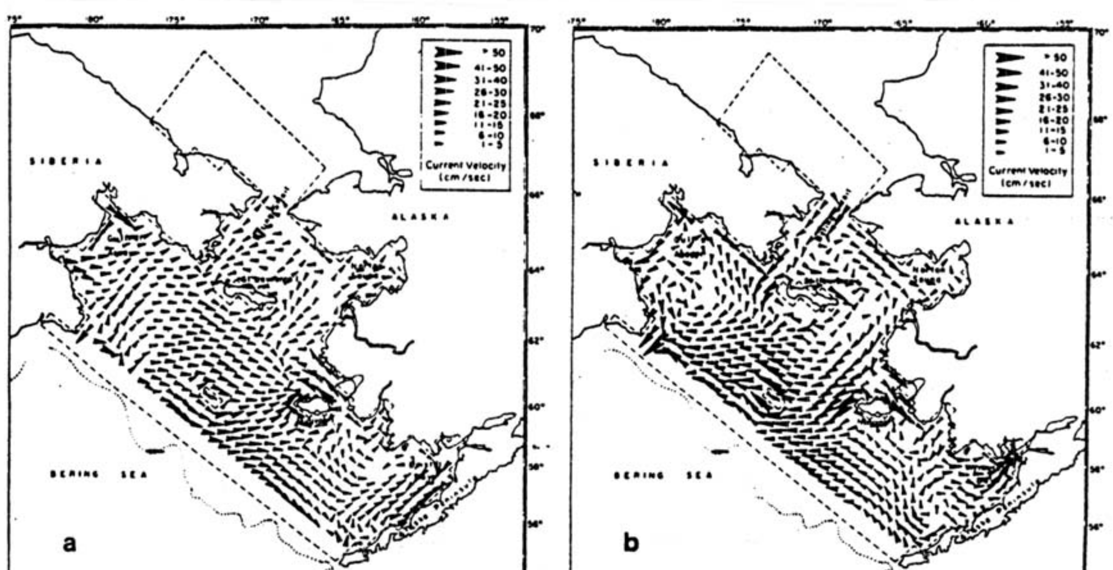


Fig. 15 Tidal currents (cm sec^{-1}) calculated from a numerical tidal model for (a) four hours before high tide, and (b) four hours before low tide at the eastern boundary (from Hastings 1975).

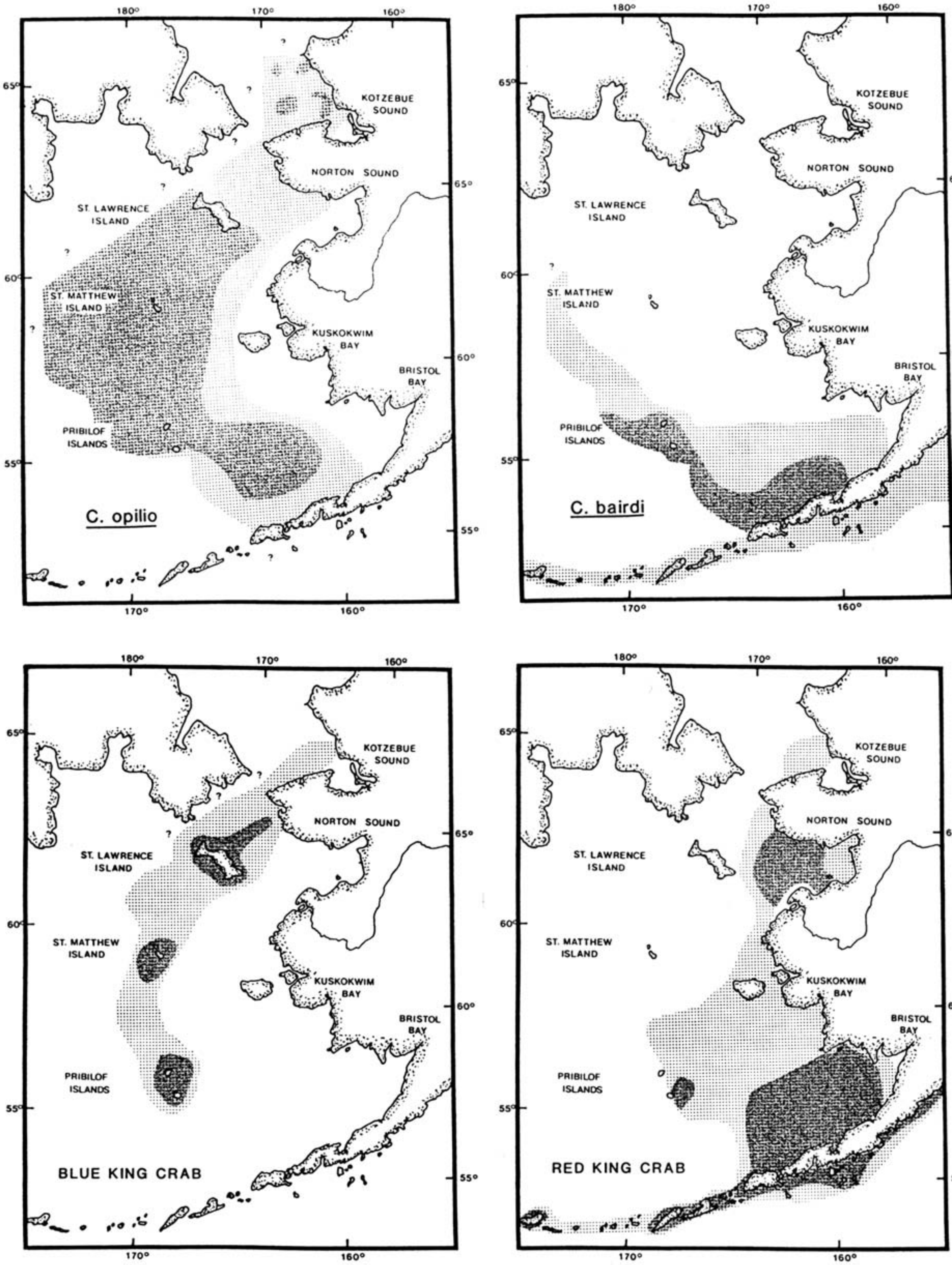


Fig. 16 *Chionoecetes* spp., blue king and red king crab stock distributions in the EBS (Otto 1981).

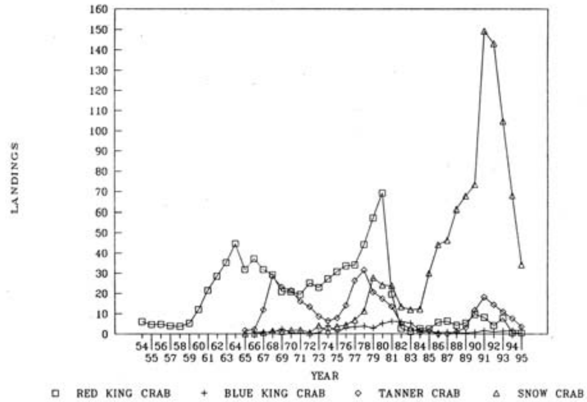


Fig. 17 *Chionoecetes* spp., blue king and red king crab landings from the eastern Bering Sea (from the Alaska Department of Fish and Game and Otto 1981).

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.

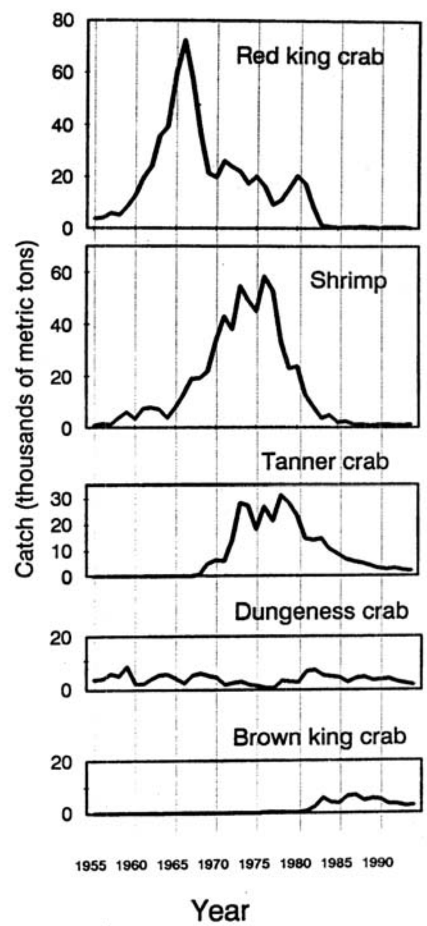


Fig. 18 Crustacean landings by species in the greater Gulf of Alaska (Orensanz *et al.* 1998).

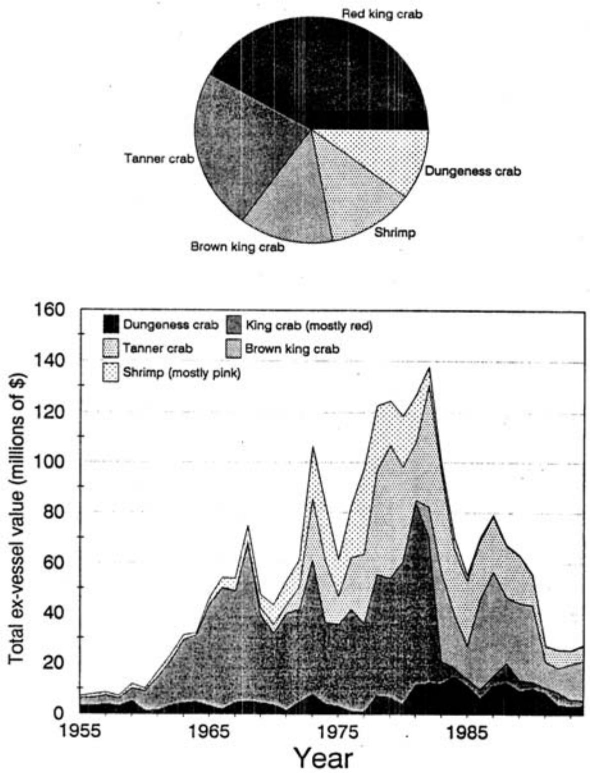


Fig. 19 Top: Relative aggregated values of the historical landings (1955-1994) for major crustacean fisheries in the greater GOA. Bottom: Values (standardized to 1983 US$) of crab landings by species in the greater GOA (Orensanz *et al.* 1998).

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.

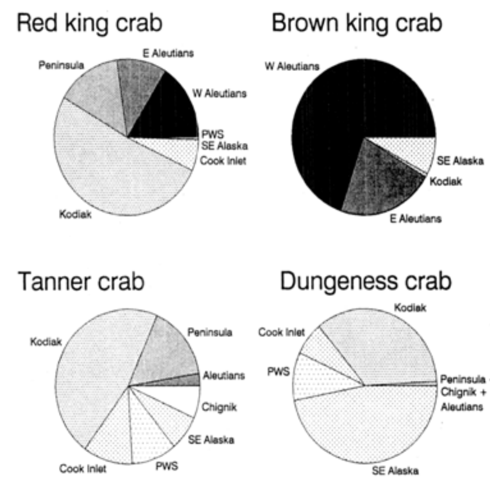


Fig. 20 Alaskan crab landings proportions for the period 1945-1995 (Bering Sea excluded) for the four most commercially valuable crab species in Alaska (Orensanz *et al.* 1998). PWS = Prince William Sound.

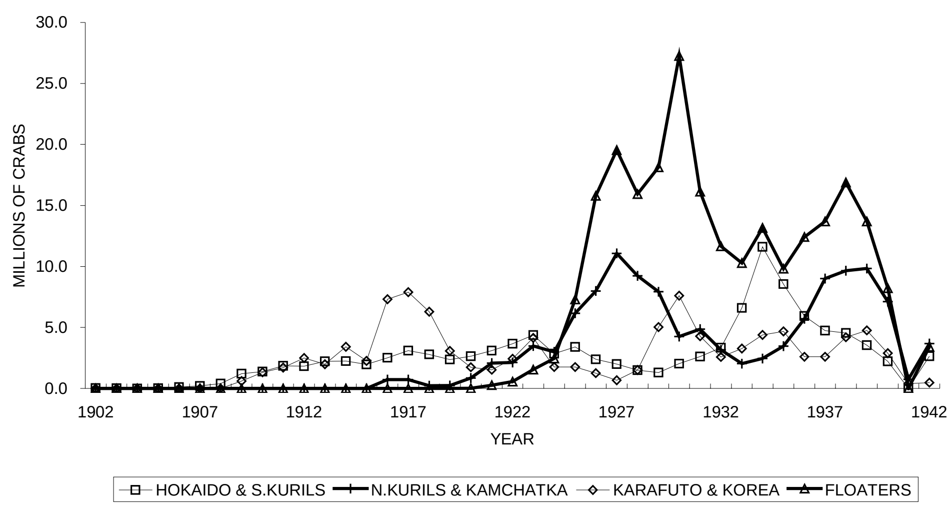


Fig. 21 Development of major pre-1940 Japanese red king crab fisheries based on records from the canned crab industry (from Cahn 1948).

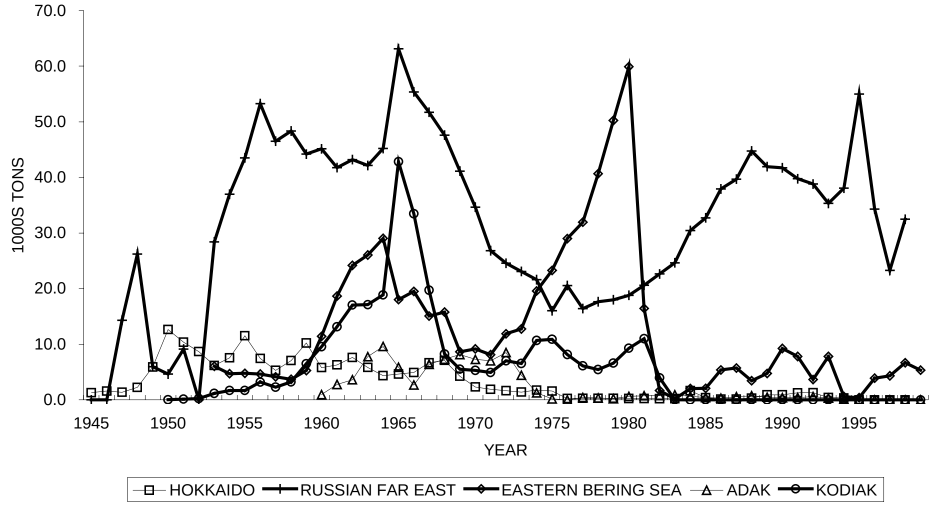


Fig. 22 Historical landings of red king crab in major fisheries since 1945.

