Fisheries biology of *Parapenaeus* species (Penaeidae) in Kagoshima Bay, southern Japan

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ABSTRACT

Parapenaeus Smith, 1885 are commercially important penaeid shrimp and are found in relatively deep waters. *Parapenaeus fissuroides* Crosnier, 1985 and *Parapenaeus lanceolatus* Kubo, 1949 are two of the dominant species in the benthic community of Kagoshima Bay, southern Japan. These shrimps are emergent fisheries resources in the bay. The present study aims to describe fisheries biology including reproduction, growth and spatiotemporal distribution of *P. fissuroides* and *P. lanceolatus* in Kagoshima Bay.

Monthly samplings were conducted at few stations and seasonal samplings were carried out at all eight stations established in Kagoshima Bay, southern Japan during 2011-2016. The samplings were conducted on board *Nansei Maru* (175 t), a training vessel of the Faculty of Fisheries, Kagoshima University, using a simple trawl net attached with submersible data loggers. In addition, previously collected samples during 2003-2010 were also used in the present study. The effective tow durations were adjusted to preset tow durations according to Fulanda and Ohtomi (2011). The catch in numbers and weight per haul were standardized to preset tow durations. All specimens of both species were sexed, and carapace length (CL) and body weight (BW) were measured. Female specimens of both species were dissected and whole gonads were removed and weighted. The gonadosomatic index (GSI) was calculated for each female: GSI (%) = 100 × [ovarian weight (g) / body weight (g)]. The ovaries of female individuals of *P. fissuroides* and *P. lanceolatus* were examined by histological observations to estimate the degree of ovarian maturation. Ovarian maturity stages were classified into four categories as follows: Stage I, undeveloped; Stage II, developing; Stage III, nearly ripe; and Stage IV, ripe. For growth analysis of these shrimps, monthly length-frequency distributions were constructed for both sexes using 1 mm intervals of CL. A computer analysis (Microsoft

Excel-add-in-solver) based on Hasselblad's maximum-likelihood method (Hasselblad, 1966) was used to fit a series of component normal distributions to the frequency distribution of each sample by sex. Each component normal distribution represents an age group in the population. CL-BW relationship was also examined for both sexes of both species.

P. fissuroides is a multiple spawner, as the ovaries of this species contained different developmental stages of oocytes. The mature females were defined as those having nearly ripe or ripe ovaries containing cortical granules in the peripheral region of the oocytes. GSI (%) significantly increased with the progress of ovarian maturation and most of the females with GSI ≥ 6% were mature. The size at sexual maturity of female *P. fissuroides* was estimated to be 23 mm in carapace length. The spawning season of this species was estimated to last from July to February with a peak during October and November.

Carapace length (CL) of *P. fissuroides* ranged from 7.7 - 27.1 mm in males and 6.4 - 36.1 mm in females. Both males and females were recruited during late autumn and winter. Growth was best described by Pauly and Gaschütz growth equation as $L_t = 25.6 [1 - \exp \{- 1.011 (t/12 + 0.539) - (0.641/2\pi) \sin (2\pi (t/12 - 0.577))\}]$ for males and $L_t = 34.3 [1 - \exp \{- 0.941 (t/12 + 0.227) - (0.581/2\pi) \sin (2\pi (t/12 - 0.603))\}]$ for females. The monthly growth rate (%) of *P. fissuroides* was the highest during July to August (summer point) and the lowest during January to February (winter point). Females grew faster and reached larger sizes than males of the same age group. The longevity of *P. fissuroides* was estimated to be around 2 years for males and 2.5 years for females.

All the individuals of *P. lanceolatus* examined histologically showed an asynchronous type of ovary. Females with nearly ripe (Stage III) and ripe (Stage IV) ovaries considered as mature, where the cortical granules were found in the peripheral region of the oocytes. The majority of

the females with GSI ≥ 4% were found to be mature. The females with GSI ≥ 4% were, therefore, considered as a simple index of maturation. The size at sexual maturity of female *P. lanceolatus* was considered to be 22 mm in CL. The spawning season of *P. lanceolatus* extends from July to April and the main spawning season lasts from September and October.

Both male and female *P. lanceolatus* were first recruited in late autumn to winter (November to January) with modal size of around 10 mm in CL. The growth patterns of CL for both sexes of this species were well described by von Bertalanffy equation as $L_t = 27.8 [1 - \exp \{- 0.081 (t + 3.559)\}]$ for male, and $L_t = 33.8 [1 - \exp \{- 0.110 (t + 0.442)\}]$ for female. Females grew faster than males of the same age group. The longevity of male and female *P. lanceolatus* was estimated to be around 27 months.

The majority of *P. fissuroides* was distributed in the central area of Kagoshima Bay around 135 m water depth, while *P. lanceolatus* was distributed both in relatively shallower (around 130 m) and deeper (180-230 m) area of the central bay. From the analysis of distribution of *P. fissuroides* and *P. lanceolatus* with the progression of age revealed different distribution pattern in the bay. *P. fissuroides* recruited, spawned and spent their life mainly in the southern central area with around 130 m water depth. In case of *P. lanceolatus*, the spawning grounds for young individuals were almost entire central part while older individuals spawned only in deeper area of central bay.

P. fissuroides and *P. lanceolatus* are emergent fisheries resources in Kagoshima Bay. The present study reveals the different distribution pattern of these shrimps in the bay, and their spawning season, size at sexual maturity, growth pattern, and longevity which are indispensable information for appropriate stock management of these species.

1. GENERAL INTRODUCTION

The Penaeidae Rafinesque, 1815 is a family of natantian decapods that is diverse and distributed worldwide. There are 48 recognized genera in the family, including *Parapenaeus* Smith, 1885 (De Grave et al., 2009). Members of *Parapenaeus* have economic importance and are found in relatively deep waters, usually more than 100 m in depth, and are distributed in the Indo-West Pacific and the tropical Atlantic regions (Holthuis, 1980). At present, 15 extant species and 3 sub species are known in this genus (Pérez Farfante & Kensley, 1997; Crosnier, 2005). Some of these species are caught commercially in the Mediterranean, and seas around Taiwan, mainland China, Japan, and Korea (Holthuis, 1980; Liu & Zhong, 1988; Chan, 1998).

Parapenaeus fissuroides Crosnier, 1985 is widely distributed in the western Pacific, from tropical to temperate regions, and occurs in deep waters from India eastward to East China Sea (Liu & Zhong, 1988), and is one of the main species in the East China and Yellow seas (Li et al., 2009). This species has supported a strong fishery since late 1980's and made great contributions to local fisheries (Liu, 2013). *Parapenaeus lanceolatus* Kubo, 1949 is widely distributed in Indonesia to Japan and Australia (Holthuis, 1980). This shrimp is commercially important in the Inland Sea of Japan (Yasuda, 1957).

The present study was conducted in Kagoshima Bay, southern Japan in the eastern East China Sea (Fig. 1.1). Temporal and spatial distribution of *P. fissuroides* were previously studied in the East China Sea by Lu et al. (2007). They reported that this species was densely distributed to the east of 100 m isobath and had neither apparent over-winter migration nor obvious spawning migration. A study of the reproduction of the species in the East China Sea found a spawning period from July to October, with a peak in August (Song et al., 2002). Growth among individuals collected off the South China Sea coast of Fujian, mainland China was studied by Ye

et al. (2006). Sex ratio and insemination of *P. lanceolatus* was studied in Korean water (Choi et al., 2005). The reproductive biology of *Parapenaeus longirostris* Lucas, 1846 was studied in the south Ionian and south Adriatic seas (Kapiris et al., 2013), European Atlantic and Mediterranean waters (Sobrino et al., 2005), northeastern Mediterranean (Manasirli & Avsar, 2008), Sea of Marmara (Bayhan, 2005), and in the northern Tyrrhenian Sea (Mori et al., 2000), while larval stages were studied in the western Mediterranean (Torres et al., 2013), distribution and migration in the northwestern Pacific (Tanaka et al., 1985), and growth in the southern Tyrrhenian Sea (Arculeo et al., 2014). The reproductive biology of *Parapenaeus longipes* Alcock, 1905 was studied on the Arabian Sea coast of India (Chakraborti & Thumber, 2007).

Seven species of *Parapenaeus* have been reported from Japan: *P. fissurus* Spence Bate, 1881, *P. lanceolatus*, *P. longipes*, *P. murrayi* Ramadan, 1938, *P. sextuberculatus* Kubo, 1949, *P. investigatoris* Alcock and Anderson, 1899, and *P. fissuroides* (Hayashi, 1992; Miyake, 1998; Nagata & Ohtomi, 2005); four species have been recorded from Kagoshima Bay: *P. investigatoris*, *P. fissurus*, *P. fissuroides*, and *P. lanceolatus* (Fig. 1.2) (Nagata & Ohtomi, 2005). *P. fissuroides* and *P. lanceolatus* are two of the dominant species in the benthic community of the bay (Chapter 6, Fig. 6.4) and are emergent fisheries resources.

