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The Bathymetric Distribution of *Chionoecetes opilio* and *C. japonicus* (Majidae; Brachyura) in the Western and Northern Areas of the Sea of Japan*

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Abstract

Queen crabs (*Chionoecetes opilio* and *C. japonicus*) were sampled by trawling and dredging in the western and northern areas of the Sea of Japan to document their bathymetric distributions. A bathymetric separation between these two species was apparent in the western area; *C. opilio* occupied waters shallower than 520 m, and partly overlapping at this depth, *C. japonicus* occurred down to 1200 m deep. In the northern area, no *C. opilio* were collected. *C. japonicus* were abundant below 1200 m and found up to 2300 m deep. As the factors affecting the bathymetric distributions of the two queen crabs, the importance of two different water masses in the Sea of Japan as well as bottom topography were suggested. Based on the results of their size distribution and sex ratio, biological factors such as migration related to reproduction and growth were also discussed.

Key words : *Chionoecetes opilio*, *C. japonicus*, bathymetric distribution, the Sea of Japan

Introduction

Two queen crabs (*Chionoecetes opilio* O. FABRICIUS and *C. japonicus* RATHBUN) inhabit the sea surrounding Japan, and are important to the fishing industry in the Sea of Japan. They occupy different bathymetric zones; *C. opilio* is commercially fished in shallow waters of less than 350 m by Danish seiners, and *C. japonicus* is caught in deep waters of more than 800 m using crab pots (SINODA 1982).

Great effort has been made to clarify the distribution of these crabs in the Sea of Japan for economical reasons. The distribution of *C. opilio* at stages from pelagic larvae to settled adults has been previously reported (e.g. ITO 1968, 1984; FUKATAKI 1969; ITO and IKEHARA 1971; KOBAYASHI and YAMAGUCHI 1978; KON 1980; WADA *et al*. 1983; YAMASAKI and KUWAHARA 1991, 1992). However, the knowledge accumulated so far is not sufficient to understand the differences in the general distribution patterns of these two crabs, partly because most studies have been made in some restricted areas and/or have dealt with only one of the species. In particular, because it lives in deeper areas than *C. opilio*, only limited

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information for *C. japonicus* has hitherto been available, due to the difficulty in quantitative and seasonal samplings.

As *C. japonicus* is one of the crabs that lives on the deepest sea floors of the world, interest in research arises not only from the fisheries but also from the ecological point of view. Not many reports have dealt with the bathymetric distribution of brachyuran crabs, even as a part of epibenthic macrofauna in deep sea floors (e.g. ROWE and MENZIES 1969; HAEDRICH *et al*. 1975; WENNER and BOESCH 1979).

In this study, sampling by trawling or dredging was conducted over a wide bathymetric range, from about 60 to 2300 m deep in the western and northern areas of the Sea of Japan. The present study aimed to add to the information available on both the bathymetric and geographical distribution of the two species. It was the first attempt to catch crabs by trawling up to about 2300 m deep along the Japanese coast in the Sea of Japan.

Materials and Methods

1 Study areas and sample collection

The study areas are shown in Fig. 1. Samplings were conducted during two cruises of the R.V. *Tansei-Maru* of the Ocean Research Institute, University of Tokyo; in the western area during the KT-90-15 cruise on 30-31 October 1990, and in the northern area during the KT-92-12 cruise from 30 August to 3 September 1992.