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.

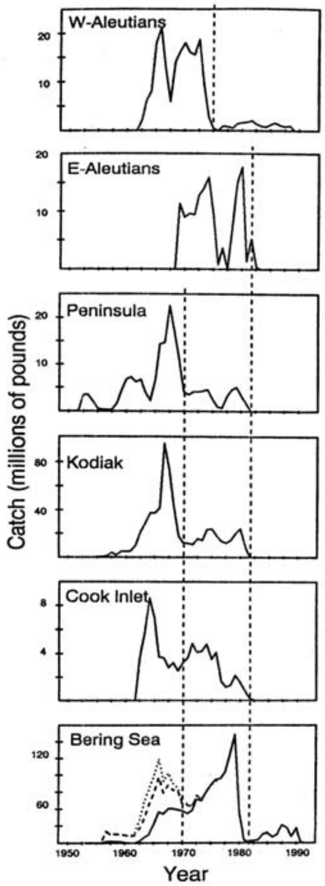


Fig. 23 Red king crab catches (10^6 pounds) during the period 1959-1995 in several management areas, including the Bering Sea (dashed and dotted lines indicate the contribution from the Japanese and Russian fleets, respectively, added on top of the catch by the American fleet, solid line). Vertical dashed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

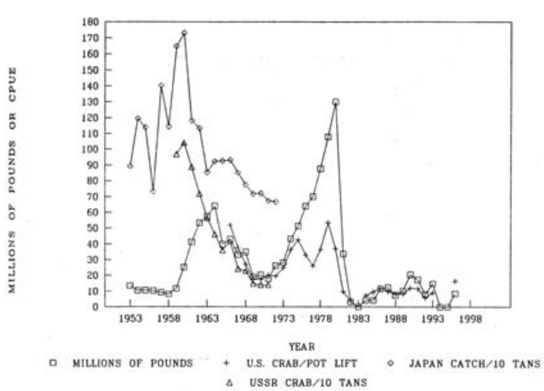


Fig. 24 Commercial landings and CPUE of Bristol Bay red king crab, 1953-1996.

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).

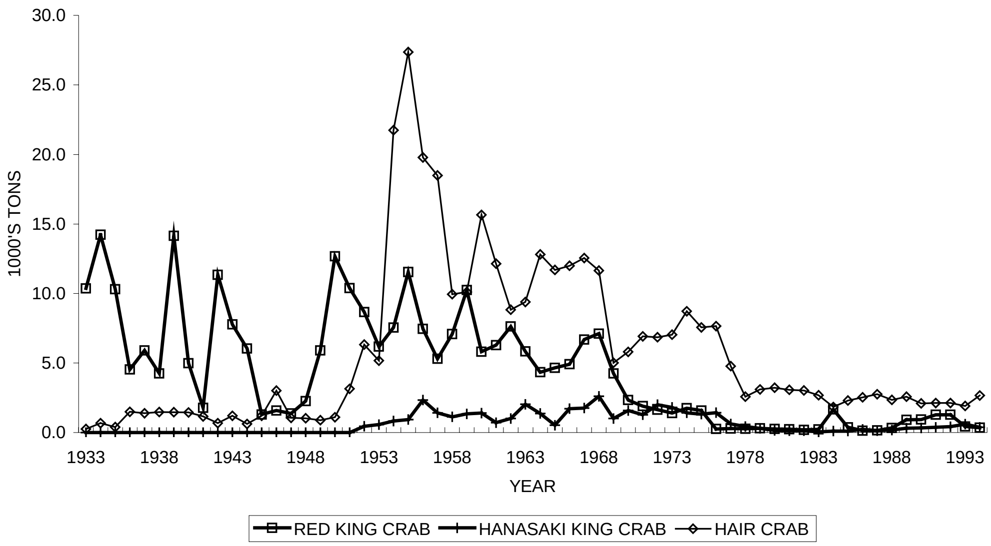


Fig. 25 Hair crab and king crab landings in Hokkaido crab fisheries.

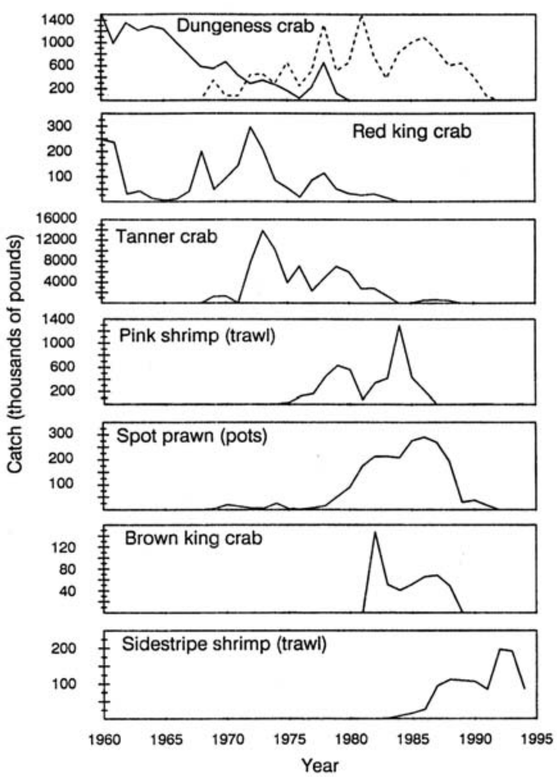


Fig. 26 Time trends in commercial landings of major crustacean resources from the Prince William Sound Management Area. For Dungeness crab, the solid and dashed lines correspond to the Orca Inlet and Copper River fisheries, respectively (from Orensanz *et al*. 1998).

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).

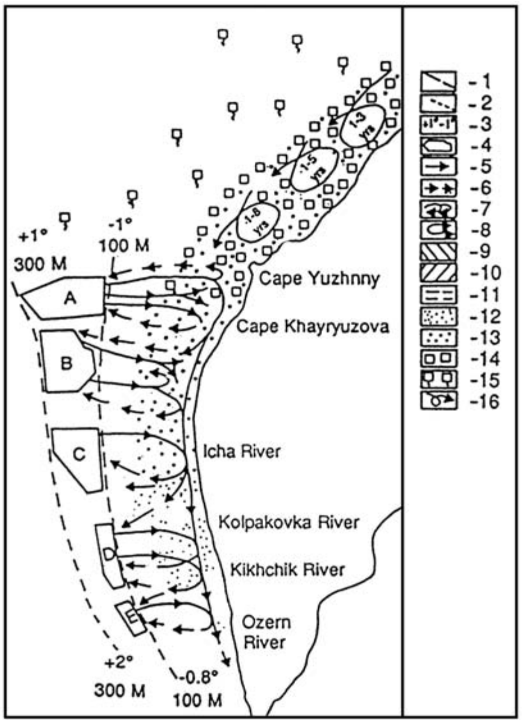


Fig. 27 Diagram of the distributional structure and ontogenetic migrations in the West Kamchatka red king crab population. 1. Isobaths; 2. Currents (not shown here); 3. Bottom water temperature; 4. Overwintering area of subpopulations: A and B – Khayryuzovskiy independent; C – Ichinskiy semi-dependent; 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).

4 Major Species and Stocks of Shrimps in the PICES Region

Three families of shrimps are commercially important in the PICES Region. Sergestidae include the akiami paste shrimp (*Acetes chinensis* and *Acetes japonica*, Plate 2), which support the largest shrimp fishery in the PICES Region, as well as the world. The Penaeidae are well-represented in the waters of China, North and South Korea and southern Japan. Major penaeid (Plate 3) fisheries exploit southern rough shrimp (*Trachysalambria curvirostrus*), kuruma prawn (Marsupenaeus japonicas), fleshy prawn (*Fenneropenaeus chinensis*) and shiba shrimp (*Metapenaeus joyneri*). The Pandalidae include the genera *Pandalus* and *Pandalopsis* (Plate 4), and this family accounts for virtually all shrimp landings from northern Japan around the North Pacific's rim to California. In terms of volume, the northern shrimp (*Pandalus borealis*, or *eos*) and the ocean shrimp (*Pandalus jordani*) have been most important economically, although six additional species have contributed substantially to the catch in various areas. Landings identified as belonging to these three families have made up 93.8% of shrimp landings within the PICES Region over the last 15 years, according to FAO statistics (Table 11). Shrimps of all types are ecologically important and a significant source of food for fishes, some marine birds (Hunt *et al.* 1981) and pinnepeds.

Penaeid and sergestid shrimps differ from pandalids in that they are not hermaphroditic, are semelparous rather than multiparous, and are relatively short lived. Most species complete their life spans in less than two years and frequently within one year, while pandalid shrimps typically live for at least three years and sometimes for seven to eight years. Sergestid and penaeid shrimps also spawn their eggs directly into the water column, in marked contrast to pandalid and crangonid shrimps that incubate their eggs on their pleopods for several months. All shrimps considered here have meroplanktonic larvae that are dispersed by currents, and inshore-offshore movements of larvae and adults appear to be important life-history phases.

Table 11 Summary of marine shrimp landings (10^3 t) from the PICES region as approximated by FAO Areas 61 (NW Pacific) and 67 (NE Pacific) and 77 (E Central Pacific). FAO Fisheries Department. Fishery Information Data and Statistics Unit. FISHSTAT Plus; universal software for statistical time series. Version 2.3 2000.

	Akiami Paste Shrimp	Penaeid Shrimps	Pandalid (Northern) Shrimps	Unknown Others	Total
1984	218.7	49.4	10.5	69.2	347.8
1985	238.3	126.3	16.4	65.2	446.2
1986	211.4	178.2	29.8	59.7	479.1
1987	305.1	150.8	35.9	61.3	553.0
1988	325.1	204.5	37.5	68.9	636.0
1989	392.2	107.4	41.6	62.0	603.1
1990	374.3	146.4	30.1	64.1	614.8
1991	388.6	141.8	26.5	59.7	616.6
1992	418.6	151.3	43.4	64.8	678.1
1993	408.1	146.1	31.9	67.5	653.6
1994	643.5	224.2	24.3	63.7	955.8
1995	680.5	203.4	25.6	50.7	960.2
1996	796.9	225.9	26.1	44.7	1,093.6
1997	778.3	252.5	27.5	44.8	1,103.1
1998	903.5	262.1	17.2	49.8	1,232.6
Total	7081.1	2570.2	424.2	896.2	10,973.8
%	64.5	23.4	3.9	8.2	100.0

Mantis shrimps (Plate 5) are not true shrimps or even decapods, but are included here as a matter of convenience rather than strict biological usage. Mantis shrimp provide for a small, interesting, and well-described fishery in Chinese waters, but are also harvested in Japan and South Korea to a minor degree.

4.1 Akiami paste shrimps (*Acetes* spp., Sergestidae, FAO Area 61)

The akiami paste shrimps (*Acetes chinensis* and *Acetes japonicus*) support fisheries in China, South Korea and Japan, and are among the northern most species of this circumtropical genus. These two species overlap in their geographic ranges and are generally not distinguished in landing statistics. The vast majority of world landings are taken in China, with South Korea, according to the FAO, a distant second (Table 11). World landings of *Acetes* are likely to be grossly underestimated since important fisheries are known to occur in India, Bangladesh, Indonesia, the Philippine Islands, and various other parts of southeast Asia. The genus is ecologically important in many areas of its occurrence and has been recognised as a key biological component of the Bohai Sea.

Most of what follows is taken from Zhaung and Deng (1999) and refers to *Acetes chinensis,* the species that dominates the fishery in the Bohai Sea. Other references include Jo and Omori (1996), Zhang (1992), and Zhang and Guangzu (1992a,b). In China, this is the most important species and it is caught with various fixed, bag-like nets. Chinese landings averaged 223,934 t from 1976 to 1997, with an average of 197,108 t (90.0%) coming from the PICES Region. In the Bohai Sea, the fishery has a 300-year history and currently accounts for about one third of all landings there. The fishery is also extremely important in the East China Sea. Within the Chinese PICES Region, 45.6% of landings are from the Bohai-Yellow Sea area and 54.7% are from the East China Sea (1976-1997). These production figures are astounding, considering that the body lengths of mature paste shrimp are 17-32 mm for males and 18-43 mm for females, and a 43 mm female is approximately 0.5 g:

$$W_{male} = 0.0065L^{2.9888}$$

$$W_{female} = 0.0005L^{3.0787}$$

South Korean landings from the Yellow Sea increased from 10,000 t in 1984 to 29,000 t in 1992, and have decreased to 16,000 t in recent years. This shrimp is usually caught in the spring and autumn by fixed long bag-like nets.

Table 12 N. W. Pacific landings of akiami paste shrimp (10^3 t, FAO)

Year	China	South Korea	Total
1984	188.445	9.791	198.236
1985	209.120	13.488	226.608
1986	175.207	15.029	190.236
1987	162.366	16.164	178.530
1988	190.589	11.767	202.356
1989	217.278	21.493	238.771
1990	211.365	24.568	235.933
1991	217.081	18.138	235.219
1992	228.726	29.348	258.074
1993	262.457	24.324	286.781
1994	326.314	18.510	344.824
1995	390.000	16.495	406.495
1996	442.460	18.495	460.955
1997	480.056	18.411	498.467
1998	571.383	15.624	587.007
Total	4272.847	271.645	4544.492
% Species	94.0	6.0	100.0

Table 13 Reported landings of penaeid shrimps, from the PICES region (10^3 t, FAO).