Insufficient studies on population biology of *Parapenaeus* species, including *P. fissuroides* and *P. lanceolatus* have been conducted around the world. The present study describes the spatiotemporal distribution, ovarian maturity stages, size at sexual maturity, spawning season, growth pattern and longevity of *P. fissuroides* and *P. lanceolatus* which are important information for appropriate stock management of these shrimps.
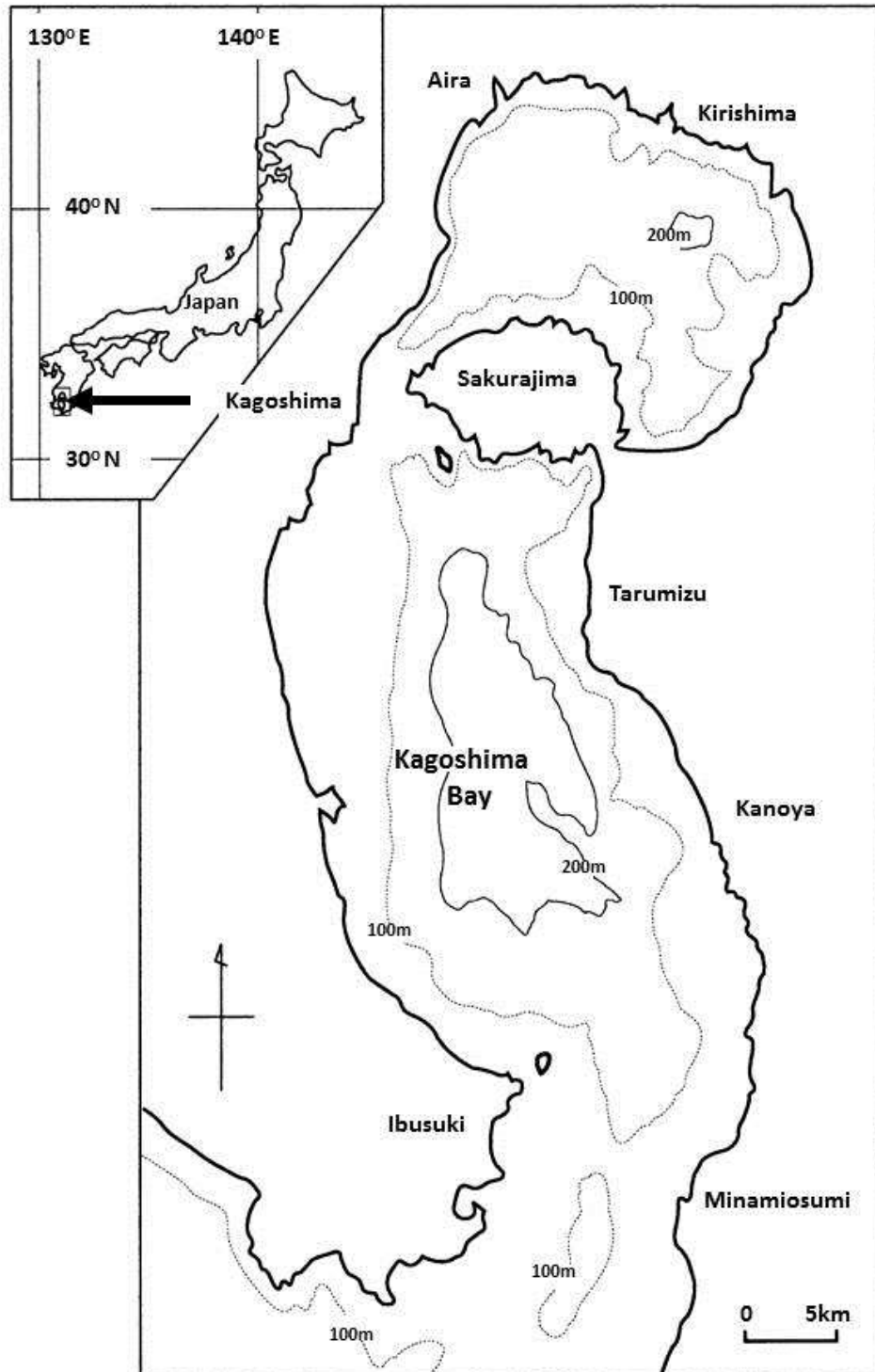
Fig. 1.1 Map of Kagoshima Bay, southern Japan.
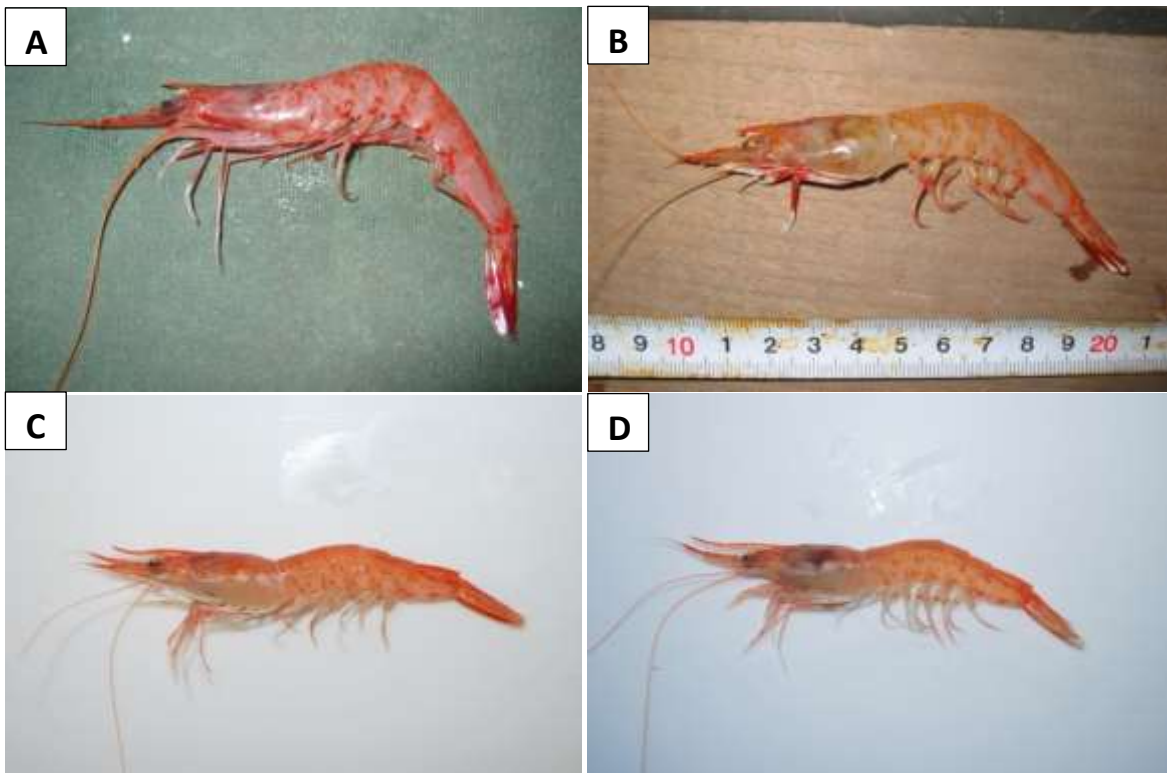
Fig. 1.2 *Parapenaeus* species recorded in Kagoshima Bay, southern Japan. A. *Parapenaeus investigatories* Alcock and Anderson, 1899; B. *Parapenaeus fissurus* Spence Bate, 1881; C. *Parapenaeus fissuroides* Crosnier, 1985; D. *Parapenaeus lanceolatus* Kubo, 1949. The specimens showed here are around 10 cm in body length.

2. REPRODUCTION OF *PARAPENAEUS FISSUROIDES*

2.1 INTRODUCTION

Reproduction is one of the important aspects of the ecology and life history of a species (Anger & Moreira, 1998). The reproductive process of shrimps includes attaining maturity, mating and spawning. Song et al. (2002) studied the reproductive biology of *Parapenaeus fissuroides* in the East China Sea near Taiwan. Very few detail studies on reproductive biology of this species have been reported in world waters. The present study describes the ovarian maturity stages, size at sexual maturity and spawning season of *P. fissuroides*.

2.2 MATERIALS AND METHODS

2.2.1 Sampling and Measurements

Samples of *P. fissuroides* were collected monthly during the daytime in Kagoshima Bay at depths of 127-134 m ($31^018^\prime6^{\prime\prime}$N and $130^039^\prime0^{\prime\prime}$E) from April 2003 to March 2005 (Period 1) and December 2011 to November 2013 (Period 2). Sampling was conducted on board *Nansei Maru* (175t), a training vessel of the Faculty of Fisheries, Kagoshima University. This ship was equipped with a simple trawl net carrying canvas kites on tip of the wings (Ohtomi et al., 2004) and a split-beam quantitative echo sounder (KFC-3000, KAIJO, Hamura, Japan). The net was 23.5 m long and a mesh size at the net body and cod end of 37.9 mm and 20.2 mm, respectively. A submersible data logger (Compact-TD ATD-HR, JFE Advantech, Nishinomiya, Japan) was attached to the head rope of the net to record water depth and temperature, with data logging set to 1 min interval. Effective tow duration was estimated by plotting logger data (depth) and echo sounder data (Fulanda & Ohtomi, 2011). Only bottom water temperature was recorded during effective tow duration was used to calculate mean temperature for each haul. Samples collected

were sorted, immediately chilled in ice on board, and fixed with 10% formalin in the laboratory within 6 hours. All specimens were sexed according to the presence of petasma for males and thelycum for females. Only female specimens (2761 individuals) were used. Carapace length (CL), between the posterior margin of the orbit and the mid-dorsal posterior edge of the carapace, was recorded with digital slide calipers (CD-15PS, Mitutoyo, Kawasaki, Japan) to the nearest 0.01 mm. Body weight was recorded by electric balance (EB-430DW, Shimadzu, Kyoto, Japan) to the nearest 0.01 g and whole gonads were removed from each female and weighed to the nearest 0.001 g. The gonadosomatic index (GSI) was calculated for each female as follows (Grant &Tyler, 1983):

$$\text{GSI (\%)} = 100 \times [\text{ovarian weight (g) / body weight (g)}].$$

2.2.2 Histological Analysis

The ovaries were examined by histological observation to estimate the degree of ovarian maturation. Small pieces of each ovary obtained from 215 females collected during March 2004 to February 2005 and January 2012 to November 2013 (CL 17.2-32.8 mm, GSI 0.01-9.10%) were dehydrated following an ethanol series, embedded in paraffin, sectioned (6 μm thickness) and stained with Mayer's hematoxylin and eosin. Preliminarily sections of the oocytes were made in three regions of the ovaries (posterior regions of the cephalothoracic lobes and anterior and middle regions of the abdominal lobes) for one female (CL 27.1 mm, GSI 7.2%). These histological sections showed similar development throughout the ovaries. The anterior regions of the abdominal lobes were therefore used for the remaining females to classify oocytes into respective developmental stages microscopically.

Ohtomi and Yamamoto (1997), Yano (1988), and Tom et al. (1987) were used to define mature females, where the appearance of cortical granules at the periphery of the oocytes and germinal vesicle breakdown throughout the cytoplasm of oocytes were considered as indication of spawning.

2.2.3 Developmental Stages of Oocytes

Oocytes were classified into six developmental stages as follows: early nucleolus, middle nucleolus, late nucleolus, yolk granule, prematuration, and maturation (Table 1). Early nucleolus stage: oocytes are small and the cytoplasm is stained with hematoxylin (Fig. 2.1A); middle nucleolus stage: nucleoli are located in the peripheral region of the nucleus and follicle cells are visible around the oocytes (Fig. 2.1B); late nucleolus stage: the cytoplasm is weakly stained with hematoxylin and the thickness of follicle layer decreases (Fig. 2.1C); yolk granule stage: yolk granules are found in the cytoplasm stained with eosin (Fig. 2.1D); prematuration stage: cortical granules are found in the peripheral region of the oocyte (Fig. 2.1E); maturation stage: yolk granules extensively accumulate throughout the cytoplasm and germinal vesicle breakdown occurs (Fig. 2.1F).

2.2.4 Size at Sexual Maturity

Size at maturity was estimated based on the histological observations of a total of 215 females. The size was examined from the percentage of mature females (PMF) in each CL class, by fitting a logistic equation described by King (2007):

$$PMF = 1/ [1 + exp \{- f (CL_M - CL_m)\}]$$
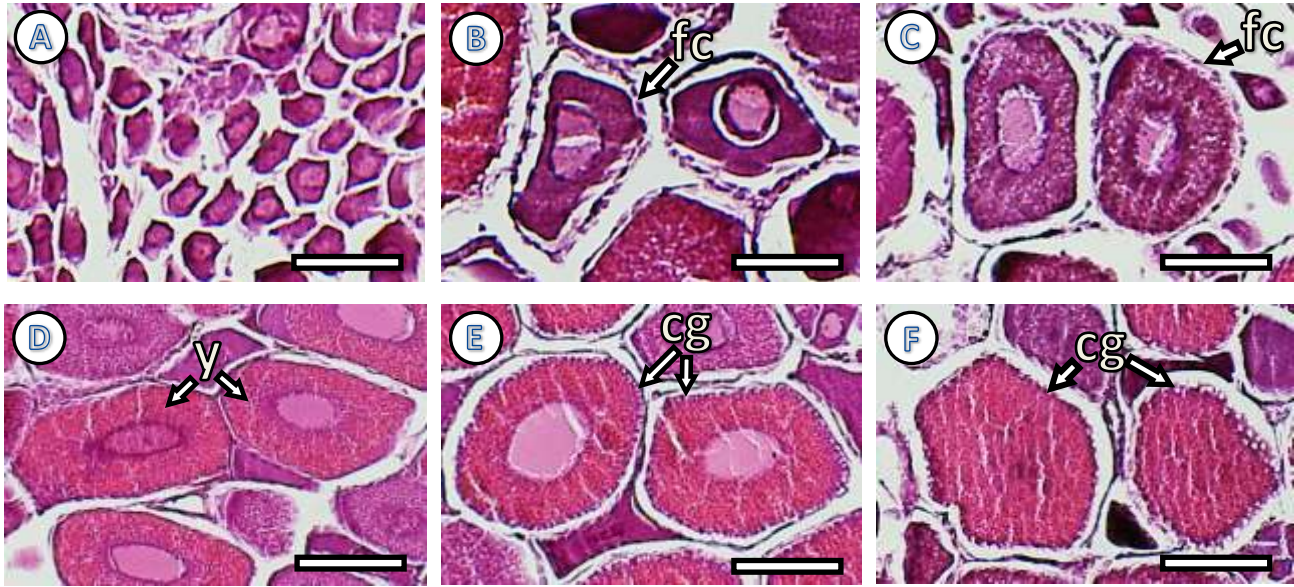
Fig. 2.1 Developmental stages of oocyte of *Parapenaeus fissuroides* Crosnier 1985. A, early nucleolus stage; B, middle nucleolus stage; C, late nucleolus stage; D, yolk granule stage; E, prematuration stage; F, maturation stage. fc, follicle cells; y, yolk granules; cg, cortical granules. Scale bar = 200 μm

where the explanatory variable, CL_M is the median of each CL class, CL_m is the size at sexual maturity at which 50% of females are sexually mature and f is the growth coefficient. PMF was less than a hundred, even in the largest CL class. Data were therefore adjusted to avoid an unreasonably high estimation of CL_m, according to the method established by King (2007). The relationship between carapace length (mm) and gonadosomatic index (%) was also investigated.