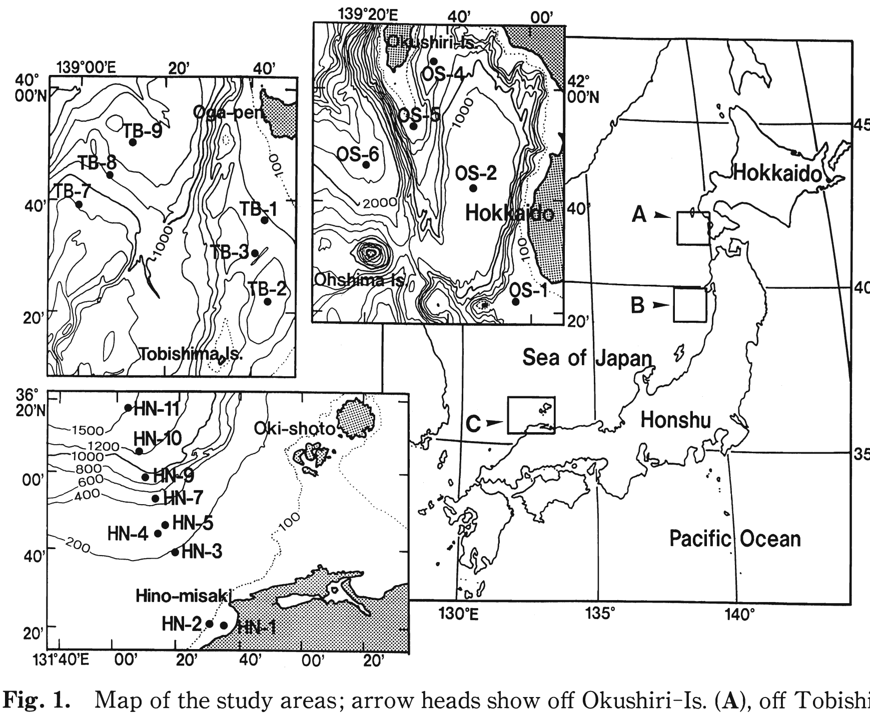

Fig. 1. Map of the study areas; arrow heads show off Okushiri-Is. (**A**), off Tobishima Is. (**B**) in the northern part, and off Hino-misaki (**C**) in the western part of the Sea of Japan.

Table 1. List of trawling and dredging stations in the R.V. *Tansei-Maru* cruises, KT-90-15 and KT-92-12.

Station	Area	Date	Time		Position		Depth (m)		Gear*)
			from	to	from	to	Min.	Max.	
HN-01	Off Hino-misaki	Oct. 30, 1990	7 : 09	7 : 17	35°19.93′N 132°34.84′E	35°20.01′N 132°35.02′E	58	59	DR
HN-02	Off Hino-misaki	Oct. 30, 1990	8 : 36	8 : 44	35°20.40′N 132°31.03′E	35°19.96′N 132°30.64′E	100	102	DR
HN-03	Off Hino-misaki	Oct. 30, 1990	13 : 23	13 : 40	35°39.14′N 132°19.52′E	35°39.18′N 132°19.37′E	194	195	DR
HN-04	Off Hino-misaki	Oct. 30, 1990	14 : 41	15 : 08	35°44.46′N 132°14.59′E	35°44.67′N 132°14.12′E	255	259	TR
HN-05	Off Hino-misaki	Oct. 30, 1990	16 : 52	17 : 21	35°46.72′N 132°15.42′E	35°46.58′N 132°16.28′E	278	284	TR
HN-07	Off Hino-misaki	Oct. 30, 1990	18 : 35	19 : 07	35°52.99′N 132°12.32′E	35°53.16′N 132°12.99′E	511	518	TR
HN-09	Off Hino-misaki	Oct. 30, 1990	22 : 20	22 : 56	35°58.63′N 132°09.63′E	35°58.19′N 132°10.28′E	997	976	TR
HN-11	Off Hino-misaki	Oct. 31, 1990	10 : 18	11 : 00	36°17.00′N 132°04.89′E	36°17.30′N 132°04.72′E	1518	1525	TR
HN-10	Off Hino-misaki	Oct. 31, 1990	15 : 07	15 : 52	36°06.43′N 132°08.12′E	36°05.39′N 132°07.83′E	1195	1233	TR
OS-01	Off Okushiri-Is.	Aug. 30, 1992	2 : 03	2 : 15	41°22.21′N 139°55.37′E	41°22.29′N 139°55.55′E	122	123	DR
OS-02	Off Okushiri-Is.	Aug. 30, 1992	5 : 00	6 : 05	41°40.49′N 139°45.59′E	41°41.89′N 139°46.59′E	1425	1427	TR
OS-04	Off Okushiri-Is.	Aug. 30, 1992	11 : 35	12 : 29	42°05.63′N 139°36.38′E	42°04.57′N 139°36.43′E	650	660	TR
OS-05	Off Okushiri-Is.	Aug. 30, 1992	14 : 16	14 : 25	41°52.90′N 139°31.80′E	41°52.86′N 139°31.67′E	132	132	DR
OS-06	Off Okushiri-Is.	Aug. 30, 1992	20 : 08	21 : 33	41°46.20′N 139°20.98′E	41°45.55′N 139°20.00′E	2309	2324	TR
TB-01	Off Tobishima Is.	Sep. 2, 1992	15 : 19	15 : 25	39°36.75′N 139°43.00′E	39°36.75′N 139°43.15′E	240	246	DR
TB-03	Off Tobishima Is.	Sep. 2, 1992	17 : 21	17 : 41	39°30.67′N 139°41.13′E	39°30.50′N 139°41.37′E	368	369	TR
TB-02	Off Tobishima Is.	Sep. 2, 1992	18 : 59	19 : 29	39°22.44′N 139°44.33′E	39°22.09′N 139°44.57′E	445	445	TR
TB-07	Off Tobishima Is.	Sep. 3, 1992	14 : 01	14 : 37	39°39.15′N 138°59.65′E	39°39.43′N 138°59.47′E	817	823	TR
TB-08	Off Tobishima Is.	Sep. 3, 1992	16 : 27	17 : 05	39°43.90′N 139°07.39′E	39°44.35′N 139°07.30′E	1253	1292	TR
TB-09	Off Tobishima Is.	Sep. 3, 1992	19 : 39	20 : 23	39°50.44′N 139°12.10′E	39°50.42′N 139°11.16′E	1480	1489	TR