Year	Cocktail Shrimp	Fleshy Prawn	Kuruma Prawn	Shiba Shrimp	Total
1984	26.202	16.308	4.592	2.293	49.395
1985	84.649	33.191	5.713	2.729	126.282
1986	139.156	30.908	4.221	3.911	178.196
1987	108.032	34.469	5.227	3.032	150.76
1988	139.101	55.557	7.723	2.086	204.467
1989	73.737	26.430	4.825	2.400	107.392
1990	97.547	39.480	5.554	3.834	146.415
1991	91.372	37.117	5.427	7.852	141.768
1992	100.664	38.980	4.809	6.882	151.335
1993	120.000	17.479	4.794	3.834	146.107
1994	167.165	47.133	4.950	4.993	224.241
1995	151.746	44.449	5.067	2.168	203.43
1996	163.060	56.534	4.045	2.211	225.85
1997	174.967	71.317	4.246	1.976	252.506
1998	175.618	79.595	3.207	3.651	262.071
Total	1813.016	628.947	74.400	53.852	2570.215
%	70.5	24.5	2.9	2.1	100.0

Spawning occurs twice per year, with spring/summer (SS) and summer/autumn (SA) generations, and most of both brood stocks die after reproduction. During the spring, gonads mature after wintering and spawning begins in June. The SS stock grows quickly in the summer and reproduces to form the SA generation. Akiami paste shrimp the longest life span is only one year. The sex ratio is about 1:1. Body length (BL) of mature male and female individuals range from 17-32 mm and 18-43 mm respectively, and size frequency structures of two generations are different. Female body lengths of the SS stock ranges from 25-40 mm and is dominated by 31-32 mm shrimp. Female body lengths of the SA stock range from 12-30 mm and is dominated by 20-30 mm shrimp.

Mating activity takes place about 15 days prior to spawning, which takes place in batches and always at night. The relationship between fecundity in egg numbers (*F*) and body length (L) in mm (absolute fecundity) is

$$F = 0.0309\ L^{3.62}$$

Typical SS females produce 7700 to 8700 eggs while a 30 mm SA female would produce 6800 eggs (40.7 eggs mg^{-1} wet weight). Akiami paste shrimp are weak swimmers and do not conduct long distance migrations, but there is a seasonal movement between shallow (summer) and deep waters (winter).

Akiami paste shrimp filter feed on phytoplankton (diatoms) and detritus but also actively prey on zooplankton (copepods, Sergestidae and bivalve larvae). The diet composition changes with habitat and seasons. With a short life span, the abundance of *Acetes* shrimp may be easily affected by natural conditions and human activities. As a result, its annual abundance and landings fluctuate extensively (Table 11).

4.2 Penaeid shrimps (Penaeidae, FAO Area 61)

About 15 species of Penaeidae are commercially important in the PICES Region. Four species of penaeid shrimps are important in the Yellow Sea and all of them extend their ranges through the East China Sea and into waters off southern Japan. Of these, the fleshy prawn (*Fenneropenaeus chinensis*), the kuruma prawn (*Marsupenaeus japonicus*), the shiba shrimp (*Metapeneaus joyneri*) and the southern rough shrimp (*Trachysalambria curvirostris*) dominate landings (Tables 11 and 13). Other species are presumably included with unspecified natantia in FAO statistics.

Economically, the fleshy prawn (*Fenneropenaeus chinensis*), also known as *Penaeus chinensis***,** (Osbeck 1765) has been the most important commercial species in the Yellow and Bohai Seas. It has also been extremely important in China and South Korea. Aquacultural landings in China including averaged 167,527 t in China and 1456 t in South Korea from 1986 to 1995 (Zhuang and Deng, 1999; and Yeon 1999). Landings from wild stocks in China and South Korea averaged 36,045 t and 1,163 t, respectively, over the same period. In the Yellow and Bohai seas, fleshy prawns have historically been exploited by South Korea, Japan, and China. Japan, however, stopped fishing in 1987. Landings from 1986-1995 were 14.7% South Korean, 5.1% Japanese and 80.2% Chinese, and averaged 7,916 t. Landings in China as a whole, as well as the Yellow-Bohai and China Seas, have declined in recent years. However, South Korean landings from wild stocks were comparatively high in the middle 1970s at 6,000 t, before decreasing dramatically to less than 1,000 t in the middle 1980s. It has shown some sign of recovery, perhaps due to the release of cultured juveniles every spring since 1986. The South Korean fishing season is April-May for the old generation and September-December for the young generation.

There are two populations in the Yellow-Bohai Sea area. One is found in the western coastal waters of South Korea while the other is found in Yellow and Bohai seas. Although the two populations have separate migratory patterns, there is some overlap in the Yellow Sea wintering grounds. Fleshy prawns tend to follow the 6°C isotherm as they begin their shoreward migration in March. The South Korean coastal stock spawns from April to June. The minimum size of the sexually mature shrimp is 38 mm CL in both male and female. After spawning, adults die. The shrimp has one reproductive cohort per year, and the life span is 13-14 months. During summer (water temperature, 23-27°C), the juveniles grow very fast, up to 14 mm CL by August and up to 45 mm by November (Cha *et al.* 2001). Thereafter, they grow very slowly. Growth equations (Yeon 1999), using the von Bertalanffy growth pattern, are:

$$\text{Female: } CL_t = 48.8(1 - e^{-3.339(t+0.058)})$$

$$\text{Male: } CL_t = 36.7(1 - e^{-3.803(t+0.226)})$$

The female grows much faster than the male. The summer season is a feeding period that culminates with mating in October-November. There is a massive mortality of males immediately after mating that leads to a large change in the sex ratio. With seasonal cooling, from November onward they start migrating to the deeper part of the Yellow Sea, where they spend the winter season.

The species has been well studied because of its importance to both aquaculture and fishing. Fishing, growth and mortality rates are well described, as are diseases. Cohort analysis, yield per recruit modelling and stock-recruitment relationships are being used in stock assessment. Because hatchery techniques are available, enhancement through the release of post-larval juveniles is being used to augment natural reproduction, and this approach has shown some promise. Currently, trawling is forbidden in the Bohai Sea and the fishery there is conducted only with fixed nets and drift nets. Trawling is the usual means of fishing elsewhere by all nations involved.

The shiba shrimp (*Metapenaeus joyneri*), is distributed in the shallow (< 20 m) waters of the Bohai, Yellow and East China Seas. Landings are reported to be about 5,000 t annually, but these statistics are not considered accurate. Shiba shrimp tend to be localized in distribution and show little evidence of migration. Chinese catches are dominated by shrimp of 100-110 mm length and weights of 11-13 g. Spawning occurs both in March-May and again in September-December. Landings for China were not presented, but FAO data show South Korean landings varying from 2,086 to 7,852 t from 1986 to 1995.

Off western South Korea, the shiba shrimp starts migrating from the deeper part of the Yellow Sea, where they spent the winter, to the western coast of Korea in the spring when surface water temperatures are 12-15°C (Cha *et al.* 1999). At this time, the gonads of both male and female are fully matured. Minimum size of the sexually mature shrimp is 22 mm CL in both male and female. Insemination occurs just before spawning. From June to August more than half the females of 20-21 mm CL are inseminated. The spawning period is from the end of June to August. Adults die after spawning. This shrimp has one reproductive cohort per year. A female spawns from 73,000 to 206,000 eggs (Cha *et al.* 1999). Fecundity is positively proportional to the size of the female. The life span is 14-15 months. During the summer (water temperature, 23-27°C), juveniles grow fast, being up to 12 mm CL by August. With autumn, waters cool, and in November, they start migrating to the deeper part of the Yellow Sea where they spend the winter. South Korean catches are composed of shrimp of mainly 12-26 mm CL. Fishing occurs from May to June for the old generation and from September to December for the young generation.

The southern rough shrimp, or cocktail shrimp (*Trachysalambria curvirostris*), also known as *Trachypenaeus curvirostris*, (Stimpson 1860) is extremely widely distributed, from Africa to Australia, as well as in southern and eastern Asia, including off China, Japan and Korea. Despite a wide distribution, directed fishing largely occurs in the PICES Region only in China and South Korea. In the PICES Region, the southern rough shrimp is particularly abundant in the Bohai and Yellow Seas. Coastal waters of Shandong Province and Korean western waters are major fishing grounds. It is also found in the East China Sea. Most fishing occurs during the reproductive and wintering seasons (in China) or during the inshore and offshore migrations (in South Korea), when dense schooling occurs. Habitat is generally 20 to 40 m in the Bohai and Yellow Seas. Spawning begins in May and peaks in June and July. The minimum size of the mature female is estimated at 14 mm CL. Fecundity is directly proportional to the size of the female, with the clutch size varying from 16,000 to 115,000 eggs (Cha 1997). As is true of other penaeids, the diet includes small mollusks, planktonic polychaetes, and crustaceans.

Chinese landings from the Yellow and Bohai Seas have increased drastically over the past 20 years, averaging 48,018 t for 1988-1997 as compared to 15,557 t during the previous decade. While there is potential for further development in the South and East China Seas, the Yellow and Bohai Seas are considered over-exploited. South Korean landings were 11,000 t in 1994. Thereafter, they decreased sharply to 3,000 t. Catches are dominated by shrimp of 12-24 mm CL. Individual size varies greatly from summer through autumn and the next spring. Growth shows a seasonal pattern, as

Female: $CL_t = 21.80(1 - e^{-\{3.175(t-0.047)+(5.700/2\pi)\sin 2\pi(t-0.057)\}})$
Male: $CL_t = 17.00(1 - e^{-\{2.237(t+0.199)+(3.864/2\pi)\sin 2\pi(t-0.069)\}})$

The female grows faster and larger than the male (Yeon 1999). Management measures being considered include catch quotas on the wintering population, time area closures to protect spawning concentrations, and effort limitations for both motorized trawling and fixed nets.

The karuma prawn (*Marsupenaeus japonicus*), also known as *Penaeus japonicus,* (Bate 1888) is also extremely wide-spread with a distribution that extends from western Africa to Japan and as far south as Australia. It is one of the world's most popular aquacultural species and aquacultural landings probably far exceed wild stock production. The kuruma prawn was the first penaeid species in the world to be successfully propagated under controlled conditions. It is the most widely cultured among temperate penaeid species, being expensive, tasty and colorful (Chiu and Chien 1994). Rothlisberg (1998) reviewed the recent literature on aspects of the biology and ecology of penaeid prawns that are relevant to the aquaculture research community and the aquaculture industry; giving much information on the karuma prawn. Aquaculture may also have accidentally introduced the karuma prawn to new areas, such as the eastern Mediterranean, although it may have occurred naturally via the Red Sea.

In South Korea and parts of Japan, these shrimp are taken with gill nets, which has lead to various selectivity experiments (e.g., Lee *et al.* 1986, Fujimori 1996). Gear selectivity of trammel nets with different mesh sizes on kuruma prawn were conducted in Ohmi Bay, Japan, and under controlled conditions in a tank at the Yamaguchi Prefecture Naikai Fisheries Experimental Station (Fujimori *et al.* 1996). These experiments resulted in an optimum mesh size recommendation of 42.8 mm for kuruma prawn of 110-140 mm body length.

The reproductive biology of female kuruma prawn was investigated in the Ariake Sea and Tachibana Bay, Japan, by Mingawa *et al*. (2000) to elucidate interannual, seasonal, individual female body size and spatial influences on the incidence of spawning. Minimum size at maturity was 130-140 mm BL. The proportion inseminated increased with body size up to 170 mm BL and then decreased. Spawning occurred in the central part of the Ariake Sea and Tachibana Bay from mid-May to mid-October, but occurred in the western central part, from mid-June to mid-September. Breeding in Korea occurs in May and June. Females carry *ca.* 700,000 eggs.

A quantitative study of brain lipofuscin content from known-age, pond-reared karuma prawns (Vila *et al*. 2000) showed that the concentration of lipofuscin increased significantly with age and was independent of sex. The relationship between age and lipofuscin concentration was described by a seasonalised von Bertalanffy function, since accumulation of the pigment slowed in fall and winter. Results indicate that the lipofuscin method is useful to estimate physiological age in penaeids and it could be useful in studies of age structure in wild populations.

A marking method for the kuruma prawn was developed by Miyajima *et al.* 1999. The method involves cutting the uropod which results in much reduced pigmentation in the regenerated part. The degree of pigment reduction increased with body length of prawn used, and a 50% reduction in comparison with uncut uropods occurred for 60 mm in BL. Laboratory studies showed little mortality. Field testing at sea proved successful application of a long-lasting mark to large samples, and presumably the method could be used to verify lipofuskin data of for population estimation.

The main fishing grounds off South Korea are located near Kojedo. Fishing grounds in Japan are wide spread and various in their characteristics. Landings of wild stock in the PICES Region have varied from 3,200-7,700 t in the past 15 years of record (Table 12).

Four of the important penaeid species (*Marsupenaeus japonicus, Fenneropenaeus chinensis, Metapenaeus joyneri*, and *Trachysalambria curvirostris*) were contrasted in our discussions and were found to differ considerably in their life history patterns within the Yellow Sea, which offers opportunities for comparative studies of environmental effects on recruitment. A joint South Korean-Chinese study of shrimp stock recruitment relationships in the Yellow Sea is being planned. This study would likely be profitable and has the advantages of occurring in a well-defined, semi-enclosed body of water, and utilising a relatively short-lived species, allowing the results of experiments to be more readily available. The kuruma prawn also occurs over large areas and offers similar opportunities.

4.3 Pandalid shrimps (Pandalidae, FAO Area 61, 67)

Pandalid shrimps are protandric hermaphrodites, and larger, older, mostly mature females individuals support fisheries. They are multiparous and may breed three to five times. There are about nine species of commercially exploited pandalid shrimps in the PICES region. All pandalids are taken in trawl fisheries either as target species or incidental catch. The main targets of trawl fisheries are ocean pink shrimp (*Pandalus jordani*), northern pink shrimp (*Pandalus borealis/ eos,* Plate 4), humpy shrimp (*Pandalus goniurus*, Plate 4) and sidestriped shrimp (*Pandalopsis dispar*, Plate 4). Note that here we depart from the American Fisheries Society's (Williams *et al.* 1989) nomenclature by using the subspecies *eos* respecting the northern shrimp. Recent authors (see Komai 1999) have referred to the Pacific form of this species as *P. eos* while retaining *P. borealis* for the Atlantic form. We are aware that collections are being made for DNA analysis of many collections at this time and have chosen to incorporate both names. Schumway *et al*. (1985) reviewed the biology of northern pink shrimps. The dock shrimp (*Pandalus dana,* Plate 4) and morotoge shrimp (*Pandalopsis japonica*) are often caught in trawls but seldom abundant enough to be a target species. The main targets of pot (trap) fisheries are the spot prawn (*Pandalus platyceros,* Plate 4) and, less commonly, the coonstriped shrimp (*Pandalus hypsinotus,* Plate 4), although other species are commonly taken.