2.2.5 Spawning Season

The spawning season was estimated from the monthly occurrences of mature females according to the histological observations and monthly changes in the GSI of females. The specimens were used from two different sampling periods. Females smaller than the size at sexual maturity were excluded from this analysis.

2.2.6 Statistical Analysis

The relationship between CL and GSI was analyzed using simple regression analysis. The differences in GSI between ovarian developmental stages were tested using Kruskal-Wallis test and, between every two stages, tested by post hoc Steel-Dwass test (Neuhäuser & Bretz, 2001).

2.3 RESULTS

2.3.1 Ovarian Maturity Stage

P. fissuroides showed an asynchronous type of ovary since all the individuals examined histologically contained different developmental stages of oocytes. Ovarian maturity stages were classified into four categories based on the developmental stage of the most advanced oocytes in the ovary: Stage I, undeveloped; Stage II, developing; Stage III, nearly ripe; and Stage IV, ripe

(Table 2.1). Nearly ripe ovaries contained prematuration-stage oocytes, where the cortical granules are found in the peripheral region. Ripe ovaries contained maturation-stage oocytes, where the yolk granules had accumulated extensively throughout the cytoplasm and the germinal vesicle had broken down. We defined females with nearly ripe (Stage III) or ripe (Stage IV) ovaries as mature, where the cortical granules appeared in the peripheral region of the oocyte.

2.3.2 Change in Gonadosomatic Index with Ovarian Maturation

In mature females having Stage III- or IV-ovaries, there was no significant correlation between CL and GSI (simple regression analysis, $P = 0.136$), which indicates that the GSI is independent of female body size. The mean and standard deviation of GSI for each ovarian maturity stage were as follows: Stage I, 1.45 ± 1.31 (n = 64); Stage II, 3.87 ± 1.61 (n = 84); Stage III, 5.68 ± 1.72 (n = 41); and Stage IV, 5.99 ± 2.01 (n = 26). We revealed significant differences between the GSI of all ovarian stages (Kruskal-Wallis test followed by post hoc Steel-Dwass test, $P < 0.05$ for all pairs) except for Stage III versus IV ($P > 0.05$).

Females with GSI 0-1% had mostly Stage I-ovaries (previtellogenic), and Stage II-ovaries (developing) appeared mostly between 2-6% GSI classes that were developing. Mature females with Stage III- or IV-ovaries first appeared at 2-3% GSI class and most of the females with GSI $\geq 6\%$ were found to be mature (Fig. 2.2). We therefore considered a GSI $\geq 6\%$ as a rough index of maturation.

2.3.3 Size at Sexual Maturity

The size of mature females having Stage III- or IV-ovaries ranged from 21.7 to 32.8 mm CL. The relationship between the percentage of mature females (PMF) and body size (CL_M) was expressed by a logistic function as follows:

$$PMF = 1/ [1 + \exp \{- 0.580 (CL_M - 23.5)\}] \ (n = 11; r^2 = 0.980, P < 0.001)$$

Fifty percent of the females were mature at 23.5 mm in CL (Fig. 2.3a). In CL-GSI relationship, the GSI values rose sharply at around 23 mm CL (Fig. 2.3b). The size at sexual maturity of female *P. fissuroides* was, therefore, estimated to be 23 mm in CL.

2.3.4 Spawning Season

The monthly changes in GSI and the occurrences of mature females based on histological observations of their ovaries are shown for two different periods in Fig. 2.4. From April 2003 to March 2005 (period 1), females with GSI ≥ 6 % occurred from July to January with a higher mean GSI from October to November (Fig. 2.4a). From December 2011 to November 2013 (period 2), females with GSI ≥ 6 % occurred from July to January and the mean GSI became higher during October to November (Fig. 2.4b). According to the histological analysis, mature females occurred from July to January in Period 1 (Fig. 2.4a) and July to February in Period 2 (Fig. 2.4b). The spawning season in Period 2 was one month longer than that in Period 1 but the month of the first spawning was the same in both periods. These observations indicate that *P. fissuroides* spawns from July to February and the main spawning season lasts from October to November.

Table. 2.1. Ovarian maturity stages together with developmental stage of the most advanced oocytes and histological condition of *Parapenaeus fissuroides* Crosnier, 1985.

Ovarian maturity stage	Developmental stage of oocytes	Histological condition
Stage I (Undeveloped)	Early nucleolus Middle nucleolus Late nucleolus	Previtellogenesis
Stage II (Developing)	Yolk granule	Progress of vitellogenesis
Stage III (Nearly ripe)	Prematuration	Appearance of cortical granules
Stage IV (Ripe)	Maturation	Germinal vesicle breakdown

Fig. 2.2 Percentage occurrence of female *Parapenaeus fissuroides* Crosnier 1985 at each ovarian maturity stage as related to gonadosomatic index class. The numbers of females examined are shown on the top.

$$\text{PMF} = 1/ [1 + \exp \{- 0.580 (CL_M - 23.5)\}]$$
$$r^2 = 0.980, P < 0.001$$
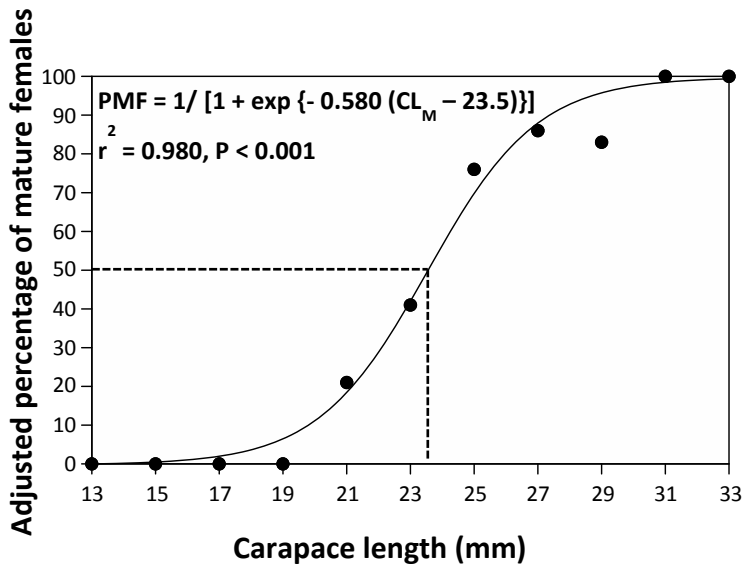
Fig. 2.3a Adjusted percentages of mature females of
Parapenaeus fissuroides Crosnier 1985 as related to
carapace length and logistic curve fitted to these data

n = 1256
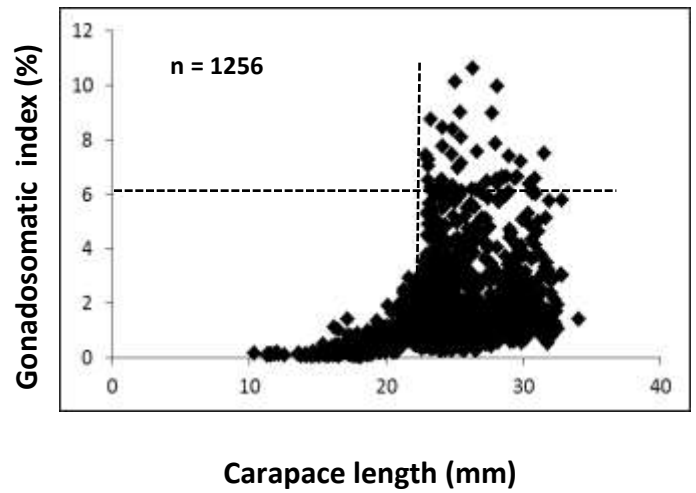
Fig. 2.3b The relationship between Gonadosomatic
index (%) and Carapace length (mm)
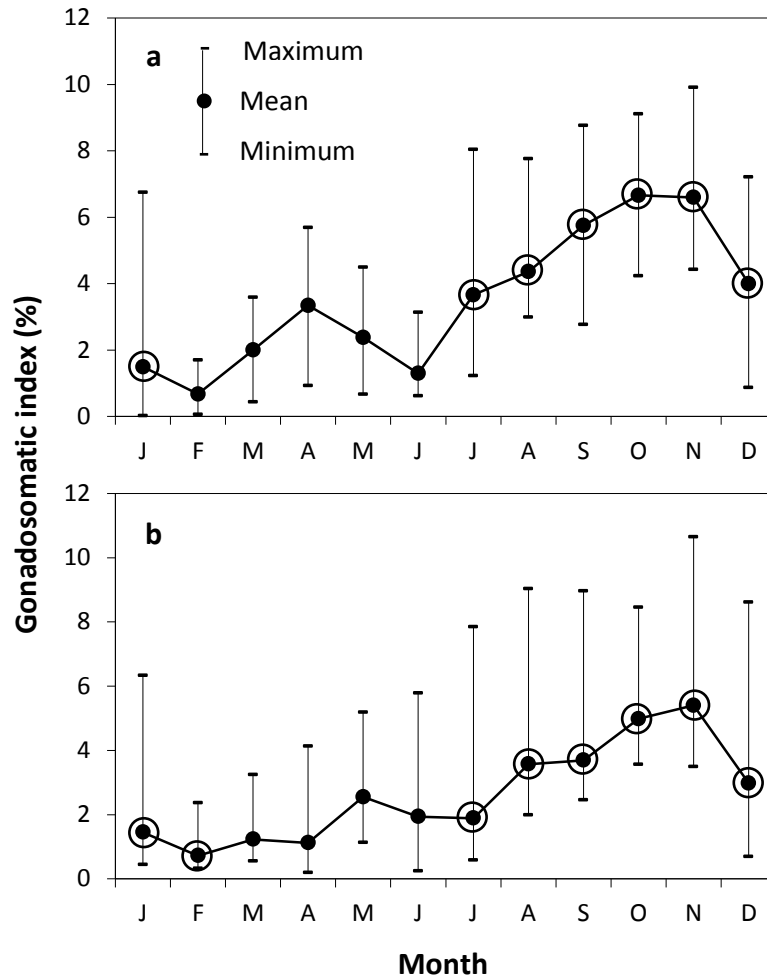
Fig. 2.4 Monthly changes in gonadosomatic index of female *Parapenaeus fissuroides* Crosnier 1985 during (a) April 2003 to March 2005 (Period 1) and (b) December 2011 to November 2013 (Period 2). The circles on the mean value indicate the occurrence of mature females according to the histological observations.
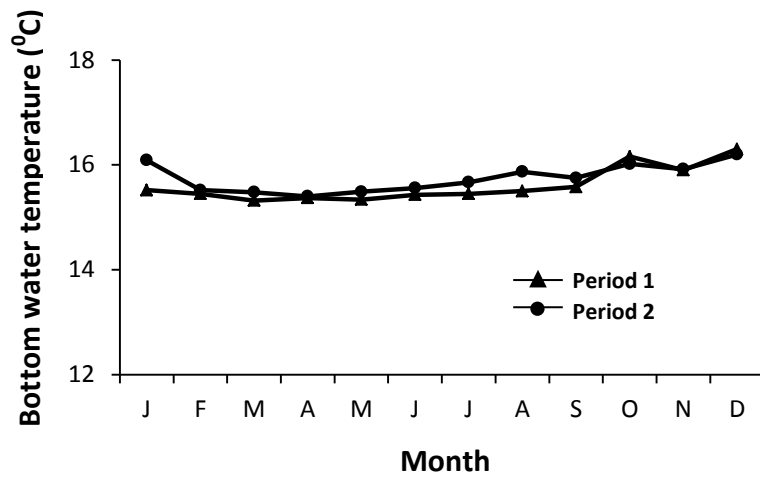
Fig. 2.5 Monthly changes in mean bottom water temperature at the sampling site of Kagoshima Bay during April 2003 to March 2005 (Period 1) and December 2011 to November 2013 (Period 2).