*) Two types of gear were used; an Ocean Reserach Institute, University of Tokyo type biological dredge with 1 m span (DR), and an Oregon State University type beam trawl with 3 m span (TR).

In collecting the crabs, two types of gear were used: an Oregon State University type beam trawl with a 3 m span and an Ocean Research Institute, University of Tokyo type biological dredge with a 1 m span. Dredging was conducted at stations shallower than 250 m. The gears used at each station as well as other information are shown in Table 1.

In the western area of the Sea of Japan, the continental slope extends gently. A transect was roughly arranged with a range from about 60 m deep on the continental shelf to about 1500 m on the continental slope off Hino-misaki, Shimane Prefecture, and 9 stations were established. Trawling was tried from HN-4 to HN-11, but the sampling met failure at HN-11 because the main wire was accidentally cut off. Dredging was carried out at HN-1 to HN-3. CTD measurements were conducted at HN-3 and HN-11 (Table 2).

In contrast to the western area, the topography is complicated in the northern area of the Sea of Japan. Therefore, the sampling stations were scattered to sample at various depths instead of arranged on a transect. There are two localities in this area; one is off Okushiri-Is. and the other off Tobishima Is. In the Okushiri area, five stations were established; OS-1, OS-4 and OS-5 were placed on the continental shelf, OS-2 was in the Okushiri Basin, and OS-6 on the continental slope. In the Tobishima area, three stations (TB-1, TB-2 and TB-3) were placed in a shallow zone without steep slope, and the other three stations (TB-7, TB-8 and TB-9) were roughly arranged in a transect along the continental slope. CTD measurement was conducted at OS-6 in this area (Table 2).

Table 2. List of CTD stations in the R.V. *Tansei-Maru* cruises, KT-90-15 and KT-92-12.