Spot prawns (*Pandalus platyceros*) are distributed from California to Alaska as far west as Unalaska Island (NMFS, unpublished) and to the Japan/East Sea. Hokkai shrimp (*Pandalus latirostris*) and morotoge shrimp are confined to Asia, while sidestriped shrimp are known from the western Bering Sea (near Cape Navarin) and North America. The remaining species are found variously on both continents. Landings occur over a broader geographic range within the PICES Region but reported landings are somewhat less than those for penaeids (Tables 10 and 13). In South Korea, catches of this family of shrimp are small and are not recorded officially, so landing data is not available.

The hokkai shrimp is a shallow water species unique to the Japan/East Sea, Hokkaido, southern Sakhalin Island and the southern Kurile Islands, where it is most commonly found in association with eel grass beds. It is taken in small trawls, push nets and hand nets of various sorts. Hokkai shrimp are green, with a striped body that doubtless helps them to conceal themselves in eelgrass beds. Hokkai shrimp are a common species in Japanese shrimp fisheries but specific information on them is fragmentary.

Pandalid shrimp populations and fisheries in Alaska collapsed in the late 1970's (Table 14, Fig. 28) and most fisheries remain closed today. Very small trawl fisheries for sidestriped shrimp and modest pot fisheries for spot prawns still persist in some areas in Alaska. The collapse of the pandalid shrimp complex in Alaska was concurrent with the late 1970s oceanographic regime shift and a sharp increase in predator populations, particularly those of Pacific cod

(*Gadus macrocephalus*, Albers and Anderson 1985). Anderson *et al*. (1997) and Anderson and Piatt (1999) showed that the regime shift in the GOA was accompanied by a sharp reduction in the abundances of a number of forage species (especially capelin, *Mallotus villosus*) and crustaceans. Humpy shrimp, which were once common in western Alaska, have been virtually absent from recent surveys.

Landings of ocean pink shrimp also declined sharply in the late 1970s, and reached their lowest levels in 1983. In contrast with northern pink shrimp populations in Alaska, they later increased in abundance. Landings of ocean pink shrimp have undergone two cycles between 1970 and 1995 (see California, Oregon & Washington landings in Table 15). The recovery of ocean pink shrimp there contrasts sharply with that of Alaskan populations, and this comparison of shrimp population dynamics would make a good retrospective study. One problem is that species were frequently combined in landing statistics, particularly in trawl fisheries where landings were simply referred to as "pink shrimp". In some cases, biological sampling may be sufficient to provide reasonable estimates of species composition. There is a great amount of this sort of reconstruction that would need to be done in most western Alaska shrimp landing analyses.

Pot fisheries for spot prawn occur mostly from Prince William Sound to Northern California. There appears to have been serial depletion of localized populations as the fishery developed in southeastern Alaska (Orensanz *et al.* 1998, Fig. 16). The spot prawn is important economically in British Columbia (Boutillier *et al.* 1998), where it is intensively fished. Fisheries become more sporadic in the southern part of this species' range.

Pandalid shrimps that occur in the Western Bering Sea, the Sea of Okhotsk and in the Sea of Japan provide additional comparative study possibilities. It is frequently unclear whether recruitment to populations or mechanisms that concentrate adults are most important in forming high densities of pandalid shrimp in open ocean environments. Both environmental effects and oceanographic forcing appear important in recruitment of pandalid shrimp stocks in the offshore open ocean regions of the eastern Pacific. Shrimp stocks in the inshore, protected regions of the Eastern Pacific Ocean seem to be much more stable and have not undergone the same fluctuations as have the offshore open water stocks.

Table 14 Reported landings of northern shrimps, Pandalidae, from the PICES Region (10^3 t, FAO).

Year	E. Cen. Pacific USA	N.E. Pacific USA	USA (1) Total	N.E. Pacific Canada	N.W. Pacific Russia	Total
1984	0.614	9.006	9.620	0.914	0	10.534
1985	0.731	14.491	15.222	1.192	0	16.414
1986	0.673	27.761	28.434	1.318	0	29.752
1987	0.827	31.794	32.621	3.264	0	35.885
1988	0.519	33.186	33.705	3.281	0.508	37.494
1989	0.548	36.417	36.965	3.119	1.478	41.562
1990	0.474	25.562	26.036	2.701	1.326	30.063
1991	0.313	20.348	20.661	4.226	1.609	26.494
1992	0.184	37.289	37.473	3.851	2.028	43.352
1993	0.880	24.058	24.938	4.498	2.462	31.898
1994	1.287	16.539	17.826	4.502	1.989	24.317
1995	1.539	13.591	15.130	8.078	2.398	25.606
1996	1.707	15.030	16.737	6.396	3.000	26.133
1997	1.288	19.131	20.419	4.702	2.426	27.547
1998	0.807	6.268	7.075	5.203	4.914	17.192
Total	12.391	330.471	342.862	57.245	24.138	424.245
%	2.9	77.9	80.8	6.4	5.7	100.0

Note: Almost all USA shrimp landings are pandalids. Canadian landings moved here from FAO "natantia nei" because Canadian Pacific landings are entirely pandalids.

Table 15 Commercial landings of pandalid shrimps from the Pacific coast of North America (10^3 t PACFIN, Pacific States Marine Fisheries Commission).

Year	Alaska	British Columbia	Washington	Oregon	California	W-O-C Sub-total	Grand Total
1970	33.682	0.698	0.420	5.662	1.892	7.974	42.354
71	43.001	0.333	0.308	4.179	1.237	5.724	49.059
72	37.239	0.360	0.718	8.693	1.189	10.600	48.199
73	52.943	0.787	2.391	10.321	0.547	13.259	66.989
74	46.402	1.202	4.230	5.907	1.081	11.217	58.822
75	44.695	0.784	4.612	10.838	2.265	17.714	63.194
76	58.519	3.503	4.201	11.518	1.542	17.261	79.282
77	52.622	2.801	5.354	22.036	7.091	34.481	89.904
78	33.245	0.712	5.578	25.854	5.973	37.405	71.362
79	23.095	0.325	5.504	13.417	2.264	21.186	44.606
1980	23.845	0.680	5.728	13.677	2.291	21.696	46.221
81	12.714	0.939	4.561	11.756	1.665	17.982	31.635
82	7.705	0.687	2.268	8.374	2.064	12.706	21.099
83	3.383	0.742	2.566	2.970	0.513	6.049	10.174
84	4.327	0.913	1.553	2.197	0.674	4.423	9.663
85	1.907	1.192	4.136	6.735	1.494	12.365	15.464
86	1.843	1.316	7.893	15.331	3.084	26.308	29.467
87	1.114	3.264	7.212	20.321	3.538	31.071	35.450
88	1.258	3.281	8.301	18.817	5.035	32.153	36.691
89	0.907	3.119	7.199	22.264	6.039	35.502	39.528
1990	1.450	2.701	6.125	14.462	3.939	24.526	28.678
91	1.721	4.226	4.513	9.852	4.698	19.063	25.010
92	1.394	3.851	5.449	21.788	8.399	35.635	40.880
93	1.287	4.498	7.011	12.212	3.538	22.761	28.546
94	1.735	4.197	2.479	7.429	5.086	14.994	20.927
95	2.245	7.961	3.291	5.491	2.612	11.394	21.600
96	1.815	9.146	2.404	7.134	4.242	13.779	24.741
97	1.799	4.720	2.248	8.872	6.255	17.375	23.894
98	1.423	5.084	0.743	2.754	0.834	4.331	10.838
TOTAL	499.319	74.022	118.993	330.860	91.081	540.934	1114.276
%	44.8	6.6	10.7	29.7	8.2	48.5	100.0

4.4 Other shrimps

There have also been some recent attempts to exploit deepwater glass shrimps, Family Pasiphaeidae. Other species of shrimp such as many Crangonidae, which provide important commercial fisheries in the northeast Atlantic, are present in the PICES Region but are only harvested to a minor extent or as incidental catch. The genus *Argis* occurs widely in northern portions (EBPR, AR, WBPR) of the PICES Region where it is and important forage species for groundfish and seals (Lowery and Frost 1981), particularly for the bearded seal, or oogruk, (*Erignathus barbatus*). Minor fisheries for *Argis* spp. occur in the PICES Region and historically, they have occurred as incidental, but utilized, catch in trawl fisheries. There is a new fishery being developed by the Russians in the Sea of Okhotsk for the extremely colorful hippolytid (*Lebbeus groenlandicus*) (Debelius 1999).

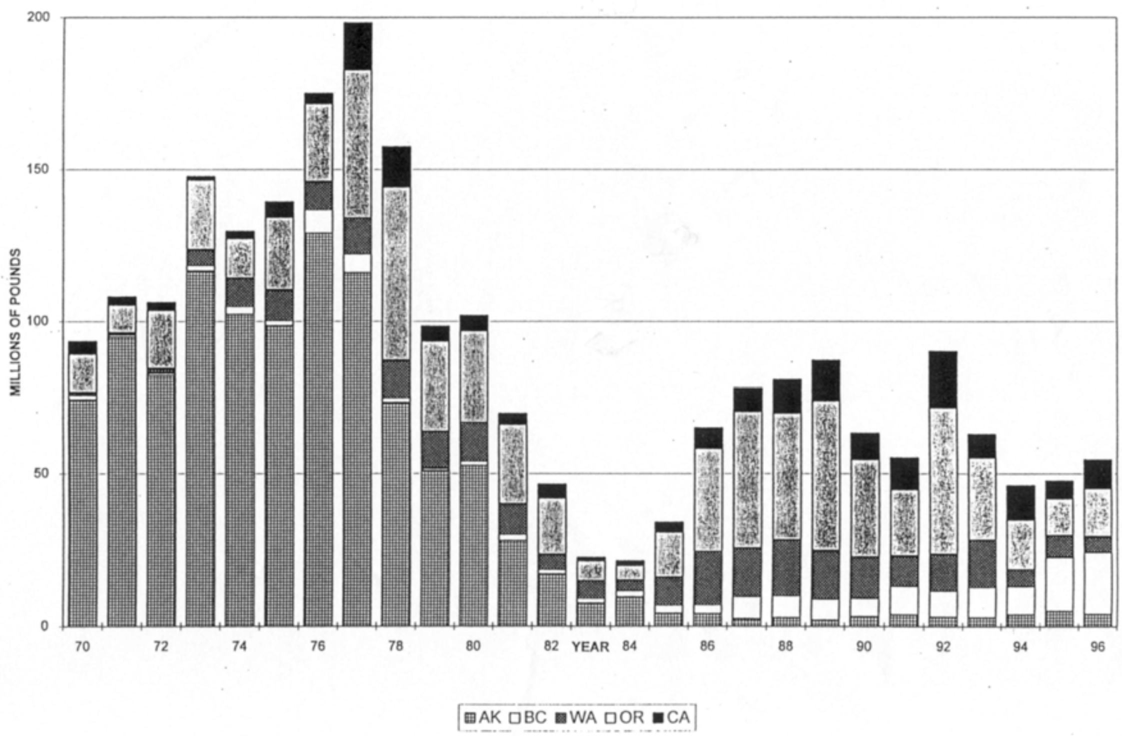


Fig. 28 Pandalid shrimp landings from California to Alaska, 1970-1996.

Interestingly, fisheries for Crangonidae are among the oldest crustacean fisheries on the West Coast of North America. The more important "ocean" pink shrimp (*Pandalus jordani*) likely received its common name in contraposition to the crangonid "bay shrimp" fishery of San Francisco. The San Francisco Bay shrimp fishery began in 1869 (Israel 1936) and exploited primarily *Crangon franciscorium*, but also *Crangon nigricaudata* and *C. nigromaculata* (Butler 1980). Jensen (1995) pictures all three species in color. These species are distributed from Alaska to southern California but have a significant fishery only in San Francisco Bay (Butler 1980). This fishery was first prosecuted with seines but later with bag nets and trawls. Some of the fixed nets used by Chinese fishermen in San Francisco Bay were similar to those used today in the Bohai Sea, and nets were frequently imported from China (Bennot 1932).

Crangon franciscorium is the largest of the three exploited species and reaches a total length of 80 mm but are more typically 50-70 mm. Males and females both mature at about 38 mm total length but females reach a larger size (Isreal 1936). In Gray's Harbor, Washington, some individuals are protandric hermaphrodites but primary females are also present (Gavio *et al.* 1994). Rathbun (1887) commented that this fishery was "by far the most important of any there [on the Pacific coast] in the line of marine invertebrates". Rathbun noted that exports reached about $100,000 (perhaps 454 t) in 1880, with most of the dried export product going to China. However, some 90 t, worth $20,000, sold at the San Francisco market. Bennot (1932) tabulated a catch of 135 t in 1915 that increased to 371 t in 1920, 704 t in 1925 and peaking at 1,386 t in 1929. Isreal (1936) noted a variation in recruitment and landings of 59–60.9 t between 1931-1936. Breed and Olson (1977) have observed incidences of a microsporidian parasite in this species to reach seasonal highs of 30%, which suggests that parasitism may play a role in this species' population dynamics. As late as 1976, landings were 20.4 t, according to U.S. National Marine Fisheries Service statistics.