2.3.5 Bottom-Water Temperature

A slight variation in monthly bottom-water temperature was observed at the sampling site for both periods (Fig. 2.5). The temperature was higher during October to January and lower during March to May. Maximum and minimum temperature was 16.3^0C in December and 15.3^0C in March, respectively. The mean bottom-water temperature was 15.6^0C for Period 1, 15.8^0C for Period 2, and tended to be constant throughout the year.

2.4 DISCUSSION

The collection of a large number of specimens is essential to examine the biological aspects of a population. It is difficult to collect a long-time series of samples from deep water, and few biological studies have been conducted on deep-water shrimps such as *P. fissuroides* in comparison to inshore species. Fortunately we were able to collect satisfactory numbers of *P. fissuroides* specimens for the present study. This allowed us to examine some aspects of the reproductive biology of the population, including ovarian maturity stage, size at sexual maturity, and spawning season of this species.

Histological observation of oocytes is considered one of the most accurate methods for the determination of female maturity (Ohtomi et al., 2003; Carbonell et al., 2006). The ovary of *P. fissuroides* was classified as asynchronous type, because it contained oocytes of different developmental stages. The species was therefore considered to have multiple spawns during a single spawning season. Similar results have been reported for the deep-water penaeoids *Solenocera melantho* de Man, 1907 (Ohtomi et al., 1998) and *Haliporoides sibogae* De Man, 1907 (Ohtomi & Yamamoto, 1997).

The condition of the ovary of *P. fissuroides* was classified into four maturity stages based on the developmental stage of the most advanced oocytes found in the ovary. Females with Stage III- or IV-ovaries having cortical granules in the peripheral region of the oocytes were defined as mature and would spawn within a few days. The appearance of cortical granules as a spawning sign has been reported for penaeoids such as *P. longirostris* (Tom et al., 1987), *H. sibogae* (Ohtomi & Yamamoto, 1997), *Marsupenaeus japonicus* Spence Bate, 1888 (Yano, 1988), *Penaeus monodon* Fabricius, 1798 (Krol et al., 1992), *Litopenaeus vannamei* Boone, 1931 (Krol et al., 1992), and *S. melantho* (Ohtomi et al., 1998). In the oocytes of *M. japonicus*, after the occurrence of cortical granules, the nuclei migrate towards the cytoplasmic membrane and then break down, which is known as germinal-vesicle breakdown (Yano, 1988). A similar observation was also reported for *H. sibogae* (Ohtomi & Yamamoto, 1997). Germinal-vesicle breakdown is initiated in the late phase of prematuration and continues until the late phase of maturation immediately prior to spawning (Yano, 1988).

The GSI increased significantly with the progress of ovarian maturity stages in *P. fissuroides*. Significant differences in GSI were revealed between undeveloped, developing, and nearly ripe ovaries. There was no significant difference between the latest two stages (nearly ripe and ripe), which were regarded as mature. Females with nearly ripe or ripe ovaries first appeared at 2-3% GSI class and there was a sharp increase in the percent occurrence of mature females at GSI $\geq$ 6% (Fig. 2.2). GSI can therefore be considered a simple and rough index to identify mature *P. fissuroides* females. GSI as an index of maturity in females has been reported for other penaeoids such as *Trachysalambria curvirostris* Stimpson, 1860 (Hossain & Ohtomi, 2008), *H. sibogae* (Ohtomi & Yamamoto, 1997), and *S. melantho* (Ohtomi et al., 1998).

Size at sexual maturity of female *P. fissuroides* was estimated to be 23 mm in CL (Fig. 2.3). The minimum size of mature females found by histological observations was around 22 mm in CL. Transforming these CLs of mature females to ages using the CL frequency distribution and the estimated growth equation, females with 23 and 22 mm CL belong to around a 1 year-old group (Farhana & Ohtomi, 2016b).

We examined the spawning season of *P. fissuroides* for two periods. The spawning season of this species was estimated to be longer and lasting from summer to winter with a peak in autumn for both periods (Fig. 2.4). No distinct change in temperature was observed between the two periods. The bottom water temperature at the sampling site tended to be constant throughout the year (Fig. 2.5). Inshore penaeid shrimps in Japanese waters tend to mature from spring to summer, April to September as in *M. japonicus* (Ohtomi et al., 2003), June to July for *Fenneropenaeus chinensis* Osbeck, 1765 (Yoshida, 1949), and May to September for *Metapenaeus joyneri* Miers, 1880 (Ikematsu, 1955). Song et al. (2002) reported the breeding period of *P. fissuroides* lasting from July to October in the near Taiwan, East China Sea, at a depth of 60-100 m. The reproductive period of *P. fissuroides* in Kagoshima Bay was found longer than that in Taiwan. Several authors (Harrison, 1988; Gage & Tyler, 1991; Bishop & Shalla, 1994) reported that a longer reproductive period seems to be a typical feature of deep-water species. The daily cycle of light and dark and the seasonal changes in the proportions of light and dark are most likely to be of importance in crustaceans (Aiken et al., 1983). Photoperiodicity induced successful maturation in *Penaeus semisulcatus* De Haan, 1844 (Aktas et al., 2003). The duration of exposure, for example, influences the timing and incidence of spawning in lobsters (Waddy and Aiken, 1992). The reproduction of *P. fissuroides* might be influenced by photoperiodicity because the spawning season lasts from around the summer

solstice (longest day) to around winter solstice (shortest day) and the peak spawning season was estimated to be in autumn, as in *Plesionika semilaevis* Spence Bate, 1888 (Pandalidae) (Ohtomi, 1997) and *S. melantho* (Solenoceridae) (Ohtomi et al., 1998) in Kagoshima Bay.

Several studies (Giese & Pearse, 1974; Sastry, 1983; Bauer, 1989; 1992) have reported that food availability for planktonic larvae was the ultimate factor for explaining seasonality in reproduction. Additional detailed studies are needed to determine the influence of food supply on the reproductive cycle of *P. fissuroides*. We could not examine frequency of spawning of this species in a single spawning season. Quantitative analyses of fecundity, frequency of spawning, and abundance of breeding stock are recommended for future stock management of this species.

3.1 INTRODUCTION

Information on growth of crustaceans is important for future management strategies. Accurate age determination of crustacean from hard part analysis is difficult because of repeated occurrence of molting. However, in the present study, a time series of length-frequency distributions was used for growth determination of *Parapenaeus fissuroides*. Detailed studies on the growth of *P. fissuroides* from any geographical area of distribution are still insufficient. The growths of other penaeids have been investigated in different waters over the world, e.g. *Parapenaeus longirostris* in the southern Tyrrhenian Sea (Arculeo et al., 2014), European Atlantic and Mediterranean waters (Sobrino et al., 2005), south Ionian and south Adriatic Sea (Kapiris et al., 2013), Saros Bay, and in the Aegean Sea (Bilgin et al., 2009); *Penaeus esculentus* Haswell, 1879, and *Penaeus semisulcatus* in the western Gulf of Carpentaria (Krikwood & Somers, 1984); *Metapenaeus joyneri* in the western coast of Korea (Cha et al., 2004). Lack of adequate knowledge on the growth of *P. fissuroides* is a barrier to sound management of this fishery.

The purpose of the present study was to provide information on the growth pattern and longevity of *P. fissuroides* based on monthly length-frequency distributions using a large number of specimens. Monthly growth rate, growth performance and the relationship between carapace length and body weight were also estimated for both sexes.

3.2 MATERIALS AND METHODS

3.2.1 Shrimp Sampling and Measurement

Shrimp sampling was carried out monthly during the daytime in the central area of Kagoshima Bay, southern Japan, at depths ranging from 127 - 133 m ($31^0 18´6´´$N and $130^0 39´0´´$E) using *Nansei Maru* (175 t), a training vessel of the Faculty of Fisheries, Kagoshima University, from April 2003 to November 2005. Shrimp sampling was conducted using a simple trawl net measuring 23.5 m in total length and a mesh size at the net body and cod end of 37.9 mm and 20.2 mm, respectively, carrying canvas kites on tip of the wings (Ohtomi et al., 2004). The vessel was equipped with a split-beam quantitative echo sounder (KFC-3000, KAIJO, Hamura, Japan). A submersible data logger (Compact-TD ATD-HR, JFE Advantech, Nishinomiya, Japan) was attached to the head rope of the net to record net depth and temperature, with data logging set to 1-minute intervals. Each trawl was towed for 10 or 20 minutes at 2 knots. Effective tow duration was estimated by the method adopted by Fulanda & Ohtomi (2011). For the present study, bottom water temperature recorded during effective tow duration was used to calculate mean temperature for each haul. The specimens were sorted, immediately chilled on board and fixed with 10% formalin in the laboratory.

The sex of all specimens was determined according to the presence of petasma for males and thelycum for females. Carapace length (CL), the distance between the posterior margin of the orbit and the mid dorsal posterior edge of the carapace was measured with a digital slide calipers (CD-15PS, Mitutoyo, Kawasaki, Japan) to the nearest 0.01 mm. Body weight (BW) was measured by an electronic balance (EB-430DW, Shimadzu, Kyoto, Japan) to the nearest 0.01 g.

3.2.2 Growth Analysis

Monthly length-frequency distributions were constructed for both sexes using 1 mm intervals of CL. A computer analysis (Microsoft Excel-add-in-solver) based on Hasselblad's maximum-likelihood method (Hasselblad, 1966) was used to fit a series of component normal distributions to the frequency distribution of each sample by sex. Each component normal distribution represents an age group in the population. The outputs from this analysis include mean CL, standard deviation and proportion of each age group.

The growth patterns for male and female *P. fissuroides* were modeled by fitting the following two equations to the mean CLs at ages estimated for each component normal distribution at each sampling dates:

von Bertalanffy equation (von Bertalanffy, 1938):

$$L_t = L_\infty \left[1 - \exp \left\{ - K \left(t - t_0 \right) \right\} \right],$$

Pauly & Gaschütz equation (Pauly & Gaschütz, 1979):

$$L_t = L_\infty \left[1 - \exp \left\{ - K \left(t/12 - t_0 \right) - \left(CK/2\pi \right) \sin \left(2\pi \left(t/12 - t_s \right) \right) \right\} \right],$$

where L_t is the CL (mm) at age t (months), L_∞ is the asymptotic CL (mm), K is the growth coefficient (year^{-1}), C is the amplitude of seasonal growth oscillation, t_s is the summer point; the time of the year when growth is the highest (winter point, $t_w = t_s + 0.5$; the time of the year when growth is the lowest) and t_0 is the hypothetical age when the CL would be zero. The Pauly & Gaschütz equation is a modification of the simple von Bertalanffy equation to fit seasonally oscillating length data (Pauly & Gaschütz, 1979). The best fitting model among these equations was selected on the basis of the Akaike's information criterion (AIC) (Akaike, 1973) and Bayesian information criterion (BIC) (Schwarz, 1978). AIC gives the chance of choosing the model with a large number of parameters, while BIC gives the chance to choose a comparatively

simple model (Shono, 2000; Yang, 2005; Nylund et al., 2007; Dziak et al., 2012). Therefore, we adopted both to select the best fitting model for the growth of *P. fissuroides*.

The monthly growth rate (MGR) was estimated for both sexes using the following equation:

$$\text{MGR} (\%) = 100 \times [(L_{t+1} - L_t) / L_t],$$

where L_t and L_{t+1} are the back-calculated CLs (mm) at age t and $t + 1$ (months) from the best fitting equation.

Growth performance index (Ø´) was calculated to compare the growth between sexes using the following equation (Pauly & Munro, 1984):

$$Ø´ = \log_{10} K + 2 \log_{10} L_\infty,$$

The values of L_∞ and K were used from the best fitting model.

3.2.3 Length-Weight Relationship

The relationship between CL and BW in both sexes was expressed by the equation of Huxley (1932): $\ln (\text{BW}) = \ln (a) + b \ln (\text{CL})$. Significant deviation of the b value from the theoretical isometric value ($b = 3$) indicates positive ($b > 3$) or negative ($b < 3$) allometric growth (Tesch, 1971), which was verified by the Student's t-test (Sokal & Rohlf, 1987). We used analysis of covariance (ANCOVA) (Zar, 1984) to test the significant differences in slope and elevation between sexes.

