# 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).

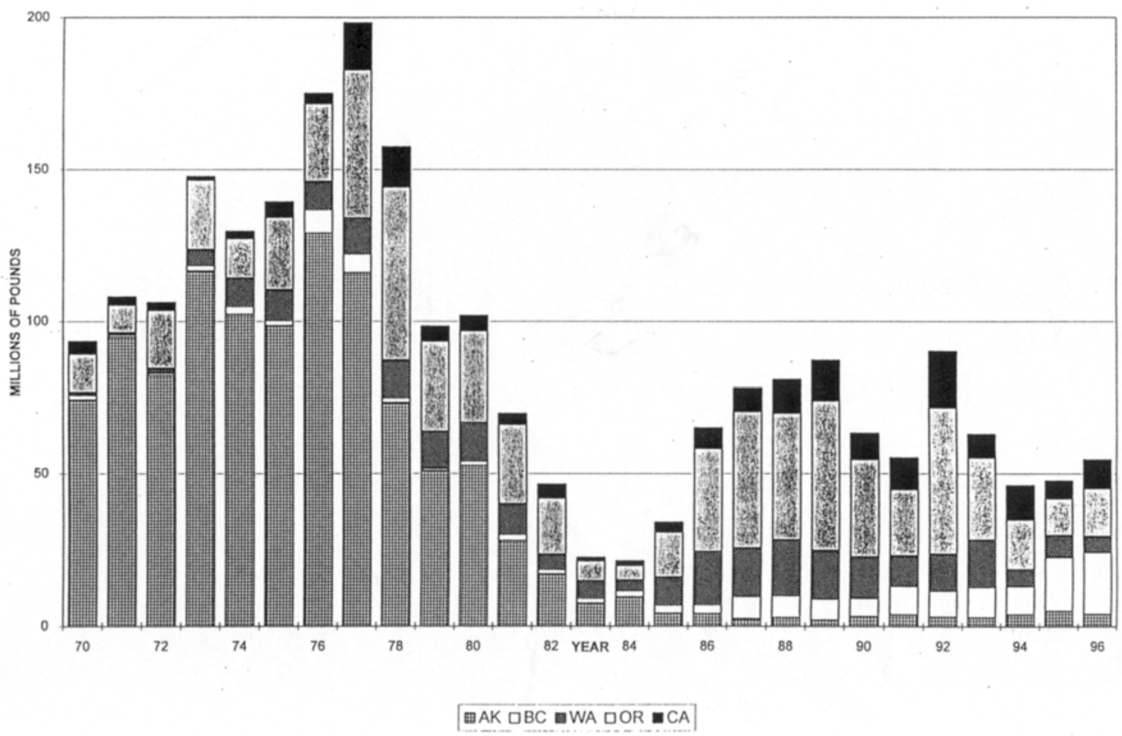


**Fig. 28** Pandalid shrimp landings from California to Alaska, 1970-1996.

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).