Station	Area	Date	Time	Position		Depth (m)
HN-03	Off Hino-misaki	Oct. 30, 1990	12 : 58	35°39.10′N	132°19.30′E	194
HN-11	Off Hino-misaki	Oct. 31, 1990	08 : 01	36°16.78′N	132°05.70′E	1501
OS-06	Off Okushiri-Is.	Aug. 30, 1992	16 : 12	41°45.71′N	139°20.82′E	2304

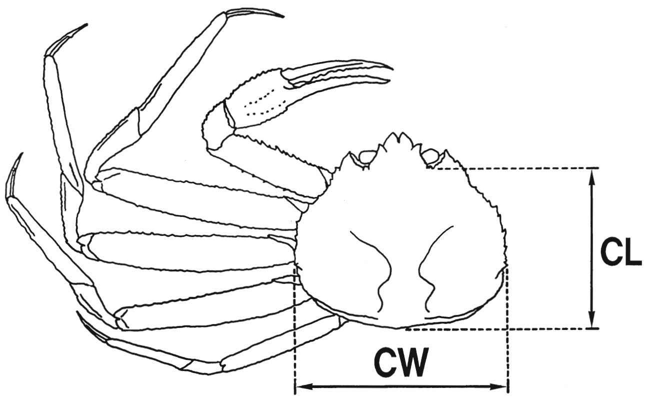

Fig. 2. Measurements of crabs used in the text; carapace length (CL) and carapace width (CW).

2 Sample treatment

Carapace length (CL) measurements were made using a vernier caliper on board (Fig. 2). The crabs obtained on the KT-90-15 cruise were checked for their sex by observing the shape of the abdomen and pleopods. Then, females were classified into ovigerous and non-ovigerous individuals. On the latter cruise, KT-92-12, non-ovigerous females were further divided into immature and non-ovigerous mature individuals because the abdomens of female *C. opilio* and *C. japonicus* become relatively wider when immature crabs molt to mature (ITO 1956, 1976)

Many small individuals whose sex could not be determined only by a brief observation on board were obtained in the northern area. These small crabs were fixed in neutralized 10% formalin seawater and taken to the laboratory for a detailed examination under microscope. Despite these detailed examination, very small specimens whose sex could not determined were regarded as 'juvenile'.

No crabs were caught by dredge sampling. Therefore, the density was only calculated for trawl sampling from the width of the trawl (3 m) and the distance it traveled in order to compare crab abundance among sampling stations. Because the trawls were, as a rule, operated for 20-30 minutes, during which they traveled the distance ranging from 445 to 2941 m with a mean of about 1300 m, the density was expressed by the number of individuals per 3000 m² (3×1000 m) for the convenience.

Results

1 Physical environment

Figure 3 shows the vertical profiles of temperature, salinity and dissolved oxygen content (DO) by CTD at the three stations; HN-3 and HN-11 in the western area and OS-6 in the northern area. At HN-11, a rapid decrease in temperature with depth was recognized above 200 m deep. Below this the temperature gradually declined to a value of

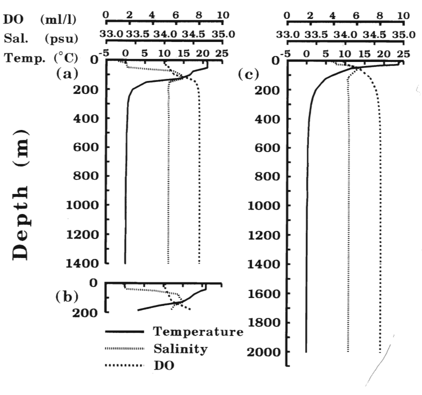

Fig. 3. Vertical profiles of temperature, salinity and DO derived from CTD measurement at HN-11 (a), HN-3 (b) and OS-6 (c).

about 0.15°C (Fig. 3a). The salinity profile showed a steep increase until a depth of about 125 m, and then a steep decrease with depths between 125 and 200 m deep. Salinity reached a constant level of about 34.068–34.078 psu at 250 m deep. The DO steeply increased with depth until 200 m deep and slowly reached a constant level of about 8.01–8.06 ml/l below 400 m. Each vertical profile pattern of temperature, salinity and DO at HN-3 was similar to that at HN-11 above 200 m, although temperature was slightly higher at HN-3 than HN-11 (Fig. 3b). At OS-6 in the northern area, the temperature profile showed a steep decrease up to a depth of about 200 m, and then became gentle. The temperature measured 0.167–0.177°C below 1300 m (Fig. 3c). The salinity near the surface was much higher than that at HN-11. It increased to 34.215 psu at 50 m deep and then decreased to 34.033 at 125 m. Below this depth it showed little change and measured a constant level of 34.061–34.064 psu. The DO steeply increased until 250 m and gradually approached 8.00–8.06 ml/l at depths below 500 m.