3.3 RESULTS

3.3.1 Growth Pattern

A total of 5,085 specimens were collected from Kagoshima Bay, among them 51.4% specimens were male and 48.6% were female. CL in males ranged from 7.7 - 27.1 mm and 6.4 -

36.1 mm in females. Both male and female *P. fissuroides* were recruited in late autumn to winter (November to January) with modal size of around 11 mm CL (Figs. 3.1 & 3.2). Mostly one or two age groups were present in each month but third age groups also appeared occasionally.

The spawning season of *P. fissuroides* extends from July to February and the main spawning period is in autumn (Farhana & Ohtomi, 2016a). The ages of individuals of each age group were determined by arbitrarily assigning 1 October (approximate peak date of main spawning season) as "day 1"of this shrimp's life cycle. The estimated growth equations for males were as follows:

von Bertalanffy equation:

$L_t = 24.5 [1 - \exp \{- 0.118 (t + 2.909)\}]$

$\quad$ (n = 47, AIC = 4622.83, BIC = 4644.08)…………………………………………… (1)

Pauly & Gaschütz equation:

$L_t = 25.6 [1 - \exp \{- 1.011 (t/12 + 0.539) - (0.641/2\pi) \sin (2\pi (t/12 - 0.577))\}]$

$\quad$ (n = 47, AIC = 4438.35, BIC = 4470.17)………………………………………… (2)

The estimated growth equations for females were as follows:

von Bertalanffy equation:

$L_t = 32.8 [1 - \exp \{- 0.093 (t + 1.969)\}]$

$\quad$ (n = 60, AIC = 6869.61, BIC = 6891.47)…..……………………………………….. (3)

Pauly & Gaschütz equation:

$L_t = 34.3 [1 - \exp \{- 0.941 (t/12 + 0.227) - (0.581/2\pi) \sin (2\pi (t/12 - 0.603))\}]$

$\quad$ (n = 60, AIC = 6351.51, BIC = 6421. 33)………………………………………… (4)

The Pauly & Gaschütz equation provided the best fitting model for describing the growth for both sexes of *P. fissuroides* based on the lowest values of AIC and BIC. Therefore, we adopted equation (2) for males and (4) for females to describe the growth of *P. fissuroides* in Kagoshima

Bay. The F-test revealed that there was a significant difference between males and females in Pauly & Gaschütz equation ($P > 0.05$). Females had a lower K value but reached larger sizes at each age and larger asymptotic size than males (Fig. 3.3).

The temporal changes of monthly growth rate (MGR %) of *P. fissuroides* throughout their life cycle in Kagoshima Bay are shown in Fig. 3.4. The changes in MGR % showed a similar pattern in both sexes. The summer point (t_s) was estimated to be 0.577 for males and 0.603 for females. These indicate that the growth rate was the highest during July to August and the lowest during January to February.

The growth performance index (Ø´) was higher for females (3.04) than males (2.83). This indicates that females grew faster than males of the same age. The longevity was estimated to be around 2 years for males and 2.5 years for females based on the time series of the CL-frequency distributions (Figs. 3.1 & 3.2).

3.3.2 Length-Weight Relationship

The CL-BW relationship indicated negative allometric growth for both sexes as the statistical t-test revealed that the allometric coefficient b values were significantly lower than 3 in both sexes ($P < 0.05$) (Table 3.1). Significant differences in both slope and elevation between sexes were detected (ANCOVA; $P < 0.001$). Transforming the estimated asymptotic CLs of male and female *P. fissuroides* to BWs, the asymptotic weights (W_∞) were calculated as 8.56 g for males and 20.16 g for females.
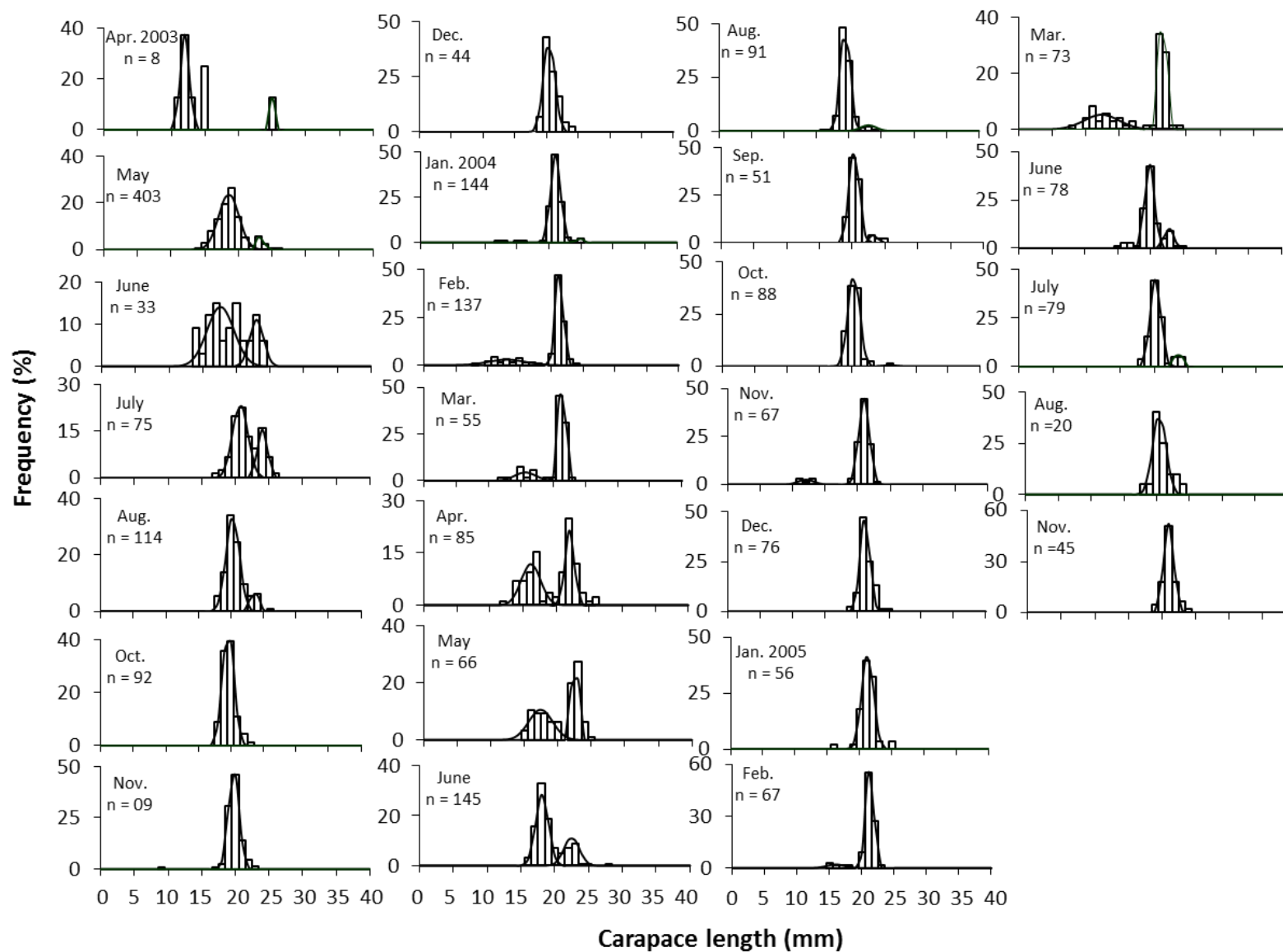
Fig. 3.1 Length-frequency distributions of male *Parapenaeus fissuroides* Crosnier, 1985 in Kagoshima Bay. Curves show the estimated normal distributions of age groups.
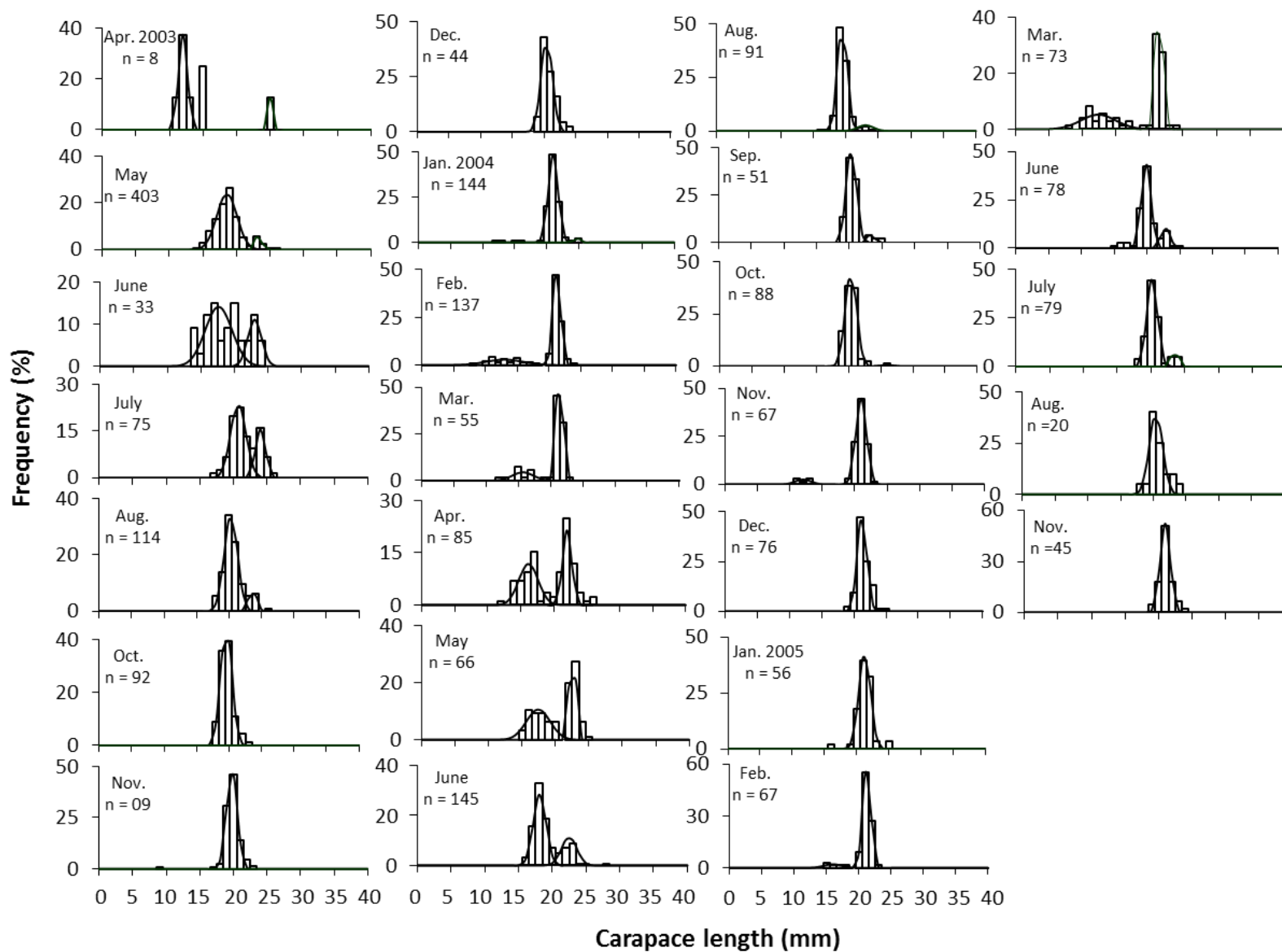
Fig. 3.2 Length-frequency distributions of female *Parapenaeus fissuroides* Crosnier, 1985 in Kagoshima Bay. Curves show the estimated normal distributions of age groups.
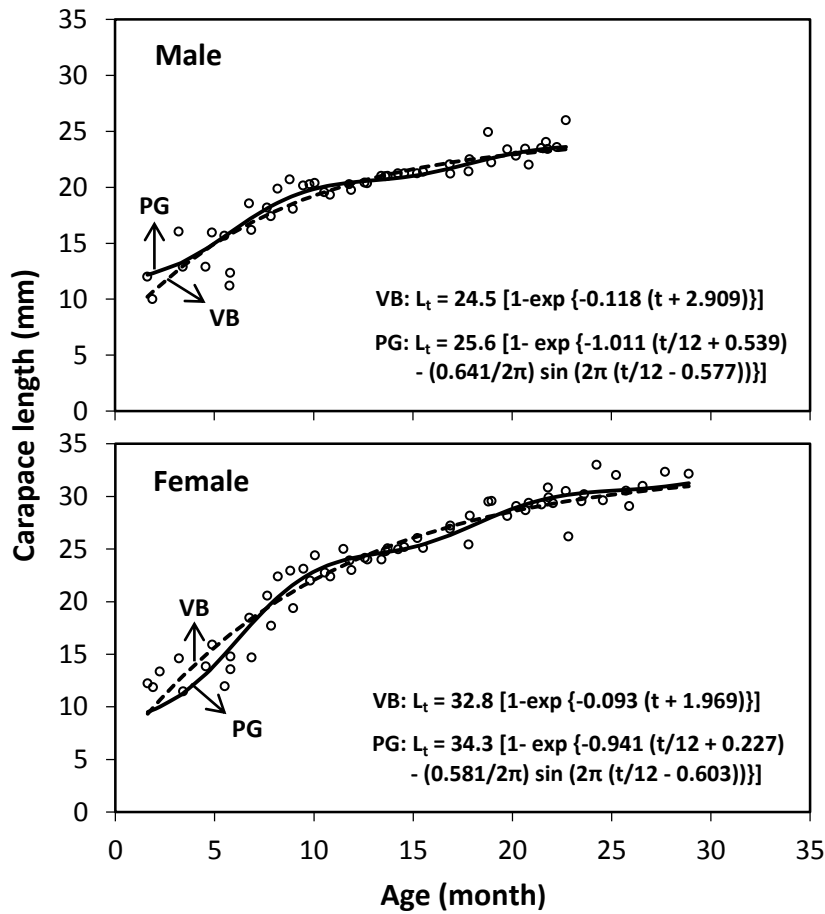
Fig. 3.3 Growth curves for male and female *Parapenaeus fissuroides* Crosnier, 1985 in Kagoshima Bay. Solid circles show the mean carapace lengths of age groups derived from Figs. 3.1 and 3.2. VB and PG indicate von Bertalanffy equation and Pauly and Gaschütz equation, respectively.
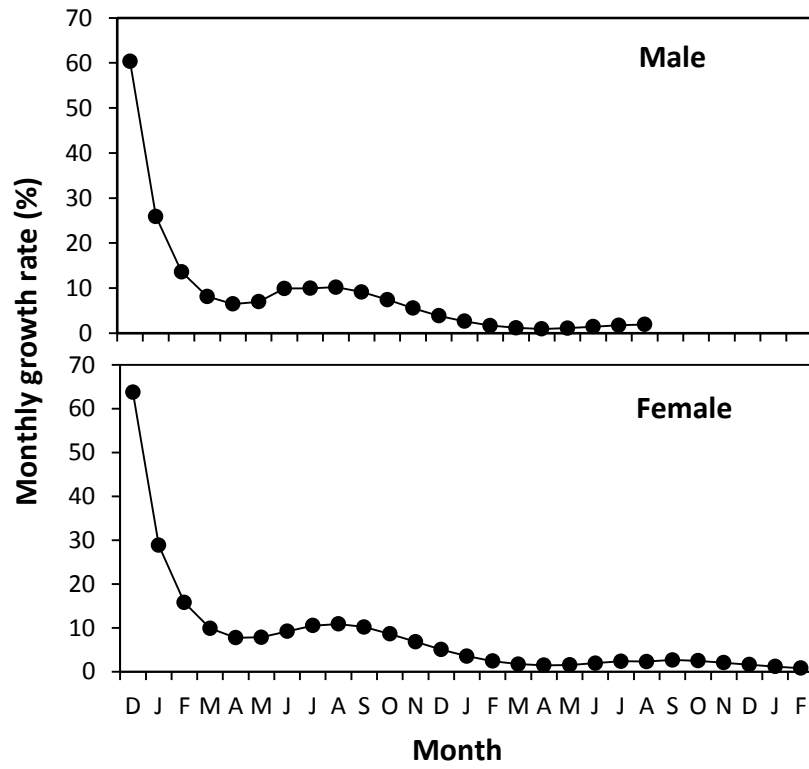
Fig. 3.4 Temporal changes in monthly growth rate (%) of male and female *Parapenaeus fissuroides* Crosnier, 1985 in Kagoshima Bay.

