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.

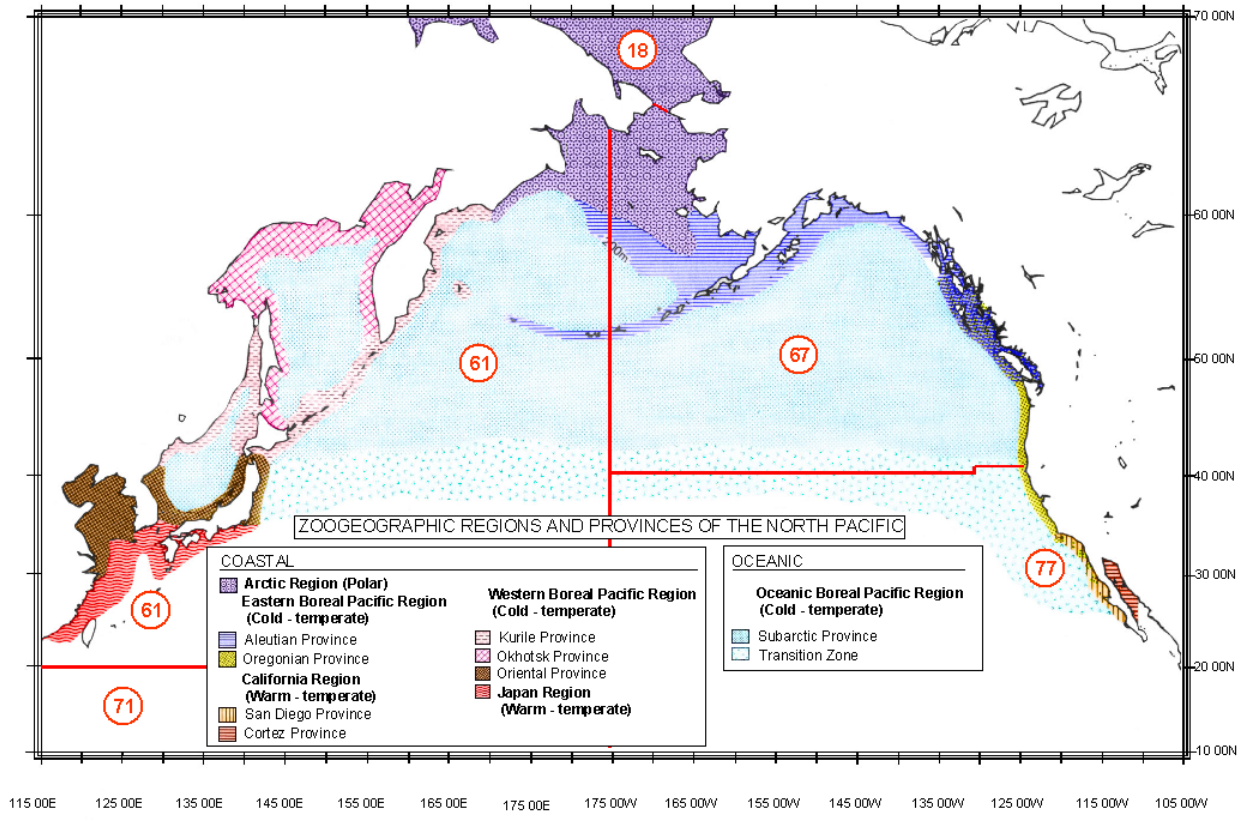

Fig. 1 Zoogeographic regions and provinces and FAO boundaries of the North Pacific. The PICES Region considered in this report is the East China Sea and the waters north of 24° in the North Pacific proper (redrawn from Allen and Smith (1988) and FAO).

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°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.

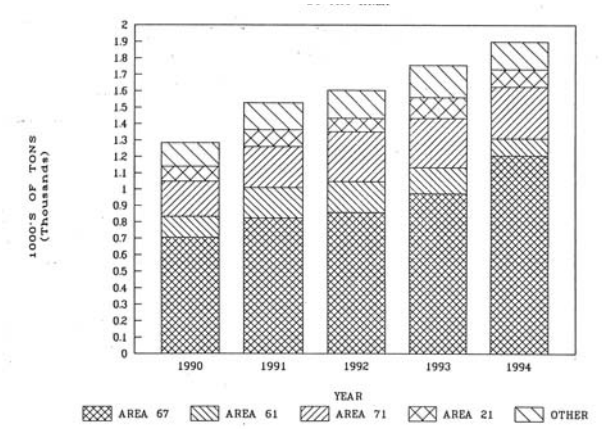

Fig. 2 World crab landings for selected FAO areas from 1990-1994.

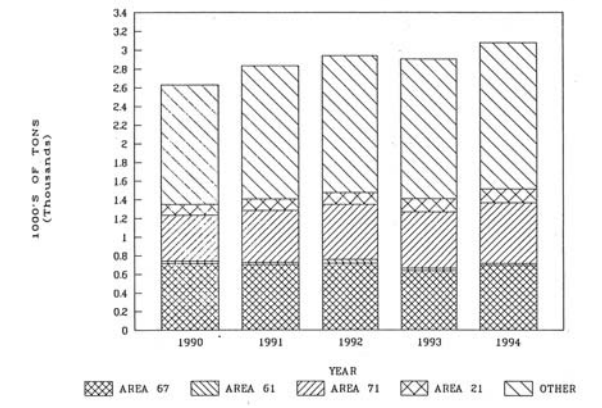

Fig. 3 World shrimp landings for selected FAO areas from 1990-1994

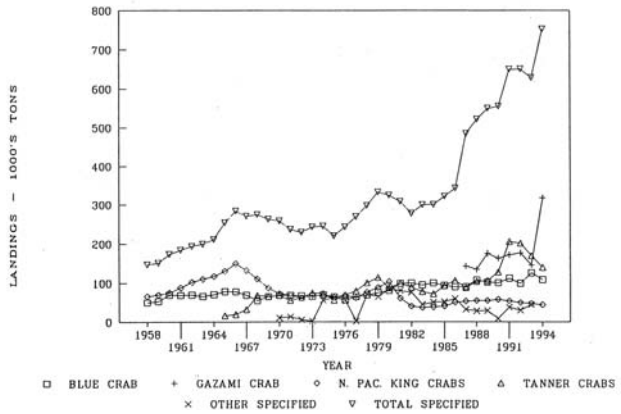

Fig. 4 FAO crab landings for selected species areas from 1958-1994.

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).