Crangon spp. of several species are found throughout the PICES Region and the working group noted their occurrences in the diets of a wide variety of finfish (Jewett and Feder 1981, Livingston *et al.* 1993). Wahle (1985) provided both a detailed summary of their feeding ecology in San Francisco Bay and an important literature review of feeding ecology of *Crangon.*

4.5 Spiny lobsters (Palinuridae, FAO Area 61, 77)

The larval life history of spiny lobsters (*Panulirus* spp.) is very complex with several stages of phyllosoma that drift with the ocean currents before transforming into a puerulus prior to settling. Laboratory studies (Sekine *et al.* 2000) suggest that the phyllosoma stage of the Japanese spiny lobster (*Panulirus japonicus,* Plate 5) lasts from 231-417 days (mean = 319.4 days), and tends to increase with the size of rearing tanks. Phyllosoma larvae are large and reach 27.9 to 34.2 mm during their last stage, which is 11-26 days. Carapace length of the puerulus stage is 6.0-8.0 mm and its duration is 9-26 days. The duration of the puerulus stage appears to be controlled by both water temperature and nutritional conditions during the phyllosoma stage. Further laboratory studies (Morikawa *et al.* 2000) reported that Japanese spiny lobsters tend to feed more actively during the night than the day, and that the rate was temperature dependent. Feeding ceased at temperatures below 13.7ºC. At higher temperatures, feeding activity increases. Laboratory studies suggest that temperature directly determines the northerly limits of spiny lobster distribution. Matsuda and Yamakawa (1997) described the effects of temperature on the growth of juvenile and adult Japanese spiny lobsters in the laboratory. This suggests there is considerable variation in growth rates within the thermal-geographic range of the species.

The distribution of Japanese spiny lobster phyllosoma larvae and free-swimming pueruli off the south coast of Kyushu Island was studied by Yoshimura *et al.* (1999) along transect lines that crossed the Kuroshio Current. These authors suggested that final stage phyllosoma larvae occur in or near the Kuroshio Current, and that molting to the puerulus stage also occurred in the same area. Free-swimming pueruli, however, were mostly found north of the Kuroshio Current, which suggests that pueruli may swim across this current to settle in coastal areas. According to Sekiguchi (1997), Japanese spiny lobster larvae are released in coastal waters inshore of the Kuroshio Current, disperse into it or are transported into the Kuroshio-Counter Current Subgyre, re-enter the Kuroshio northeast of the Ryukyu Archipelago, and then recruit through the Kuroshio to Japanese coastal habitats. Detailed oceanographic studies are now needed to trace the long larval drift of Japanese spiny lobster larvae.

Yoshimura and Yamakawa (1998) studied the benthic ecology of settled puerulus and juvenile stages up to 23 mm CL. Both the settled puerulus and juvenile stages were found individually in small holes near algae on the side or underside of rocks or around boulders in nearshore shallow waters.

Megumi (1999) studied the gonadosomatic index (GSI), i.e., the ratio of area of the lumen to that of the seminiferous tubules, and sperm density by season in male Japanese spiny lobsters off Oshima Island, Japan. For functionally mature individuals (i.e., above 54 mm CL), germinal cells at all stages of spermatogenesis were found in the testis, and sperm were present in the vas deferens throughout the year. Seasonal changes in the three reproductive indices, however, indicated a distinct seasonality in spermatogenesis. The GSI was highest before the spawning season. Sperm densities were highest during and one month after the spawning season (from June to September), but was significantly lower in the other months.

Growth, age composition, and recruitment of Japanese spiny lobster have been estimated from length-frequency analyses (Yamakawa 1997). Von Bertalanffy growth curves with seasonal growth oscillations were estimated for each sex. Growth rates fluctuated from year to year, which suggests the presence of density-dependent processes. The most prominent age group in the catch was age 2. Mortality rates after age 2 were estimated up to *ca.* 70-80% per year on average. The size selectivity of tangle nets for spiny lobster was inferred based on the recruitment of age one lobsters during the fishing season and its fluctuations between years. It is interesting to note that the Japanese spiny lobster fishery is conducted with nets while most of the world's lobster fisheries use pots or traps.

Yamakawa *et al.* (1994) expanded the DeLury's method to include 14 maximum likelihood models with variables that included environmental factors such as water temperature, lunar cycle, and the intensity of ocean waves. The optimal model was applied to catch-effort data from the Japanese spiny lobster gillnet fishery. Models were very responsive to water temperature, phase of the moon, and ocean wave patterns. Modeled variations in catchability were probably attributable to changes in lobster activity patterns associated with fluctuations of environmental factors.

Tuiki *et al.* (1999) investigated fishery management of juvenile Japanese spiny lobsters using a fisheries model, fishing data and market records. Predicted yields were compared among several patterns of fishing for juveniles in the shallow water. Simulations showed an increased yield when the fishing area was regulated, and that yield increased despite a constant catch number when fishing efforts were concentrated in the last months of the season. Regulation of fishing area in concert with an increased proportion of fishing effort expended during late fishing periods was found to improve the utilization of juveniles.

California spiny lobsters (*Panulirus interruptus*) occur only in the warmer waters south of Point Conception, California. They provide important fisheries along the Pacific coasts of Mexico and central America. The fishery is restricted to Southern California in the PICES Region, and has been regulated since the early 1900s. There has been a closed season between mid-March and early October since 1935 to allow for spawning. The size limit is 83 mm in carapace length. Fecundity studies of *Panulirus interruptus* on the West coast of Baja California (Pineda Barrera *et al*. 1981) showed that 114 berried females, ranging from 63-163 mm carapace length (235 to 4, 115 g total weight) carried an estimated 91,000-1,988,000 eggs and that fecundity was inversely related to latitude. California spiny lobsters may hence have relatively low fecundity. Mating occurs from January to August and eggs are carried from May to August, while molting appears to occur mostly from May through October (Mitchel *et al*. 1969). Laboratory studies indicate that there are six phylosome stages that occur within a total larval lifespan of up to 114 days (Dexter 1972). Settlement of the puerulus stage of *Pandirus interruptus* in Baja California showed a conspicuous seasonal cycle where autumn (September to October) was the dominant season with second minor peak in spring (Guzman-del Proo 1996). Extensive larval surveys indicated that recruitment of lobsters probably depends on retention of larvae in coastal eddies or coastal countercurrents rather than by return from offshore waters by the Equatorial Countercurrent or the Equatorial Undercurrent (Johnson 1971). Coastal eddies or countercurrents may be particularly important for successful recruitment in California where offshore counter currents are lacking. California spiny lobsters are important predators of sea urchins, *Strongylocentrotus franciscanus* and *S. purpuratus* (Tegner and Levin 1983), and hence there is a possible negative interaction between economically important fisheries.

The total commercial catch for lobster in 2000 in California was about 356 t, most of which was exported to the Far East. California spiny lobsters are one of California's few stable fisheries because commercial landings have ranged between 181 and 272 t over the past 20 years. In San Diego County, where nearly half of the state's commercial catch was brought to the docks, lobsters are the most lucrative seafood commercially fished. Last year, 162 t of lobster with a wholesale value of $2.2 million were taken from local waters. There is no record of the perhaps substantial catches taken by sport divers and hoop netters

4.6 Mantis shrimps (Stomatopoda, Squillidae, FAO Area 61)

Mantis shrimps are stomatopods (Squillidae) and are not closely related to the much more familiar decapod shrimps. DeBelius (1999) provides an excellent pictorial presentation of the group. We include them here for comprehensiveness and because they are unique and interesting animals, although of only small importance economically except in the Bohai Sea where one species (*Oratosquilla oratoria*, Plate 5) is commercially important. Mantis shrimps are widely distributed in Chinese waters and are also found around Korea and Japan, where they were historically more important than presently. Compared to decapod shrimps in the area, these animals are slow growing and reach 150-175 mm TL length at age 3. The maximum size is 210 mm TL (113 g) for females and 177 mm TL (68 g) for males.

Mating occurs in September and October. They often occur in burrows during the winter season (December to March), leading to low catch rates then. Catch rates are similar during the other months. Larvae first occur in plankton samples in May and persist in the plankton for 4-5 months. Larvae reach a maximum size of 26 mm TL, as compared to 30 mm TL for the first benthic stages, observed in November. In 1982, the spawning biomass in the Bohai Sea was estimated at 2,500 t and overall abundance was estimated at about 5,000 t (Zhaung and Deng 1999).

5 Oceanography

In all regions, the oceanography of inshore waters is too site specific to be generalized, and so will not be discussed here in detail. This does not mean that oceanography at this scale is not important to crustaceans, though, as inshore oceanographic features seems to be the dominant factors in determining many, if not most, significant recruitment events with Dungeness crab at least.

Thomson (1981) summarized the prevailing surface currents in the North Pacific Ocean in Figure 29. Currents in the northwest Pacific (Fig. 30) are more complex and variable than in the northeast Pacific because of a more complex topography. The Kamchatka Peninsula, Japan, and the Korean Peninsula create the Okhotsk Sea, the Japan/East Sea and the Yellow Sea, while the Aleutian Islands create the Bering Sea. In contrast, the east-moving Subarctic Current divides when in encounters North America at about the latitude of British Columbia, creating the southern flowing California Current and the northern flowing Alaska Current. The lack of basin-sized water bodies in the north-eastern Pacific may mean that the ocean climate there is more affected by regime shifts in the North Pacific as a whole, although theses events are only now just beginning to be understood.

From British Columbia south, there is a wind-driven seasonal shift in dominant surface coastal current direction, with the Davidson Current flowing northwards in the winter and it being absorbed into the southward flowing, more offshore California Current during the summer (Fig. 31). This reversal in current direction in the spring in particular appears to have implications for at least Dungeness crab. This species has about a four month larval period, and with larval hatching in the southern waters prior to the current reversal, newly hatched larvae tend to be transported offshore and potentially hundreds, if not thousands, of kilometers northwards. The reversal of current direction around the middle of the larval period then tends to transport larvae onshore and southwards. While the actual dispersal fates of individual larvae are unknown, there seems to be extensive mixing of larvae from most of the nearshore coastal regions where adult Dungeness crab occur.

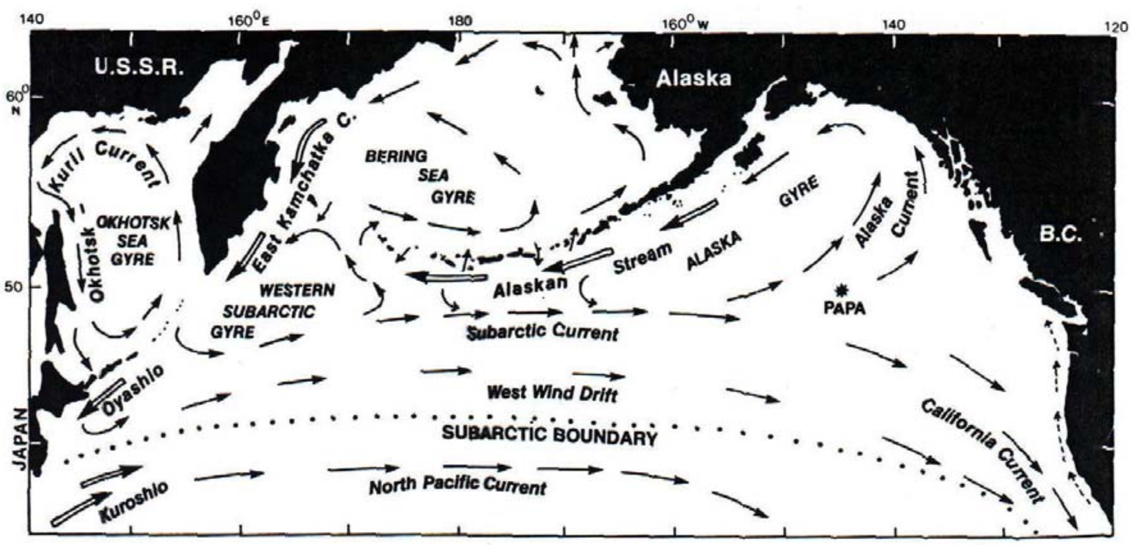


Fig. 29 Schematic diagram of prevailing surface currents in the North Pacific Ocean. Double arrows are intense boundary currents, typically 1-2 $m \cdot s^{-1}$; over most of the region, speeds are less than 0.24 $m \cdot s^{-1}$. Broken arrows correspond to the winter Davidson Current off the north California to southern British Columbia coast (Fig. 13.17 from Thomson 1981).

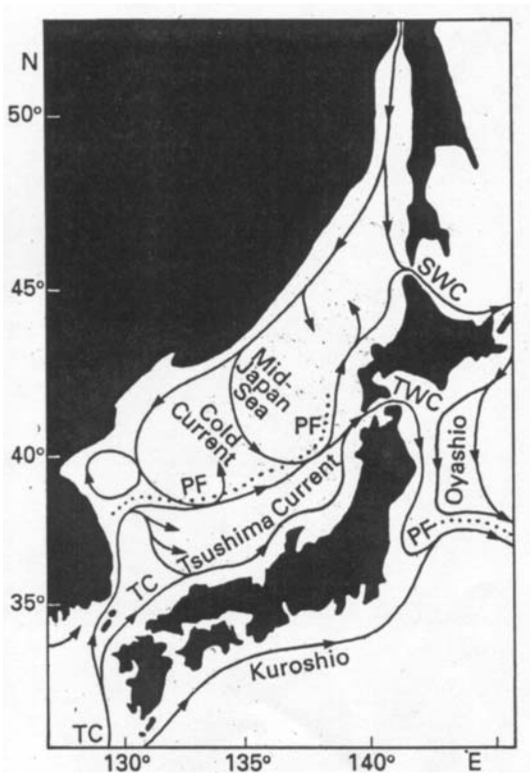


Fig. 30 Surface currents in the Japan/East Sea (Fig. 5.1.1-10 from http://mob.nfesc.navy.mil/documents/BNI/EnvSpec/report-pdfs/Sect5Figs1.PDF)

How regional currents disperse crustacean larvae of other species, and in other areas, is largely unknown, although there appears to be an upcurrent movement of maturing red king crab on the western side of the Kamchatka Peninsula, and subsequent downstream dispersal of larvae along that coast by the counter-clockwise Okhotsk-Kuril Current.

At the northern latitudes, there are a number of counter-clockwise gyres, notably within the GOA and Bering Sea (Fig. 29), of south-eastern Kamchatka, and in the Sea of Okhotsk. There is water exchange between the GOA and the Bering Sea between the Aleutian Islands, and a strong current (East Kamchatka Current) off the eastern Kamchatka Peninsula that becomes the Oyashio Current off northern Japan. This latter current turns eastward at the Subarctic Boundary, feeding the Subarctic Current and West Wind Drift, which both move across the Pacific towards North America.