Table 3.1 Allometric relationships between body weight (BW in g) and carapace length (CL in mm) of *Parapenaeus fissuroides* Crosnier, 1985 in Kagoshima Bay. The equation is: ln (BW) = ln (a) + b ln (CL). CL range, sample size (n) and coefficient of determination (r^2) are also given.

Sex	n	CL range (mm)	a	b	r^2
Male	1352	7.74 - 27.07	0.00192	2.590	0.933 ($P < 0.05$)
Female	1552	6.36 - 36.09	0.00271	2.556	0.967 ($P < 0.05$)
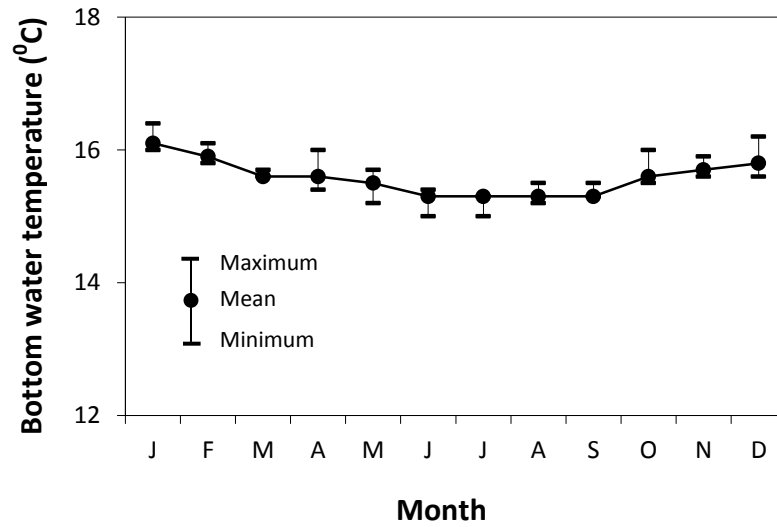
Fig. 3.5 Monthly changes in bottom water temperature at the sampling
site in Kagoshima Bay from January 2003 to December 2004.

3.3.3 Bottom Water Temperature

Maximum and minimum bottom water temperatures were recorded as 16.4^{0} C in January and 15^{0} C in June, respectively at the sampling area. There was no distinct seasonal trend observed in monthly bottom water temperature and it tended to be constant at around 15.6^{0} C throughout the year (Fig. 3.5).

3.4 DISCUSSION

The age and growth of crustacean natural population are usually estimated by using length-frequency distributions (Gulland & Rosenberg, 1992). Fewer studies have been conducted on age and growth of deep water species compared to inshore species due to the difficulties of collecting long series of large samples. In the present study, we were able to collect a large series of specimens of *P. fissuroides* from Kagoshima Bay, southern Japan. Though we used fishing gear with large mesh size, we were fortunately able to capture a considerable amount of small individuals during their recruitment period, which allowed us to estimate age and growth using length-frequency distributions.

The body size of females was consistently exceeding that of males throughout the study period. Quan- tu et al. (2006) also reported that females of *P. fissuroides* were larger than males in the northeast Fujian Outer-sea. In the time series of length-frequency distributions, a perceptible shift in modal carapace length with time was observed for both sexes. This species recruited during November to January and continued to grow. Their longevity is around 2 years for males and 2.5 years for females (Figs. 3.1 & 3.2). In comparison with *Parapenaeus longirostris* found in European Atlantic and Mediterranean waters, the longevity of *P. fissuroides* was shorter, as Sobrino et al. (2005) reported that the longevity of *P. longirostris* there was

around 3 years. The asymptotic CL of *P. longirostris* was larger than that of *P. fissuroides* and was distributed comparatively in deeper waters. The difference in the longevity between species may be attributed to the differences in bathymetric distribution and deeper water shrimp exhibit longer life cycles as well as maximum sizes compared to shallow water species (King & Butler, 1985).

Growth patterns were modeled using two growth equations both in males and females (Fig. 3.3). The fitted Pauly & Gaschütz growth model suggested that growth rates of both male and female *P. fissuroides* followed a seasonal oscillation. The MGR (%) of shrimp is correlated with the frequency of moulting and moulting frequency is correlated with numerous factors (Hartnoll, 2001). The MGR (%) of *P. fissuroides* was the highest during July to August (summer point) and the lowest during January to February (winter point) both in males and females (Fig. 3.4). This suggests that the growth slows down during the reproductive period from summer to winter. Ohtomi & Irieda (1997) also reported the growth of *Solenocera melantho* to slow down during the reproductive period in Kagoshima Bay. The moult activity stops or slows down during the reproduction in many crustaceans (Scheer, 1960). In reproductive period, the accumulation of energy may be necessary to respond to the development of oocytes and the activities of enzyme decline which are related to the stages of moulting cycle (Charron et al., 2014). The seasonal oscillation of growth rate of *P. fissuroides* was likely to be related to reproductive cycle in the bay. Several studies (Pauly et al., 1984; García, 1985; Pauly et al., 1995; Swain et al., 2003; Ye et al., 2003; Cha et al., 2004; Silva et al., 2008; Castillo-Jordán et al., 2010) reported that seasonal oscillation of growth rate is related to seasonal variations in water temperature. However, there was no marked seasonal trend in the bottom water temperature in Kagoshima Bay (Fig. 3.5). Hossain and Ohtomi (2010) reported that the moulting or growth of

Trachysalambria curvirostris was not affected by bottom water temperature in Kagoshima Bay. Yacouba et al. (2014) reported that rainfall influences the growth of *P. longirostris* in West Africa due to the resulting abundance of food. The variation in availability of food can be an important factor for seasonal growth pattern of *P. fissuroides*. Therefore, the feeding habits of this species in this bay are needed to be explored in future research.

Females had higher L_∞ and lower K values than males. Several studies on other penaeid shrimps reported similar observations (e.g., Sobrino, 1998; Pauly et al., 1984; Cha et al., 2002; Ohtomi & Irieda, 1997). Since the growth pattern of shrimps is not linear, the direct comparison of growth parameters is biologically not reasonable (Cartaxana, 2003). The growth performance index (Ø´) is an easy procedure that can be used to compare the growth between sexes of a species and between species rather than comparison of L_∞ and K, as these parameters are intrinsically negatively correlated (Pauly & Munro, 1984). The estimated growth performance index (Ø´) of females' *P. fissuroides* was higher than that of males indicating that females grew faster than males at same age. Similar observations were reported by Kapiris et al. (2007), while studying *P. longirostris* in the Hellenic Ionian Sea.

The allometric relationship between CL and BW was presented by log transformed linear equation for both males and females (Table 3.1). The body weight of males increased faster with carapace length after recruitment size than that of females. However, the absolute growth of males was slower than females (Fig. 3.3). The W_∞ for females is more than twice as large as that of males, which makes females commercially more important.

The present study provided information on demographic parameters such as asymptotic length, growth coefficient, growth performance and longevity which will be helpful for designing a fishing management strategy to ensure a sustainable exploitation of *P. fissuroides* in

Kagoshima Bay. For proper stock management of this species, studies need to be carried out on the duration of their planktonic phases and the settlement periods of this penaeid shrimp in Kagoshima Bay as well as in other deep waters.

4. REPRODUCTION OF *PARAPENAEUS LANCEOLATUS*

4.1 INTRODUCTION

Reproductive biology is one of the main concerns for proper management practices. Choi et al. (2005) studied the sex ratio and insemination rate of *Parapenaeus lanceolatus* in Korean waters. Insufficient studies on reproductive biology of this species have been reported in world waters. Farhana and Ohtomi (2016a) studied reproductive biology of *Parapenaeus fissuroides* in Kagoshima Bay. For proper management strategies of *P. lanceolatus*, information and adequate knowledge on the biology of this species are needed to be explored. The present study describes the reproductive biology of *P. lanceolatus* including ovarian maturity stages, size at sexual maturity and spawning season.