The overall trends of the vertical profiles of temperature, salinity and DO of HN-11 in the western area and OS-6 in the northern area were quite similar. However the depth at which the rapid change of the three measurements occurred was shallower at OS-6 than HN-11. On the other hand, each of the three measurements at HN-11 reached to a constant level at about 200 m deep, which was shallower than the depths at OS-6. Below these depths, all three measurements were nearly equal at both HN-11 and OS-6.

2 Distribution of *C. opilio* and *C. japonicus*

(1) Western Area

This is the only area in which both *C. opilio* and *C. japonicus* were obtained. *C. opilio* were taken at the three stations from about 250 m to about 520 m deep (Fig. 4). The highest density of 15.9 ind./3000 m^2 was observed at HN-5 at a depth of 280 m and the next came from HN-7 with a density of 11.4. On the other hand, *C. japonicus* were collected at HN-7, HN-9 and HN-10, with the most coming from the latter two stations, the densities of which were 53.4 and 39.0, respectively. Only one specimen (0.9 at density) was obtained from HN-7, where *C. opilio* also occurred up to this depth.

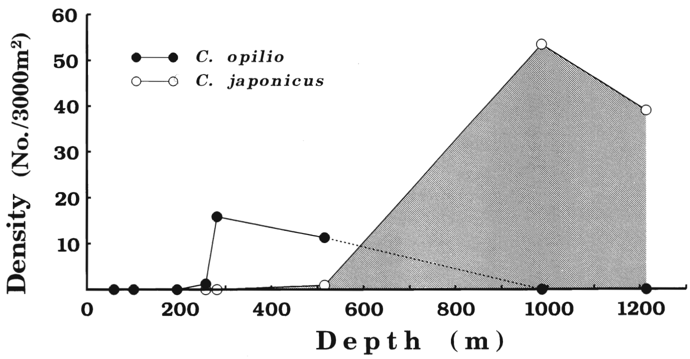

Fig. 4. Relationship between density and depth for *C. opilio* and *C. japonicus* in the western area.

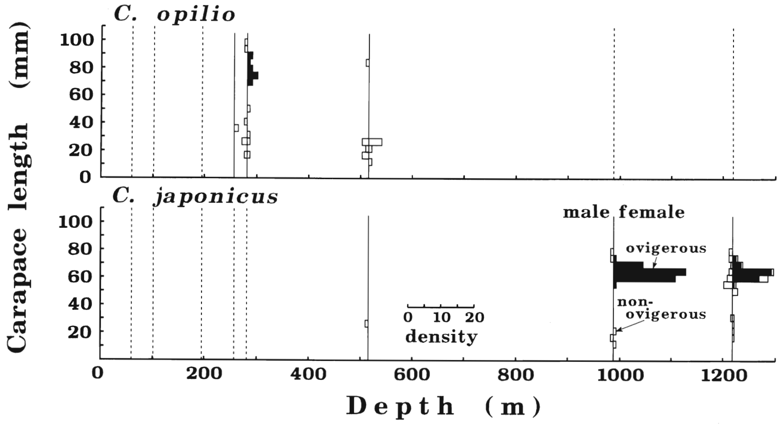

Fig. 5. The size distribution of *C. opilio* and *C. japonicus* at each sampling station in the western area. Vertical broken lines indicate station depths at which no crabs were collected despite sampling hawls.

Figure 5 shows the size distribution of these two crabs at each station arranged with increasing depths. All the female *C. opilio* larger than 60 mm CL were ovigerous. They occurred only at HN-5 with a density of 8.3, where the total density was the highest described previously. In contrast, specimens smaller than 60 mm CL were obtained from all stations where *C. opilio* were collected.