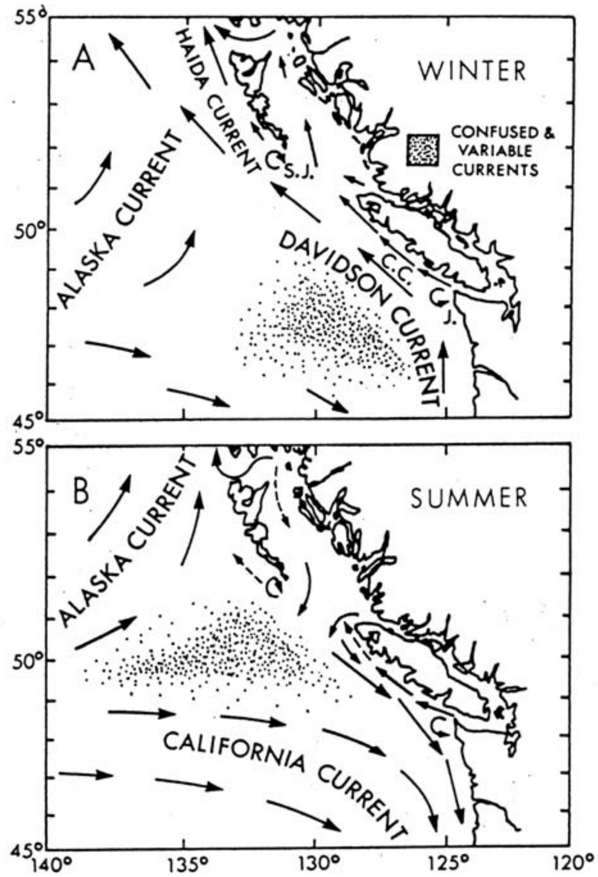


Fig. 31 Regional surface circulation pattern for the northeast Pacific Ocean for A. winter and B. summer based on water property surveys and ship drift information. J. = Juan de Fuca Eddy, C.C. = Vancouver Island Coastal Current, S.J. = Cape St. James Eddy (from Thomson *et al*. 1989).

West of Japan, branches of the Kuroshio Current moves northwards into the Yellow Sea and through the Korea (Tsushima) Strait between South Korea and Japan into the Japan/East Sea. This creates a counter-clockwise gyre towards the head of the Yellow Sea, and the Yellow Sea Warm Current that sweeps around Korea into the eastern portion of the Japan/East Sea, joining the other branch of the Kuroshio Current, the Tsushima (Warm) Current (Fig. 31). There is a cold current (Korean Cold Current) that flows south from the Sea of Okhotsk along the coast in the western Japan/East Sea, creating a series of counter-clockwise gyres. Surface outflow from the Japan/East Sea is eastwards along the northern and southern shores of Hokkaido.

In summary, overall oceanography of the North Pacific is complex, and any variable that would affect many crustacean stocks simultaneously would have to be quite widespread and of considerable regional influence. It is generally accepted that such a widespread climate shift occurred in North Pacific marine ecosystems about 1977, and there is debate about whether additional ones also occurred in 1989 and around 1998 (McFarlane *et al.* 2000). The suggestion for these latter regime shifts has come from a composite climate index based on three aspects of ocean climate conditions (Aleutian Low Pressure Index, the Pacific Atmospheric Circulation Index and the Pacific Interdecadal Low Pressure Index) being linked to decadal changes in eastern Pacific fish population parameters (Beamish *et al.* 1999; King *et al.* 2000). To date, evidence of such regime shifts has not been shown from crustacean landings data, but this does not necessarily mean that large-scale oceanographic events are not affecting crustaceans. Rather, the short time series of credible data and unexplained population collapses form other causes may simply be masking potential signals in crustacean populations of regime shifts.

5.1 Oceanography and recruitment

Major stocks of crabs and shrimps considered by WG 12 inhabit or historically occurred in all of the PICES areas identified by the Climate Change and Carrying Capacity (CCCC) Program, but not in the deep waters underlying the Eastern and Western Subarctic Gyres. There appear to be few trans-boundary stocks with respect to regions or basins, although a given region may contain multiple stocks of a species. For example, the EBS Region contains three stocks of red king crab in Norton Sound, Bristol Bay and around the Pribilof Islands. PICES areas and identified ocean basins are hence often useful geographic units with respect to crab and shrimp stocks.

There appears to be no particular climatic or oceanographic patterns that are unique to crustaceans, as opposed to finfish. Further the same zoogeographic regions that have been differentiated for finfish seem to be largely applicable to macrobenthic crustaceans. These regions correspond well with the ten PICES-GLOBEC CCCC Program Components and seem to derive from large-scale oceanographic features. It is noted, however, that boundaries of zoogeographic provinces may change with increasing depths.

We noted that there were intraspecific as well as interspecific differences in life history mechanisms that related to these regions. These differences may provide natural clines or dichotomies that could be exploited for experiments. For example, in the Sea of Okhotsk (Rodin 1985) and in Bristol Bay (see above), red king crab populations appear to be located so that there is a classic (Jones 1968) denatant drift of larvae to nursery areas and a contranatant ontogenetic migration. By contrast, in the GOA, onshore migration of adults and spawning in semi-enclosed waters seem to be an important mechanism (Gray and Powell 1966, McMullen 1967, Powell 1964, Powell and Nickerson 1965, Powell *et al*. 1973, Powell *et al*. 1974) to ensure that larvae reach suitable nursery grounds. There may be very different climatic effects on these two strategies. Experimentation might deal with contrasting growth and mortality between such regions.

Primary and secondary production in planktonic communities are translated to meroplanktonic larval stages of macrobenthic crustaceans and may be related to year-class strength through match-mismatch mechanisms relating to the timing of phytoplankton blooms relative to larval release. Detritus from upper levels feeds into the secondary production of benthic infauna that serve as primary food sources for crabs and shrimps, as well as other epibenthic fauna. Also, many shrimps make nocturnal vertical migrations in order to feed on zooplankton (Barr 1970, Barr and McBride 1967, Percy 1970).

Physical properties of the bottom and ecological relationships within the benthos have probably not been considered very heavily in CCCC Program deliberations, but are inescapably important relative to crabs and shrimps and other benthic crustaceans.

Crabs and shrimps are much less mobile than finfish and hypothetically less able to adjust their times and places of spawning relative to productivity or other conditions in the euphotic zone that might affect larval survival. Benthic crustaceans may have to cope with ambient, but suboptimal, conditions during egg hatching and early life history while many finfish can move with water masses to better optimize conditions. It is also noteworthy that many northern species of benthic crustaceans carry eggs for about a year prior to hatching and that their larval life span is long (week-months) relative to most fishes (days to weeks). These consequences of relative immobility and long embryonic-larval periods could lead to greater variability in recruitment for crabs and shrimps as opposed to finfishes of the same regions.

Climatic variability may affect crustacean populations directly through recruitment processes as noted above. In much of the GOA and EBS, effects may also have been mediated through predation. For example the regime shift that occurred in the late 1970s produced strong year classes of several ground fishes that in turn may have resulted in decreased shrimp abundance through predation and or competition (Albers and Anderson 1985).

Because many of the region's groundfish are long lived, there is an inertia re change in species dominance within a region. A regime shift that resulted from short-term climatic or oceanographic phenomena could potentially produce long-term ecological effects due to the persistence of strong year classes. This may also be relevant with respect to longer-lived crustaceans such as king and snow crabs.

Top down versus bottom up control of species composition and relative abundance is likely very different between pelagic and benthic crustacean habitats. Most crabs and shrimps in the region have relatively long larval periods (as much as 90 days) during which they are meroplanktonic. It is not clear how meroplankton might be controlled or influenced by the holoplankton community through competition or predation. Interactions between the two groups certainly provide a broad topic of research and experimentation.

Hypothetically, if both meroplankton and phytoplankton abundance were controlled by the dynamics of primary productivity, then there may be a way to use information on primary productivity to model year-class success through the larval phases.

Bottom up control may involve the rate of transfer of primary production to the bottom as detritus. One hypothesis is that warmer conditions are conducive to greater zooplankton abundance or diversity and greater respiration in the upper water column. Since more energy would be consumed in upper layers, less might become available to lower layers or the bottom where detritus may be consumed by filter feeders, that in turn become food for macrobenthic crustaceans. Wind patterns affecting surface water currents appear to be important in some cases.

Top down control through predation may occur when changes in finfish biomasses result in increases or decreases in crab and shrimp biomasses. Albers and Anderson (1985) were able to largely account for declines in shrimp biomass in Pavlof Bay, Alaska, by using conservative estimates of Pacific cod (*Gadus macrocephalus*) predation. The same might be said of certain marine mammals. For example, bay populations of Dungeness crab may be being controlled through sea otter predation (Kimker 1985, Shirley *et al.* 1995).

Some crustacean populations may, in part, be achieving longer-term stability in abundance because of either the coincidental presence of favorable oceanographic regimes or the possible selection over time of unique larval behaviors. An example of the former is the sustained availability of Dungeness crab in McIntyre Bay in Dixon Entrance. This area is the site of continuous counter-clockwise current gyre just to the left of the northern part of Hecate Strait, which separates the Queen Charlotte Islands from mainland BC. Dungeness crab have a relatively long planktonic larval period (3-4 months) in late winter and spring. While the source of larvae may either be local or from some more remote location, sufficient larvae seem to always be retained in this gyre so as to support a substantial fishery in the extensive shallow sand substrate along the southern boundary of the gyre. Crawford and Jamieson (1996) modeled the region's oceanographic features, and have demonstrated that the gyre retains larvae that might otherwise be advected to a less favorable habitat.

An example of selection for unique larval behaviors within a population, and the subsequent independence of some populations from wide-scale oceanographic events that may affect other populations of the species, is that of Strait of Georgia/Puget Sound (Salish Sea) Dungeness crab. Jamieson and Phillips (1993) reported that megalopae of these crab have a vertical diel migration of about 140 m, whereas outer coast megalopae have a vertical diel migration of only about 25 m. The inner waters of the Salish Sea are connected to outer coast waters primarily through the Strait of Juan de Fuca, which is about 200 m deep, 161 km long and 18–27 km wide. Because of the large freshwater discharge of the Fraser River into the Strait of Georgia, Juan de Fuca Strait has an estuarine flow, with outflowing surface water (generally above 100 m depth) and deeper inflowing outer coast water. During the spring and summer, daylight is 14-16 hr and night is about 8-10 hr. As a result, Salish Sea megalopae are mostly in deeper inflowing waters while outer coast megalopae are always in outflowing surface waters. This difference in behavior is suggested to prevent Salish Sea larvae from being flushed out of the Salish Sea during this crab's long larval period, and by separating the crab populations, may allow for the continued genetic selection that was required to achieve this difference in behavior.

Dungeness crab (*Cancer magister*) have cyclic populations from Central California to Washington State, but Alaskan and British Columbia landings are more consistent from year to year and do not display the cyclic patterns observed southwards. Alaskan landings are not in synchrony with that of the contiguous 48 states of the U.S. or with Canada, and landings may instead be market driven over some portion of the historical landings time-series. Since patterns differ between zoogeographic provinces, comparative studies may provide insight into mechanisms of population control.

The reason for the lack of a cyclic fluctuation in abundance not being observed in British Columbia appears to be because of local oceanography (Thomson *et al.* 1998). The brackish water outflow from Juan de Fuca Strait arising from Fraser River discharge into the inner Strait of Georgia moves to the right because of the Coriolis force arising from the Earth's spin. This outflow thus hugs the west coast of Vancouver Island to about its northern tip, where it tends to jet offshore, and is known as the Vancouver Island Coastal Current. During the summer, when outer coast waters from the northern tip of Vancouver Island southwards mostly move southwards, this inner water coastal current, which averages about 30 km in width, continues to move northwards. A boundary zone thus exists off the outer coast of Vancouver Island between the two counter currents, and this seems to operate as a barrier to the shoreward movement of Dungeness crab megalopae that occur in abundance seaward of the Vancouver Island Coastal Current. As explained above, the surface outflow of Juan de Fuca Strait contains virtually no Dungeness crab larvae.

Observations (Jamieson *et al.* 1989) indicated that during substantial storm events, which have southern winds, water piles up against Vancouver Island, which extends to the northwest. This hydraulic head, even though measured in only centimeters, can stop the outflow of Juan de Fuca Strait waters, thereby removing the countercurrent barrier boundary and allowing the Dungeness crab larvae concentrated there to move shorewards, movement which can be rapid because of the storm winds. To survive after settlement, Dungeness crab must settle in waters less than about 50 m depth. Such storm events typically last for 5-7 days, and sufficiently strong ones only seem to occur infrequently in the spring when megalopae are present in abundance. During the past 15 years, substantial crab settlements on the West Coast of Vancouver Island only occurred 2-3 times. This, coupled with the relative lack of suitable sandy substrate off the mostly fjord-like, west coast of Vancouver Island, has meant that the substantial cycling in abundance of crab populations that has characterized California to Washington State waters in recent decades has not occurred in Canada.

The list of factors used to explain changes in Dungeness crab populations is a fair sampling of factors that are thought to control crab populations in general. Additionally, predation on adults (Livingston *et al.* 1993), parasitism and epizootic diseases (Sparks 1985, Sparks and Hibbits 1979, Sparks and Morado 1985) are documented in a number of king and Tanner crab populations. Tanner and snow crabs have broad distributions across several zoogeographic provinces and provide opportunities similar to those for king crabs.

6 Sampling and Data Analysis

WG 12 discussed this topic very briefly, the major issue being skewed distributions resulting from aggregated populations and methods of dealing with them. We also discussed catchability experiments and improved more quantitative visual methods of surveying with submersibles, such as a LASER Line Scan System. A field guide to biological sampling and observation techniques (Jademec *et al.* 1999) has been developed by the University of Alaska that is an excellent protocol for the taking and coding of field observations of crabs in general.