4.2 MATERIALS AND METHODS

4.2.1 Sampling and Measurements

Shrimp samples were collected during daytime once or twice a month in the central area of Kagoshima Bay ($31^0 25´0´´$N and $130^0 37´60´´$E) at depths of 127-228 m from January 2011 to February 2016. Shrimp was sampled using *Nansei Maru* (175 t), a training vessel of the Faculty of Fisheries, Kagoshima University which was equipped with a simple trawl net carrying canvas kites on tip of the wings (Ohtomi et al., 2004). The total length of the net was 23.5 m and the mesh size of net body was 37.9 mm and cod end was 37.9 mm. Samples collected were sorted and immediately chilled in ice on board. All specimens were preserved in 10% formalin in the laboratory and sexed according to the presence of petasma in males and thelycum in females. Sex determination was possible for all specimens. Carapace length (between the posterior margin

of the orbit and the mid-dorsal posterior edge of the carapace), CL (mm) and body weight, BW (mm) were recorded to the nearest 0.01 mm and 0.01 g, respectively. Whole gonads were removed from each female and weighed to the nearest 0.001 g. The gonadosomatic index (GSI) was calculated for each female:

$$GSI\,(\%) = 100 \times [\text{ovarian weight (g)} / \text{body weight (g)}].$$

4.2.2 Histological Analysis

The ovaries were preserved in 10% formalin for histological observation. Small pieces of each ovary from 108 females collected during January 2011 to February 2016 (CL 15.9-34.0 mm, GSI 0.12-6.13%) were dehydrated following an ethanol series, embedded in paraffin, sectioned (6 μm thickness) and stained with Mayer's hematoxylin and eosin. The ovaries from one female (CL 28.2 mm, GSI 6.13%) were considered to section in three regions (posterior regions of the cephalothoracic lobes and anterior and middle regions of the abdominal lobes) for observing the oocyte development. These experimental sections showed similar development throughout the ovaries. Therefore, the anterior regions of the abdominal lobes were used for the remaining females to classify the developmental stages of oocytes.

The developmental stages of the oocytes were categorized according to Ohtomi and Yamamoto (1997) (Fig. 4.1, Table 4.1). Cortical granules at the periphery of the oocytes and germinal vesicle breakdown throughout the cytoplasm of oocytes were considered as indication of spawning as considered in *Parapenaeus longirostris* (Tom *et al*., 1987), and in *P. fissuroides* (Farhana & Ohtomi, 2016a).

4.2.3 Developmental Stages of Oocytes

The oocytes were divided into six developmental stages as follows:

1. Early nucleolus stage: oocytes are small and the cytoplasm is stained with hematoxylin (Fig. 4.1A).

2. Middle nucleolus stage: nucleoli are located in the peripheral region of the nucleus and follicle cells are visible around the oocytes (Fig. 4.1B).

3. Late nucleolus stage: the cytoplasm is weakly stained with hematoxylin and the thickness of follicle layer decreases (Fig. 4.1C)

4. Yolk granule stage: yolk granules are found in the cytoplasm stained with eosin (Fig. 4.1D).

5. Prematuration stage: cortical granules are found in the peripheral region of the oocyte (Fig. 4.1E).

6. Maturation stage: yolk granules extensively accumulate throughout the cytoplasm and germinal vesicle breakdown occurs (Fig. 4.1F).

4.2.4 Size at Sexual Maturity

Size at maturity was estimated based on the minimum size of mature females in histological observations and the percentage of mature females (PMF) in each CL class, by fitting a logistic equation explained by King (2007):

$$PMF = 1/[1 + \exp\{-f(CL_M - CL_m)\}]$$

where the explanatory variable, CL_M is the median of each CL class, CL_m is the size at sexual maturity at which 50% of females are sexually mature and f is the growth coefficient. PMF was

less than a hundred, even in the largest CL class. Data were therefore adjusted to avoid an unreasonably high estimation of CL_m. The relationship between CL and GSI was also observed.

4.2.5 Spawning Season

The spawning season was estimated from the monthly occurrences of mature females according to the histological observations and monthly changes in the GSI of females. Females smaller than the size at sexual maturity were excluded from this analysis.

4.3 RESULTS

4.3.1 Ovarian Maturity Stage

All the individuals of *P. lanceolatus* examined histologically showed an asynchronous type of ovary. The ovaries could be classified into four stages based on the developmental stage of the most advanced oocytes in the ovary: Stage I, undeveloped; Stage II, developing; Stage III, nearly ripe; and Stage IV, ripe (Table 4.1). We defined females with nearly ripe (Stage III) and ripe (Stage IV) ovaries as mature, where the cortical granules are found in the peripheral region of the oocytes. Germinal vesicle had broken down throughout the cytoplasm in ripe ovaries.

4.3.2 Change in Gonadosomatic Index with Ovarian Maturation

In mature females, no significant correlation was detected between CL and GSI (simple regression analysis, n = 33, $P = 0.246$), which reveals that the GSI is independent of female body size. The mean and standard deviation of GSI for each ovarian maturity stage were as follows: Stage I, 1.79 ± 0.80 (n = 39); Stage II, 2.75 ± 0.73 (n = 36); Stage III, 3.69 ± 1.01 (n = 24); and

Stage IV, 4.78 ± 0.62 (n = 9). Significant differences between the GSI of all ovarian stages (Kruskal-Wallis test followed by post hoc Steel-Dwass test, $P < 0.05$ for all pairs) were detected.

All females with GSI 0-1% had Stage I-ovaries (previtellogenic), and females with GSI 1-3% mostly had Stage II-ovaries (developing). Mature females with Stage III- or IV-ovaries first appeared at GSI 1-2%. The majority of the females with GSI ≥ 4% were found to be mature (Fig. 4.2). Females with GSI ≥ 4% were therefore considered as a reliable index of maturation.

4.3.3 Size at Sexual Maturity

The minimum size of mature female having nearly ripe or ripe ovaries was 21.6 mm in CL according to histological examination. The relationship between the percentage of mature females (PMF) and body size (CL_M) was expressed by a logistic function as follows:

$$PMF = 1/[1 + \exp\{-0.586\,(CL_M - 22.8)\}]\ (n = 10;\ r^2 = 0.814,\ P < 0.001)$$

Fifty percent of the females were mature at 22.8 mm in CL (Fig. 4.3a). The relationship between CL and GSI revealed that the GSI values rose sharply at around 22 mm in CL and the minimum sized female with GSI ≥ 4% was 21.8 mm in CL (Fig. 4.3b). By considering these observations, the size at sexual maturity of female *P. lanceolatus* was estimated to be 22 mm in CL.

4.3.4 Spawning Season

Females with GSI ≥ 4% appeared from July to April, with a higher mean GSI from September to October. Mature females having nearly ripe and ripe ovaries appeared during July and September to April in histological observation (Fig. 4.4). The spawning season of *P. lanceolatus*
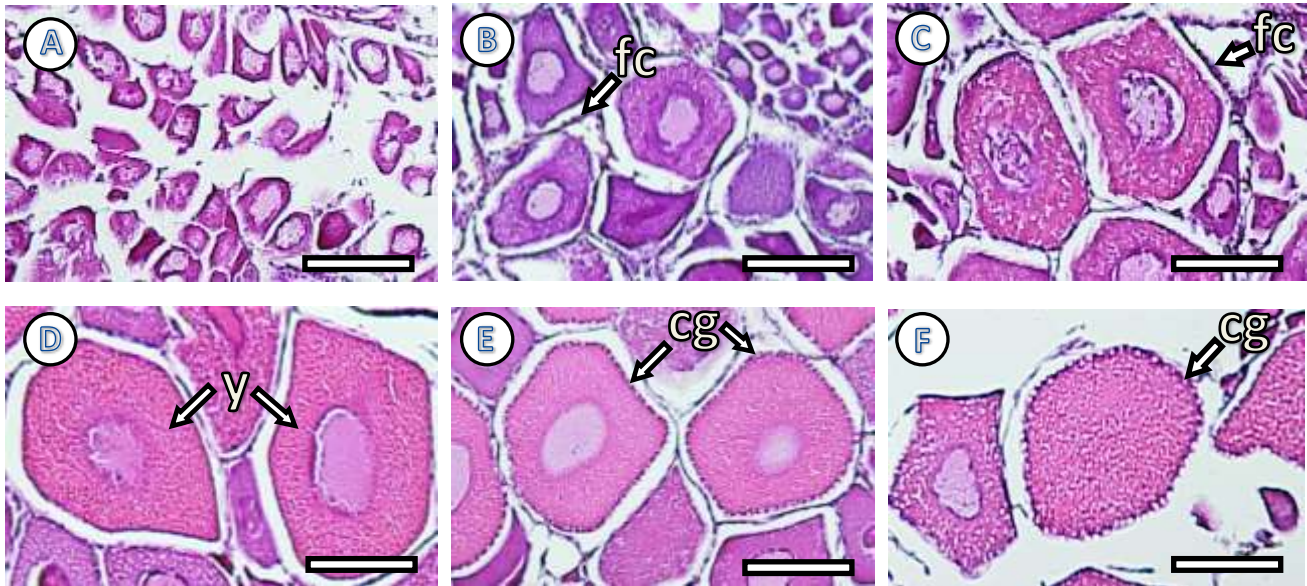
Fig. 4.1 Developmental stages of oocyte of *Parapenaeus lanceolatus* Kubo 1949. A, early nucleolus stage; B, middle nucleolus stage; C, late nucleolus stage; D, yolk granule stage; E, prematuration stage; F, maturation stage. fc, follicle cells; y, yolk granules; cg, cortical granules. Scale bar = 200 μm.

Table. 4.1 Ovarian maturity stages together with developmental stage of the most advanced oocytes and histological condition of *Parapenaeus lanceolatus* Kubo 1949.

Ovarian maturity stage	Developmental stage of oocytes	Histological condition
Stage I (Undeveloped)	Early nucleolus Middle nucleolus Late nucleolus	Previtellogenesis
Stage II (Developing)	Yolk granule	Progress of vitellogenesis
Stage III (Nearly ripe)	Prematuration	Appearance of cortical granules
Stage IV (Ripe)	Maturation	Germinal vesicle breakdown