Large female *C. japonicus* of 60-70 mm CL dominated those of any other size groups in this area. Males larger than 55 mm CL were collected mainly at the deepest station HN-10 and the densities of females larger than 50 mm CL were comparatively high at both HN-9 and HN-10. The sex ratios were more biased to female at HN-9 (1 : 22.7) than HN-10 (1 : 4.8). Like *C. opilio*, *C. japonicus* smaller than 40 mm CL were found in all stations where this species was obtained in this study.

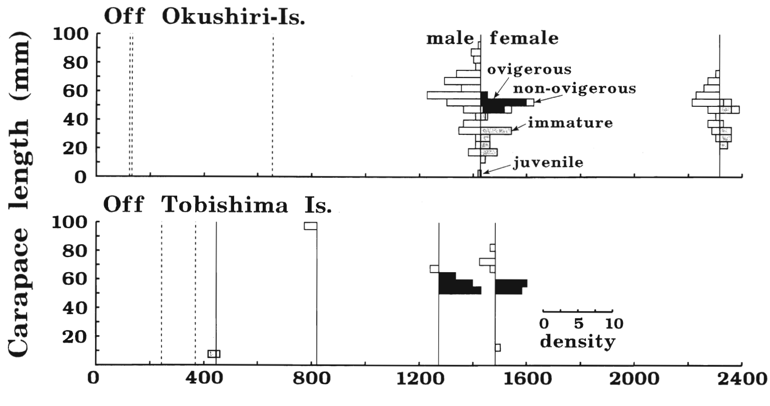

Fig. 6. The size distribution of *C. japonicus* at each sampling station off Okushiri-Is. and off Tobishima Is. in the northern area. Vertical broken lines indicate station depths at which no crabs were collected despite sampling hawls.

(2) Northern Area

No *C. opilio* were obtained at stations where samplings were undertaken in the northern area during the cruise of KT-92-12. Fig. 6 shows the bathymetric size distribution of *C. japonicus* in the two localities. This species occurred in the wide bathymetric range of about 450-2300 m deep, and most of the crabs were obtained from deeper than 1200 m. The maximum densities off Okushiri-Is. and Tobishima Is. were 62.6 at OS-2 of 1430 m and 14.2 at TB-8 of 1270 m deep, respectively.

The density and size range of crabs off Okushiri-Is. had a tendency to be much higher and wider than off Tobishima Is. Non-ovigerous and immature females were collected at both OS-2 and OS-6 but all of the 33 ovigerous females were obtained at OS-2 of 1420 m. The crabs obtained from OS-2 covered the widest size range among the stations described in this study; including the smallest (CL 3.2 mm) of all specimens collected in the field so far. The details of this will be reported elsewhere.

At the other locality, off Tobishima Is., all mature females were ovigerous and captured only at the two stations, TB-8 at 1270 m and TB-9 at 1490 m deep. Most of the crabs obtained in this locality were larger than 50 mm CL and there were only three small crabs.

Putting the northern and western areas together, most specimens were taken from stations deeper than 950 m. The density off Tobishima Is. was lower than that off Okushiri-Is., but the density of the latter was quite similar to that in the western area. The density of ovigerous females and the proportion of females to males were much lower in the northern area than the western area. The size of mature female *C. japonicus* was also different between two areas; all ovigerous females showed a size distribution with a single mode of about 67.5 mm CL in the western area, and 52.5 and 55 mm CL off Okushiri-Is. and off Tobishima Is. in the northern area, respectively.

Discussion

According to a review of the vertical structure of water mass of the Sea of Japan by NAGANUMA (1985), the warm Tsushima Current flows into the Sea of Japan, but the depth to which it extends is 200 to 300 m, below which there exists relatively uniform water called 'Proper Water Mass of the Japan Sea'. The CTD measurements in this study clearly showed the existence of these two water masses, and their borders were well indicated by the thermoclines at the depths of 200 and 250 m in the western and northern areas, respectively. The physical environment of the bottom was not measured at each station but it could be represented by the values of CTD measurements at corresponding depths on the vertical profiles, partly because measurements made at shallow and deep stations in the same area did not show much difference. Therefore, samplings in this study covered a wide depth range over these two water masses.