6.1 Spatial structuring of crab and shrimp populations

Discussions were limited to well known stocks as examples of various processes and their effects rather than a systematic consideration for all stocks that we have identified. This was necessary due to the large number of stocks involved and the fragmentary information available for many of them. In general it appears that spatial structure is extremely important in the maintenance of recruitment for crab and shrimp stocks.

The existence of discrete aggregations at fine spatial scales are well known for many crab and shrimp stocks. At large spatial scales, meta-population structure is often perpetuated by larval drift, occasionally to the point that some geographical units may be non-functional from a reproductive standpoint. This may be true of snow crab in very cold portions of the northern Bering Sea where few reproductively active snow crab are found (Jewett 1981**,** Wolotira *et al.* 1977). The same larval drift may result in genetic interchange between populations in the Bering Sea and those in the Chukchi Sea (Paul *et al.* 1997).

Current patterns, and the adaptations of crab behaviour to them, re demonstrated by the Dungeness crab studies referred to above in the section on “Oceanography and recruitment”. As suggested, it can be quite complex, meaning that to fully understand any species population dynamics, detailed studies will likely be required.

6.2 Effectiveness of marine sanctuaries and restrictions on fishing activities for crabs and shrimps

This topic was also briefly considered. There are apparently few marine sanctuaries that were established primarily to protect crabs and shrimps in the PICES Region. One exception is found in the northern portion of the West Kamchatka Shelf where red king crab nursery grounds are closed to both trawling and pot fishing. Those that might be useful in this regard protect habitat for a multiplicity of purposes (e.g. no dredging, dumping, mineral exploration, removal of artifacts, etc) other than perpetuation of adjacent fisheries by means of “no-take zones”. This does not preclude establishing sanctuaries for this latter purpose, though, and we recognized that sanctuaries are being considered in management planning for a variety of fisheries. Most frequently, closures to fishing gear of certain types are used in the management of crabs and shrimps. Reasons for these latter “sanctuaries” are typically site-specific, and include allocation across sectors, bycatch minimization, minimization of sublegal species retention, navigation concerns, and efforts to control fleet capitalization.

WG 12 also noted that several areas are now closed to bottom trawling to protect crab stocks, and that various marine sanctuaries are being planned or proposed in the United States, Canada and Japan.

Finally, in Canada and the U.S. at least, seasonal protection of some crab stocks occurs, not though marine protected areas, but through fisheries regulations. These have been established to stop both crab fishing and trawling at seasonal times of crab molting (soft-shell condition) (see Jamieson and Lessard 2000 for Canadian examples).

7 Acknowledgements

Numerous colleagues have inadvertently contributed to WG12 over the past several years through timely discussions of fisheries, stock conditions and population dynamics. These discussions have occurred in a wide variety of fishery management meetings as well as the more traditional symposia and workshops referenced above. Understanding gained through participation in these forums and discussions and the importance of continuing them must hence be acknowledged, along with the large contribution of member nations to supporting infrastructure and research. Many important contributions are anonymously placed in the World Wide Web as well and are acknowledged as a rich source of information. We especially thank Susan Ashcroft of the California Department of Fish and Game for providing information on the San Francisco Bay shrimp fishery, and Dr. Jung Hwa Choi, PICES Secretariat, for his assistance in the formatting of this document.

Contributions by non-members also added to the usefulness of our deliberations. We thank: Jan Armstrong for taking excellent notes during our long and very productive meeting in Nemuro; Dr. Jiro Kittaka for allowing us to visit the Tokyo Science University's Nemuro City Fisheries Research Institute, the City of Nemuro and its organising committee for their excellent planning, support and hospitality, The Honorable Oyho-san, Mayor of Nemuro for his personal interest; Dr. P. Livingston for her presentation at Fairbanks concerning the workings of GLOBEC; Dr. M. Kashiwai for his presentation at Fairbanks concerning the general workings of PICES; the Chinese meeting organizers, Qingdao; Jan Haaga of the National Marine fisheries Service Kodiak Laboratory for graphics and plates; Clair Armistead of the Kodiak Laboratory for ARCINFO plots.

7.1 Other matters

The Working Group noted with pleasure that the NAFO/PICES/ICES Symposium "Pandalid Shrimp Fisheries - Science and Management at the Millennium" took place in Dartmouth, Nova Scotia, September 8-10, 1999, with Jim Boutillier of WG 12 as the PICES Co-convener. PICES involvement with this workshop had been recommended by WG 12 and we were glad to we could participate in its planning. The last international workshop dealing with Pandalidae was in Iceland in 1993 and the last symposium dealing with pandalid shrimps worldwide was the "International Pandalid Shrimp Symposium" held by University of Alaska Sea Grant in Kodiak, Alaska, in 1979. There were 96 participants in the recent joint symposium including eight invited speakers to four sessions. Sessions included: 1) environmental and trophic considerations, 2) stock assessments, 3) management, and, 4) harvesting and processing. There were 23 oral presentations and 15 posters. The symposium was attended by representatives from 15 nations.

We are glad to note that WG 12 meetings have lead to cooperative Canadian-South Korean projects. Dr. In Ja Yeon worked in Nanaimo with Dr. Glen Jamieson and colleagues during 2000-2001, and Dr. Sung-Yun Hong is spending his 2001/2002 sabbatical in Vancouver and Nanaimo, Canada, with DFO researchers. As a result of contacts made at the working group, a two-year (1999-2000), joint South Korea-Canada collaborative program, involving Dr. Hong, Dr. Ian Perry (DFO, Canada) and Mr. Boutillier was established to develop early life history information on select shrimp and crab species. A South Korean student, Wongyu Park, who completed his M.Sc. under Dr. Hong at Pusan National Fisheries University, has spent a number of months working in Nanaimo describing the early life histories of a number of crustacean species. Larvae of sidestriped shrimp, dock shrimp, bristly crab (*Acantolithodes hispidus*) and a grooved Tanner crab (*Chionoectes tanneri*) were successfully reared and described (manuscripts for primary publication are in preparation). This research will aid studies of shrimp and crab recruitment and abundance fluctuations, as well as help with determining if grooved and benizuwai Tanner crabs represent distinct species or simply separate populations on either side of the North Pacific. This work also laid the foundation for a

Ph.D. study by Mr. Park at the University of Alaska, Juneau, that is now in progress. Part of this work was funded through the PICES Trust Fund.

We thank our Chinese colleagues for introducing us to shrimp aquaculture in China and particularly for organizing a trip to their experimental station. The extent of aquacultural production was impressive. We note that world-wide aquacultural production has generally been growing at a greater rate than landings from wild stocks in recent years according to FAO Statistics.

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9 APPENDICES

Appendix 1. Membership of PICES Working Group 12

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Appendix 2. Attendance at PICES WG 12 meetings by Working Group members (* Co-Chairmen) and observers who attended meetings in: 1) Nanaimo 1996, 2) Nemuro 1997, 3) Fairbanks 1998, 4) Qingdao 1999.

Members:

CANADA	Jim Boutillier (1,2,4) Glen Jamieson (1,2,3,4)
CHINA	Zhi-ming Zhuang (4)
JAPAN	Hideo Sekiguchi (2,3,4)
REPUBLIC OF KOREA	Sung Yun Hong (2,3,4) In-Ja Yeon (2,3)
RUSSIAN FEDERATION	Boris G. Ivanov (2,3,4) Vitaly E. Rodin * (2,3,4) Yuliya B. Zaitseva (2)
U.S.A.	David A. Armstrong (1,2,3) Robert S. Otto * (1,2,3,4)

Observers:

Nemuro: M. Kashiwai (PICES Science Board), Y. Nagata (PICES/CCCC Co-Chairmen), J. Kittaka (Science University of Tokyo), F. Abrunhosa (Science University of Tokyo), E.V. Radhakrishnan (Regional center CMFRI, India), S. Ivanov (TINRO, translator) and J. Armstrong (University of Washington).

Fairbanks: Makoto Kashiwai (Chairman, Science Board), Alexander A. Kurmazov (TINRO, Russia), Patricia Livingston (CCCC/IP Co-Chairman), Alan M. Springer (University of Alaska), S. Ivanov (TINRO, translator) and Bradly G. Stevens (NMFS Kodiak Laboratory)

Qingdao: Jingyau Deng (Yellow Seas Fishery Research Institute, YSFRI), Jisheng Chen (YSFRI), Ling Tong (YSFRI), Shengli Cai (YSFRI), and S. Ivanov (TINRO, translator).

In 1996, members were named in May and there was limited time for travel arrangements prior to the October meeting. The 1996 meeting was attended by only four members from the United States and Canada and was primarily organizational. Attendance was 11 of 15 members in 1997 and 8 of 15 members in 1998. Five nations were represented in both years. Attendance was 8 of 15 members in 1999 and this was the first meeting at which all six member-nations were represented. Cumulatively, 17 members were appointed by national bodies and 12 members attended one or more meetings. At 1997, 1998 and 1999 meetings members unanimously expressed their belief that scientists from the Democratic Peoples Republic of Korea (North Korea) should attend future PICES meetings if possible since we were unable to receive information over the full range of several stocks in the Japan/East Sea and the Yellow Sea.

Appendix 3. A taxonomic list of species of crabs, shrimps, and lobsters exploited in the PICES Region (major taxon according to American Fisheries Society Special Publication 17, common names per AFS or UN/FAO, if possible). Question marks (?) indicate either uncertainty as to range, importance or general interest, or the need for further definition. Almost all species below have known commercial, recreational or subsistence fisheries that exploit them. * = important species considered by WG12

Phylum, Subphylum, or Superclass: Crustacea

CRABS *et al*:

Class: Malacostraca
Subclass: Eumalacostraca
Order: Decapoda
Suborder: Pleocymata
Infraorder: Brachyura
Section: Oxyrhyncha
Superfamily: Majoidea
Family: Majidae
(Spider crabs)

Tanner crab	*Chionoecetes bairdi* *
Snow crab	*C. opilio* *
Angled Tanner crab	*C. angulatus* *
Grooved Tanner crab	*C. tanneri* *
Benizuwai Tanner (Red Snow) crab	*C. japonicus* *
Arctic Lyre crab	*Hyas coarctatus*
Pacific Lyre crab	*H. lyratus*
Sheep crab	*Loxorhynchus grandis*

Section: Cancridea
Superfamily: Cancroidea
Family: Atelecyclidae
(Horse crabs)

Hair crab	*Erimacrus isenbeckii* *
Helmut crab	*Telmessus cheiragonus*

Family: Cancridae
(Rock crabs)

Dungeness crab	*Cancer magister* *
Red Rock crab	*C. productus*
Yellow Rock crab	*C. anthonyii*

Section: Brachyrhyncha
Superfamily: Portunoidea
Family: Portunidae
(Swimming crabs)

Sand crab	*Portunus pelagicus*
Gazami crab	*P. trituberculatus* *
Mud crab	*Scylla serrata*

Infraorder: Anomura
Superfamily: Paguroidea
Family: Lithodidae
(Stone and King crabs)

Red King crab	*Paralithodes camtschaticus* *
Blue King crab	*P. platypus* *
Hanasaki King crab	*P. brevipes* *
Golden King crab	*Lithodes aequispinus* *
Scarlet King crab	*L. couesi* *
Paralomis spp	*Paralomis multispinus*
Paralomis spp	*Paralomis verrilli*
Puget Sound King crab	*Lopholithodes mandtii*

SHRIMPS

Class: Malacostraca
Subclass: Eumalacostraca
Order: Decapoda

Suborder: Dendrobranchiata
Superfamily: Penaeoidea
(Penaeoid shrimps)
Family: Penaeidae

Kuruma shrimp/prawn	*Marsupenaeus japonicus* *
Fleshy prawn	*Fenneropenaeus chinensis* (=*orientalis*)
Shiba shrimp	*Metapenaeus joyneri* *
Yoshi shrimp	*M. ensis* *
Cocktail shrimp	*Trachysalambria curvirostris*

Superfamily: Sergestoidea
Family: Sergestidae

Akiami paste shrimp	*Acetes chinensis* *, *A. japonicus* *

Suborder: Pleocyemata
Infraorder: Caridea
Superfamily: Pandaloidea
(Pandalid shrimps)
Family: Pandalidae

Sidestriped shrimp	*Pandalopsis dispar* *
Morotoge shrimp	*P. japonica* *
Northern shrimp	*Pandalus borealis/eos* *
Humpy shrimp	*P. goniurus* *
Dock shrimp	*P. danae*

Coonstriped shrimp	*P. hypsinotus* *
Ocean shrimp	*P. jordani* *
Spot shrimp	*P. platyceros* *
Hokkai shrimp	*P. latirostris* *

Superfamily: Crangonoidea
Family: Crangonidae

Northern sculptured shrimp	*Sclerocrangon boreas* *
Uneven sculptured shrimp	*S. salebrosa* *
San Francisco Bay shrimp	*Crangon franciscorum*
Arctic argid shrimp	*Argis dentata*
Kuro shrimp	*A. lar*

SPINY LOBSTERS

Class: Malacostraca
Subclass: Eumalacostraca
Order: Decapoda

Suborder: Pleocyemata
Superfamily: Palinuroidea
(Palinurid lobsters)
Family: Palinuridae

California spiny lobster	*Panulirus interruptus*
Japanese spiny lobster	*P. japonicus* *

MANTIS SHRIMPS

Class: Malacostraca
Subclass: Hoplocarida
Order: Stomatopoda
Suborder: Unipeltata
Superfamily: Squilloidea
Family: Squillidae

Chinese mantis shrimp	*Oratosquilla oratoria**

Appendix 4. Important PICES Region crab, shrimp, and lobster stocks classified as to stock size, abundance trends, type and degree of fishery development. Current stock abundance is intraspecific relative to its historical level: small (s), medium (m) and large (l). Long-term trends are periodically fluctuating (P), decreasing (D) and increasing (I). Fishery types are characterized as commercial (C), recreational (R) and subsistence (S). Fishery status is characterized as undeveloped (U), developing (D), fully developed (F) or closed to commercial fishing(*).