C. opilio lived in a bathymetric range of about 200-600 m deep at temperatures of 0.3 to 0.9°C, and its range partly overlapped with *C. japonicus* at about 500-600 m deep (ca. 0.3°C) in the western area of the Sea of Japan in this study. The range of water temperature within which *C. japonicus* was captured was between about 0.15 and 0.5°C with an abundant collection between 0.15 and 0.18°C, and the crabs were obtained up to depths of 2320 m by trawling. From the results obtained, it seems likely that *C. opilio* occurs in the uppermost part of the 'Proper Water Mass' where the Tsushima Warm Current more or less affects its physical condition and that *C. japonicus* occupies the lower part where the environmental change is hardly detectable. This distributional segregation of the two species was also reported by KOBAYASHI *et al.* (1963). Furthermore, in reporting on the distribution patterns of epibenthic populations along the continental slope, HAEDRICH *et al.* (1975) and WENNER and BOESCH (1979) found faunal boundaries and suggested the importance of temperature, even with slight differences.

For the bathymetric distribution of *C. opilio*, KOBAYASHI (1989), studying near Okishoto, which is close to the present study area, reported on a similar depth range of about 200–600 m. *C. opilio* has been fished widely in the North Pacific and the northwest Atlantic, but the bathymetric ranges of fishing grounds are more or less different. ELNER (1982) reported that the commercial ground of *C. opilio* lies between 50 and 400 m deep in the northwest Atlantic, and SAINT-MARIE *et al.* (1988) found a dense population on quite shallow bottoms of 2.5–10 m deep in the Gulf of St. Lawrence. SLIZKIN (1989) also reported that the bathymetric distribution range of this crab is 15–630 m deep and the temperature of their habitat falls within the range of −1.8 to 7.2°C in the north Pacific. This range is wider than that of 0.3 to 0.9°C obtained in this study. For *C. japonicus*, available information on its distribution in relation to the temperature has been very limited, because (1) the fishing of this crab began in 1959 by crab pots, much later than that of *C. opilio* (SINODA 1982), (2) this crab dwells in deep waters, which makes regular samplings very difficult, and (3) although some taxonomic problems have to be solved (DERJUGIN and KOBJAKOWA 1935; NISHIMURA 1938; YAMAMOTO 1950), *C. japonicus*, in a strict sense, is only found in the Sea of Japan and the Pacific Ocean along Japan (SAKAI 1976; MIYAKE 1983).

NISHIMURA (1966) divided demersal fish communities based on the bathymetric distributions of some representatives examined up to about 500 m deep: 'okaba communities I–VI' and 'taraba communities I–III' in order from shallow to deep locations. He applied this to benthic invertebrates and included *C. opilio* and *C. japonicus* in the 'taraba community II' found at 200–300 m and the 'taraba community III' found at depths of more than 350–400 m, respectively. OGATA *et al.* (1973) examined deep sea fauna more minutely by a series of trawl experiments up to 1200 m deep around the Yamato Bank and the North Yamato Bank in the central part of the Sea of Japan. According to their results, *C. opilio* dominates in the community at depths of about 250–400 m, and *C. japonicus* in the deepest community extending more than 800 m deep. The present study supports their results. They also mentioned that species like *C: japonicus* living in the deep waters of the Sea of Japan, is eurybathy, or a species that inhabits a wide depth range. Its deepest catch recorded in the Sea of Japan is 2630 m by crab pot (JAPAN SEA NATL. FISH. RES. INST. unpublished data). The deepest sampling operation in this study was carried out at 2320 m, where crabs were still abundant. This suggests that *C. japonicus* occurs beyond these depths. Samplings at such a great depth are needed to obtain further information on its distribution.

Among brachyuran crabs other than *Chionoecetes* living in deep water below the continental shelf, only the bathymetric distribution of the genus *Geryon* has been studied. *G. qyunquedens* occurs between 275 and 1280 m deep in the western North Atlantic (SCHROEDER 1959) and between 269 and 1670 m in the Middle Atlantic Bight (WENNER and BOESCH 1979). Another species of this genus, *G. maritae* was reported as having been obtained at depths between 400 and 900 m off South West Africa (MELVILLE-SMITH 1985). Compared to the depth ranges of these crabs, *C. japonicus* could be regarded as one of the brachyuran crabs living in the deepest parts of the world.

KON (1980) studied the size composition of *C. opilio* according to depth for the population in Wakasa Bay, central part of the Sea of Japan. He suggested that maturing males and females participate in copulation at 225 m, and large males and multiparous females aggregate at depths below 275 and about 250 m deep, respectively. The results of this study revealed that ovigerous females (including all multiparous specimens collected) occurred in concentration at 280 m, which was deeper than the 250 m reported by KON (1980) and 240 m by YAMASAKI *et al*. (1985). KON (1980) also reported that the settlement occurs at about 300 to 350 m deep, but the collection of young crabs from 250 to 520 m deep in this study suggests a wider depth range of the settlement than he mentioned. In order to clarify the cause of these differences found in the results, the more information on this aspect should be accumulated.

Populations of *C. opilio* in shallow waters show a spring breeding migration in Newfoundland (HOOPER 1986) and the northwestern Gulf of St. Lawrence (SAINT-MARIE and HAZEL 1992). PEREYRA (1966) reported that mature males and females of *C. tanneri*, a deep water species, occur together during mating and copulation seasons, but separately during non-mating seasons. Ovigerous females of *C. opilio* collected at only one station may indicate this migration coupled with their reproductive activity. SAINT-MARIE and HAZEL (1992) also reported the possibility of molting migration towards shallow waters where they exclusively found exuviae. Thus, migration has to be taken into account to understand the bathymetric distribution of these crabs in detail.

Unlike the species mentioned above, very little information on migration is available for *C. japonicus*. The high proportion of females against males observed in this study may be related to their mating. In order to clarify the migration pattern, if any, seasonal samplings over a wide bathymetric range are needed.

Because females of *C. japonicus* do not molt after attaining their maturity, mature females of 67.5 mm CL in the western area and 52.5–55 mm in the northern area indicate the difference of size at which they mature. The mature sizes were reported to be 58 to 64 mm in carapace width (CW) in the central area of the Sea of Japan (ITO 1976) and about 75 mm CW off the southwestern coast of Hokkaido, Japan (WATANABE and SUZUUCHI 1983). These two studies suggested that the mature size is larger in the northern area than the central area, but the opposite was found in this study. FUJITA *et al*. (1988) suggested the importance of water temperature for the mature size of male *C. opilio* and *C. bairdi* after finding a positive correlation between the water temperature and their mature size. Because *C. japonicus* lives in the 'Proper Water Mass', in which the water temperature hardly changes, difference in temperature does not explain this phenomenon. Other factors have to be taken into account.

The reason why no *C. opilio* were caught in the northern area in this study remains unclear. A probable explanation for this is the topographical differences between two areas; the isobaths are relatively complicated in the northern area where the shelf is not well developed and the continental slope declines rapidly down to 1200 m off Okushiri-Is. and 800 m off Tobishima Is. More detailed studies should be planned for the distribution of queen crabs in relation to the bottom topography.

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日本海西部及び北部海域におけるズワイガニとベニズワイの深度分布

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日本海西部及び北部海域において，トロールとドレッジによりズワイガニとベニズワイの深度分布を調査した．西部では，前種は後種に比べ生息水深が浅く，水深約520mで分布の重複がみられた．北部ではベニズワイのみが採集され，水深2320mまでの分布を確認した．両種の分布に対する水塊の性質や海底地形の重要性を論議した．さらに，各々の種の甲幅組成と性比から，深度分布への繁殖や成長に伴う移動などの生物的要因の関与が示唆された．