	Abundance		Long-term		
	Historical	Current	Trend	Type	Status
Crab *et al*:					
Tanner crab (*C. bairdi*)					
SE Alaska	s	s	D	C,R,S	F
Cook Inlet	m	s	D	C,R,S	F
Kodiak	l	s	D	C,R,S	F
S Al. Peninsula	l	s	D	C,R,S	F
E Aleutians	s	s	D	C,R,S	F
W Aleutians	s	s	D	C,S	U
E Bering Sea	l	m	D	C	F
NW Bering Sea	s	s	D	C	F
Koryak Coast	m	?	?	C	F
Olyutorskiy Bay	l	?	?	C	F
W Kamchatka	m/l	?	?	C	F
Angled Tanner crab (*C. angulatus*)					
Canada	?	?	?	C	U
Gulf of Alaska	?	?	?	C	U
Aleutian Islands	?	?	?	C	U
E Bering Sea	?	?	?	C	U
N Sea of Okhotsk	m	?	?	L	U
Grooved Tanner crab (*C. tanneri*)					
Calif.-Washington	?	?	?	C	U
Canada	?	?	?	C	U
Gulf of Alaska	?	?	?	C	U
Aleutian Islands	?	?	?	C	U
E Bering Sea	?	?	?	C	U
W Bering Sea	s	?	?	L	U
Snow crab (*C. opilio*)					
E Bering Sea	l	l	P	C	F
W Bering Sea	l/m	l/m	?	C	F
Koryak Coast	m	?	?	C	F
Olyutorskiy Bay	s	?	?	C	F
E Kamchatka	s	?	?	C	F?
W Kamchatka	m	?	?	C	D
N Sea of Okhotsk	l	m	P	C	F
E Sakhalin Is.	l	m/l	D	C	F
W Sakhalin Is.	s	?	?	C	F
Japan/East Sea	l	m	D	C	F
Benizuwai Tanner crab (*C. japonicus*)					
E Japan/East Sea	l?	m?	?	C	F?
W Japan/East Sea	l	l	?	C	D

	Abundance		Long-term		
	Historical	Current	Trend	Type	Status
Hair crab (*E. isenbeckii*)					
E Bering Sea	m	m	?	C	F
Aleutian Islands	s	?	?	C	L
E Kamchatka	s	s	?	C	U
SE Kamchatka	m	m	?	C	F
Kurile Islands	m	m	?	C	F
E Sakhalin Is.	s	s	?	C	F
W Sakhalin Is.	m	s	?	C	F
Hokkaido	l	m	?	C	F
E Japan/East Sea	m	l	?	C	F
Korean Coast	m	s	D	C	F
W Japan/East Sea	m	m	?	C	F
Sand crab (*P. pelagicus*) ? Stocks					
FAO Area 61	l	?	?	C	?
Gazami crab (*P. trituberculatus*) ? Stocks					
FAO Area 61	l	?	?	C	F
Korean Coast	l	l	D	C	F
Mud crab (*S. serrata*)? Stocks					
FAO Area 61	l	?	?	C	F?
Dungeness crab (*C. magister*)					
S California	m	s	D,P	C,R	F
N Calif.-Wash.	l	l	P	C,R	F
Puget Sound	m	m	P	C,R	F
Canada, WCVI	m	m	?	C,R,S	F
Canada, ECVI	m	m	?	C,R,S	F
Canada, QCI	l	m	D,P	C,R	F
Canada, Central	m	m	?	C,R,S	F
SE Alaska	l	m	P	C,R,S	F
Cook Inlet	m	s	D,P	C,R,S	F
Kodiak	l	s	D,P	C,R,S	F
S Ak. Peninsula	m	s	D,P	C,R,S	F
E Aleutians	m	s	D	C,R,S	F
E Bering Sea	s	s	?	C	F
Red King crab (*P. camtschaticus*)					
Canada	s	s	?	C,R,S	D
S E Alaska	s	s	?	C,R,S	F
Cook Inlet	m	s	D	C,R,S	*
Kodiak	l	s	D	C,R,S	*
S Ak. Peninsula	l	s	D	C,R,S	*
E Aleutians	l	s	D	C,S	*
W Aleutians	l	s	D	C,S	*
Bristol Bay	l	s	D	C	*
Pribilof Islands	s	s	D	C,S	*/F
Norton Sound	s	s	?	C,R,S	F
E Kamchatka	s	s	P	C	F
W Kamchatka	l	s	D	C	F
NW Sea of Okhotsk	m	s/m	P	C	F
Kurile Islands	s	?	?	C	F
E Sakhalin Is.	s	s	D	C	F
W Sakhalin Is.	s/m	s	D	C	F
Hokkaido	s/m	s	?	C	F

	Abundance		Long-term		
	Historical	Current	Trend	Type	Status
Blue King crab (*P. platypus*)					
SE Alaska	s	s	?	C,R,S	F
Prince William S.	s	s	?	C,R,S	*
Other G. of Alaska	s	s	?	C,R,S	*
Pribilof Islands	l	s	D	C,S	*/F
St. Matthew Is.	l	m	D	C,	*/F
N Bering Sea	s	s	?	C,S	F
Cape Navarin	m	s	D	C	F
S Koryak Coast	m	m	D	C	F
E Shelikhov Bay	l	m	P	C	F
NW Shelikhov Bay	m	m	P	C	F
St. Iona Is.	s	s	D	C	F
E Sakhalin Is.	s	s	D	C	F
W Sakhalin Is.	s	s	D	C	F
Hokkaido	s	?	?	C	F
W Japan/East Sea	s	s	D	C	F
Scarlet King crab (*L. couesi*)					
Calif.-Washington	?	?	?	?	U
Canada	?	?	?	?	U
Gulf of Alaska	?	?	?	C	D
Aleutian Islands	?	?	?	C	D
E. Bering Sea	s	?	?	C	D
W. Bering Sea	m	m	?	C	U
N. Sea of Okhotsk	l	m	?	C	U
Golden King crab (*L. asquispinus*)					
Canada	s	s	?	C	U
SE Alaska	m	s	?	C	F
Other G. of Alaska	s	s	?	C	F
E Aleutians	m	m	D?	C	F
W Aleutians	l	l	D?	C	F
Bristol Bay	s	s	?	C	F
Pribilof Islands	s	s	?	C	F
N Bering Sea	s	s	?	C	D
E Sakhalin Is.	s	s	?	C,S	U
W Sakhalin Is.	m	s	?	C	F
N Sea of Okhotsk	l	s	D	C	F
Kurile Is.	M/l	m	D?	C	F
Hokkaido	s	?	?	C	?
Shrimps					
Kuruma prawn (*M. japonicus*) ? Stocks					
FAO Area 61	l	?	?	C	F?
Korean Coast	m	m	D	C	F
Fleshy prawn (*F. chinensis*) ? Stocks					
FAO Area 61	l	?	?	C	F?
Korean Coast	l	l	F	C	F
Shiba shrimp (*M. joyneri*) ? Stocks					
FAO Area 61	l	?	?	C	F?
Korean Coast	m	m	D	C	F
Yoshi shrimp (*M. ensis*) ? Stocks					
FAO Area 61	?	?	?	C	F?

	Abundance		Long-term		
	Historical	Current	Trend	Type	Status
Southern rough (Cocktail) shrimp (*T. curvirostris*) ? Stocks					
FAO Area 61	l	?	?	C	F?
Korean Coast	s	s	D	C	F
Akiami paste shrimp (*A. chinensis*) ? Stocks					
FAO Area 61	l	?	?	C	F?
Korean Coast	l	l	D	C	F
Morotoge shrimp (*P. japonica*) ? Stocks					
FAO Area 61	s	s	P	C	F
Korean Coast	?	?	?	C	F?
Sidestriped shrimp (*P. disper*)					
Calif.-Wash.	s	?	?	C	F?
N Coast B.C.	l	l	?	C	U-F
S Coast B.C.	m	s	D	C	F
SE Alaska	s	s	?	C	F
Prince William S.	l	s	D	C	F
Cook Inlet	m	s	D	C	*
Kodiak	l	s	D	C	*
S Ak Peninsula	l	s	D	C	*
E Aleutians	m	s	D	C	F
W Bering Sea	s	s	P/I	C	D
Northern shrimp (*P. borealis/eos*)					
N Coast B.C.	s	s	?	C	F
S Coast B.C.	s	s	D	C	F
SE Alaska	s	s	D	C	F
Cook Inlet	m	s	D	C	F
Kodiak	l	s	D	C	F
S Ak Peninsula	l	s	D	C	F
E Aleutians	m	s	D	C	F
E Bering Sea	l	s	D	?	?
W Bering Sea	s/m	m	?	C	D
W Kamchatka	s/l	l	?	C	D/F
N Sea of Okhotsk	m/l	l	?	C	D/F
E Sakhalin Is.	m/l	l	?	C	D/F
W Sakhalin Is.	m	m	?	C	F
N Japan/East Sea	m	m	?	C	U
Humpy shrimp (*P. goniurus*)					
Cook Inlet	s	s	D	C	*
Kodiak	m	s	D	C	*
S Ak Peninsula	m	s	D	C	*
E Aleutians	s	s	D	C	*
E Bering Sea	m?	s	D	?	U
W Bering Sea	s/l	s/m	?	C	U/D
W Kamchatka	s	s	?	C	U/D
S Sakhalin Is.	s/m	s	?	C	U/D
Hokkai shrimp (*P. latirostris*) Stocks ?					
FAO Area 61	m	m	?	C	D/F
W Japan/East Sea	m	m	P	C,R,S	D
S Sakhalin Is.	m	s/m	P	C,R,S	D/F
S Kurile Is.	m	s/m	P	C,R,S	D/F

	Abundance		Long-term		
	Historical	Current	Trend	Type	Status
Ocean shrimp (*P. jordani*)					
Calif.-Wash.	l	?	P	C	F?
Offshore, B.C.	m	s	D	C	F
Inshore, B.C.	s	s	?	C	F
Spot shrimp (*P. platyceros*)					
Calif.-Wash.	s	?	?	C,R	F?
Canada	l	l	?	C,R	F
SE Alaska	l	m	D?	C,R,S	F
Prince William S.	l	m	D?	C,R,S	F
Cook Inlet	s	l	D	C,R,S	F
Northern sculptured shrimp (*S. salebrosa*)					
W Bering Sea	s	s	?	C	U
E Kamtchatka	m	m	?	C	U
Uneven sculptured shrimp					
W Bering Sea	s	s	?	C	U
E Kamtchatka	m	m	?	C	U
Spiny Lobsters					
California spiny lobster (*Panulirus interruptus*) Stock ?					
S Califonia	s	s	?	C	F
Hawaii	m	m	P	C	F
Japanese spiny lobster Stock ?					
SE Japan					
Inland sea (*P. japonicus*)					
Mantis Shrimps Stocks ?					
Chinese mantis shrimp (*O. oratoria*)					
Bohai Sea	l	l	P	C	F

PLATE 1

Portunus trituberculatus

Chionoecetes opilio

Chionoecetes bairdi

Cancer magister

Chionoecetes japonicus

PLATE 2

Paralithodes brevipes

Paralithodes camtschaticus

Paralithodes platypus

Lithodes aequispina

PLATE 3

Acetes chinensis

Acetes japonicus

Fenneropenaeus chinensis

Marsupenaeus japonicus

Metapenaeus joyneri

Trachysalambria curvirostris

PLATE 4

Pandalopsis dispar

Pandalus borealis/eos

Pandalus hypsinotus

Pandalus goniurus

Pandalus paltyceros

Pandalus danae

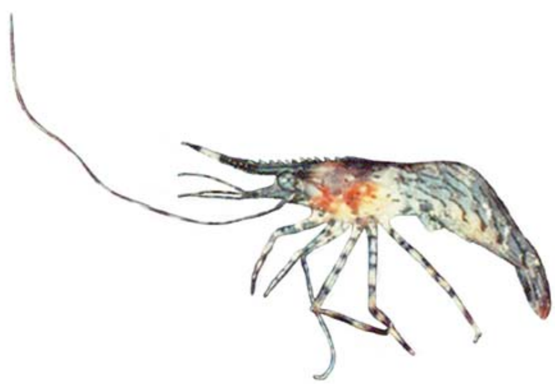
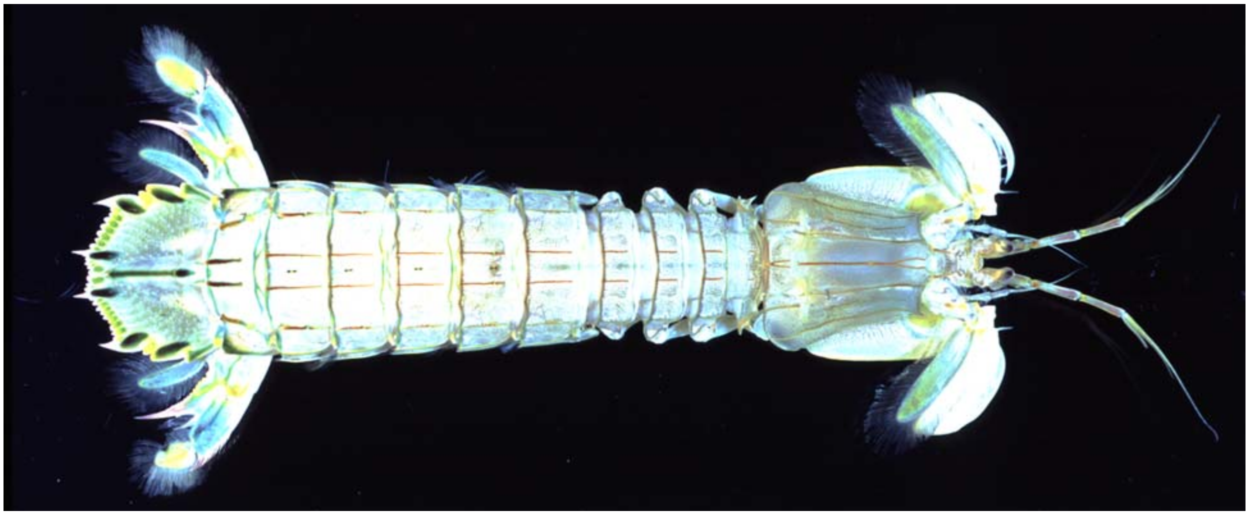


PLATE 5

Oratosquilla oratoria



Panulirus japonicus