Fig. 4.2 Percentage occurrence of female *Parapenaeus lanceolatus* Kubo, 1949 at each ovarian maturity stage as related to gonadosomatic index class. The numbers of females examined are shown on the top.
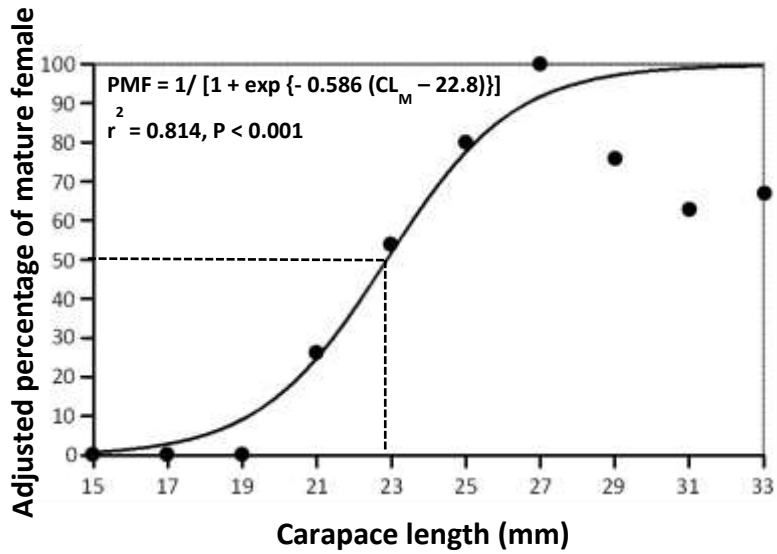
Fig. 4.3a Adjusted percentage of mature females of *Parapenaeus lanceolatus* Kubo, 1949 as related to carapace length (mm) and logistic curve fitted to these data
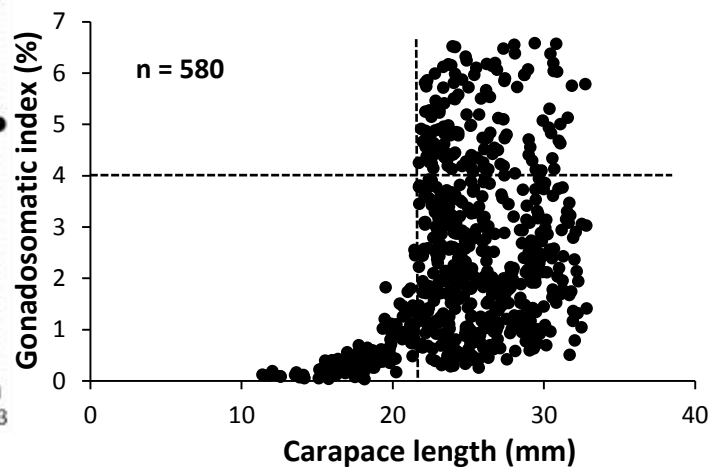
Fig. 4.3b The relationship between gonadosomatic index (%) and carapace length (mm) of *Parapenaeus lanceolatus* Kubo, 1949.
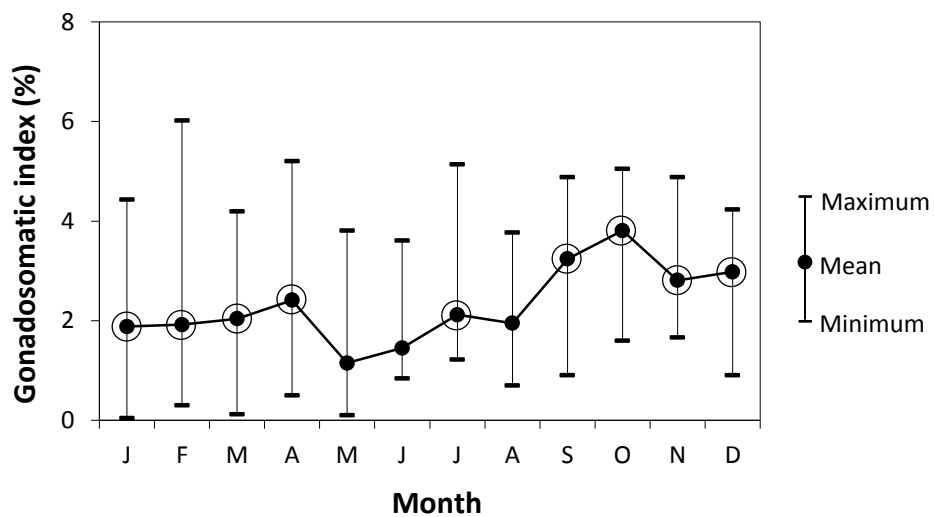
Fig. 4.4 Monthly changes in gonadosomatic index of female *Parapenaeus lanceolatus* Kubo, 1949 during 2011 to 2013.The circles on the mean value indicate the occurrence of mature females according to the histological observations.

was therefore, to be estimated from July to April and the main spawning season was during September and October.

4.4 DISCUSSION

It was difficult to collect a long time series of samples of *P. lanceolatus* in deep waters. In the present study, several aspects of the reproductive biology of this species, including ovarian maturity stage, size at sexual maturity, and spawning season were studied using a sufficiently large number of specimens collected from Kagoshima Bay, southern Japan.

The developmental stages of oocytes were examined by histological observation and the ovaries of this species were considered as asynchronous, indicating this species is a multiple spawner. Similar results have been reported for *P. fissuroides* (Farhana & Ohtomi, 2016a). The ovaries of *P. lanceolatus* were classified into four maturity stages based on the developmental stage of the most advanced oocytes found in the ovary. Females with spent ovaries could not be detected during the present study. The females having cortical granules in the peripheral region of the oocytes considered as mature. According to Yano (1988), germinal-vesicle breakdown is initiated in the late phase of prematuration and continues until the late phase of maturation immediately prior to spawning. This stage was detected for *P. lanceolatus* which would spawn soon.

According to the histological study, GSI significantly increased with the ovarian maturity stages in *P. lanceolatus*. Significant differences in GSI were revealed between ovarian stages and a majority of females with GSI $\geq$ 4% was mature with nearly ripe and ripe ovaries (Fig. 4.2). The females with GSI $\geq$ 4% obtained only during the spawning season (Fig. 4.4). Therefore, a GSI $\geq$ 4% was considered a simple index to identify mature females in *P. lanceolatus*. GSI was

considered as a good index to identify the maturity in females for other penaeoidae such as *P. fissuroides* (Farhana & Ohtomi, 2016a), *Marsupenaeus japonicus* (Ohtomi et al., 2003), *Solenocera melantho* (Ohtomi *et al*., 1998), *Trachysalambria curvirostris* (Hossain & Ohtomi, 2008), *Metapenaeopsis sibogae* de Man, 1907 (Rahman & Ohtomi, unpublished).

Size at sexual maturity for females was considered to be 22 mm in CL (Fig. 4.3). The size of mature females ranged from 21.6-34.3 mm in CL. Transforming these CLs to ages using the estimated growth equations, females with 21.6 mm CL belong to around a 1 year-old group and 34.3 mm CL belong to 2 year-old group (See Chapter 5). The minimum size of mature female in early spawning season (July) was 28.8 mm in CL which belongs to 2 year old group. It can therefore be considered that only older individuals matured in the early spawning season.

A longer reproductive period is a typical feature for deep-water species (Harrison, 1988; Gage and Tyler, 1991; Bishop & Shalla, 1994). A prolonged spawning season was observed for *P. lanceolatus* ranging from July to April (Fig. 4.4) and this shrimp distributed in deeper waters of Kagoshima Bay (Fig. 6.5, Chapter 6). Choi et al. (2005) studied the insemination rate of this species in Korean waters sampled only January and inseminated female was found in this month. In the present study, environmental variables such as seasonality in food supply, current flows were not considered. Though *P. lanceolatus* is a multiple spawner, the frequency of spawning in a single spawning season could not be explained in the present study.

5. GROWTH OF *PARAPENAEUS LANCEOLATUS*

5.1 INTRODUCTION

Growth in penaeid shrimp can be defined as the increase in length or weight and a discontinuous process with a succession of moults (Hartnoll, 1982). Detail studies on growth and longevity of *Parapenaeus lanceolatus* in world waters are evidently lacking. The present study aimed to provide information on asymptotic length, growth coefficient, growth performance and longevity based on length-frequency distributions of this species in Kagoshima Bay, southern Japan. The relationship between carapace length and body weight was also examined for both sexes.

5.2 MATERIALS AND METHODS

5.2.1 Shrimp Sampling and Measurement

The study was conducted using samples collected from the central area of Kagoshima Bay, southern Japan, at depths ranging from 127 - 237 m during January 2011 to January 2013 using *Nansei Maru* (175 t), a training vessel of the Faculty of Fisheries, Kagoshima University. Shrimp sampling was conducted using a simple trawl net carrying canvas kites on tip of the wings (Ohtomi et al., 2004). The dimensions of the net were 23.5 m long, 37.9 mm and 20.2 mm mesh size at the net body and cod end respectively. Each trawl was towed for 10 minutes at 2 knots. The specimens were sorted to the species level, chilled immediately in ice on board and preserved with 10 % formalin in the laboratory.

All specimens collected were sexed by the presence of petasma for males and thelycum for females. Carapace length (CL) was measured with a digital slide calipers (CD-15PS, Mitutoyo,

Kawasaki, Japan) to the nearest 0.01 mm. Body weight (BW) was measured by an electronic balance (EB-430DW, Shimadzu, Kyoto, Japan) to the nearest 0.01 g.

5.2.2 Growth Analysis

Monthly length-frequency distributions were constructed using 1 mm intervals of CL for both sexes. A series of component normal distributions were fitted to the length-frequency of each sample by sex, using a computer analysis (Microsoft Excel-add-in-solver) based on Hasselblad's maximum-likelihood method (Hasselblad, 1966). Each component normal distribution was assumed an age group in the population. The outputs from this analysis include mean CL, standard deviation and proportion of each age group. Then, ages in months were assigned to the mean CLs considering 1 September as birth date. This assumption was done because the main spawning season of *P. lanceolatus* was September to October (Chapter 4, Fig. 4.4).

The growth patterns for male and female *P. lanceolatus* were modeled by fitting the following two equations to the mean CLs at ages estimated for each component normal distribution at various sampling dates during 2011-2013:

von Bertalanffy equation (von Bertalanffy, 1938):

$$L_t = L_\infty \left[1 - \exp \{ - K (t - t_0) \} \right],$$

and Pauly & Gaschütz equation (Pauly & Gaschütz, 1979):

$$L_t = L_\infty \left[1 - \exp \{ - K (t/12 - t_0) - (CK/2\pi) \sin (2\pi (t/12 - t_s)) \} \right],$$

where L_t is the CL (mm) at age t (months), L_∞ is the asymptotic CL (mm), K is the growth coefficient (year^{-1}), C is the amplitude of seasonal growth oscillation, t_s is the summer point; the time of the year when growth is the highest (winter point, $t_w = t_s + 0.5$; the time of the year when growth is the lowest) and t_0 is the hypothetical age when the CL would be zero. Akaike's

information criterion (AIC) (Akaike, 1973) and Bayesian information criterion (BIC) (Schwarz, 1978) were used as an indicator of the precision. The lowest value of AIC and BIC indicate the best fitted model.

5.2.3 Length-Weight Relationship

The relationship between CL and BW was examined based on the equation expressed by Huxley (1932): ln (BW) = ln (a) + b ln (CL). The linear equation was fitted separately for males and females of *P. lanceolatus*. The *t*-test was used to test whether the b value departed significantly from expected hypothetical isometric value ($b = 3$). The asymptotic lengths (L_∞) of male and female were transformed to asymptotic weights (W_∞).

5.3 RESULTS

5.3.1 Growth Pattern

The overall sample was composed of 51.4 % males (9.9 - 26.4 mm CL) and 48.6 % females (8.3 - 34.3). Both male and female *P. lanceolatus* were first recruited in late autumn to winter (November to January) with modal size of around 10 mm in CL (Figs. 5.1 & 5.2). The size of newly recruited age group rapidly increased until the spawning season. The growth equations of von Bertalanffy and Pauly & Gaschütz with AIC and BIC values for males were obtained as:

$L_t = 27.8 [1 - \exp \{- 0.081 (t + 3.559)\}]$

$\quad$ (n = 42, AIC = 3483.48, BIC = 3504.03)……………………………………… (1)

$L_t = 28.7 [1 - \exp \{- 0.867 (t/12 + 0.4) - (0.161/2\pi) \sin (2\pi (t/12 - 0.826))\}]$

$\quad$ (n = 42, AIC = 3488.4, BIC = 3519.21)…………………………………………... (2)

The estimated growth equations for females were as follows:

$L_t = 33.8 [1 - \exp \{- 0.110 (t + 0.442)\}]$

$\quad$ (n = 39, AIC = 3754.05, BIC = 3774.48)…..……………………………………….. (3)

$L_t = 36.6 [1 - \exp \{- 0.995 (t/12 + 0.07) - (0.323/2\pi) \sin (2\pi (t/12 - 0.757))\}]$

$\quad$ (n = 39, AIC = 3927.52, BIC = 3958.16)…………………………………………… (4)

$\quad$ The growth curves are illustrated in Fig. 5.3. Based on the lowest value of AIC and BIC, von Bertalanffy equations provided the best-fit model for describing the growth for both sexes of *P. lanceolatus*. Equation (1) for males and (3) for females were, therefore, adopted to describe the growth of this shrimp. The F-test revealed that there was a significant difference between males and females in growth equation ($P < 0.05$). Females had a higher K value and larger asymptotic size in comparison to males (Fig. 5.3). The longevity for both sexes of *P. lanceolatus* was estimated to be around 27 months.
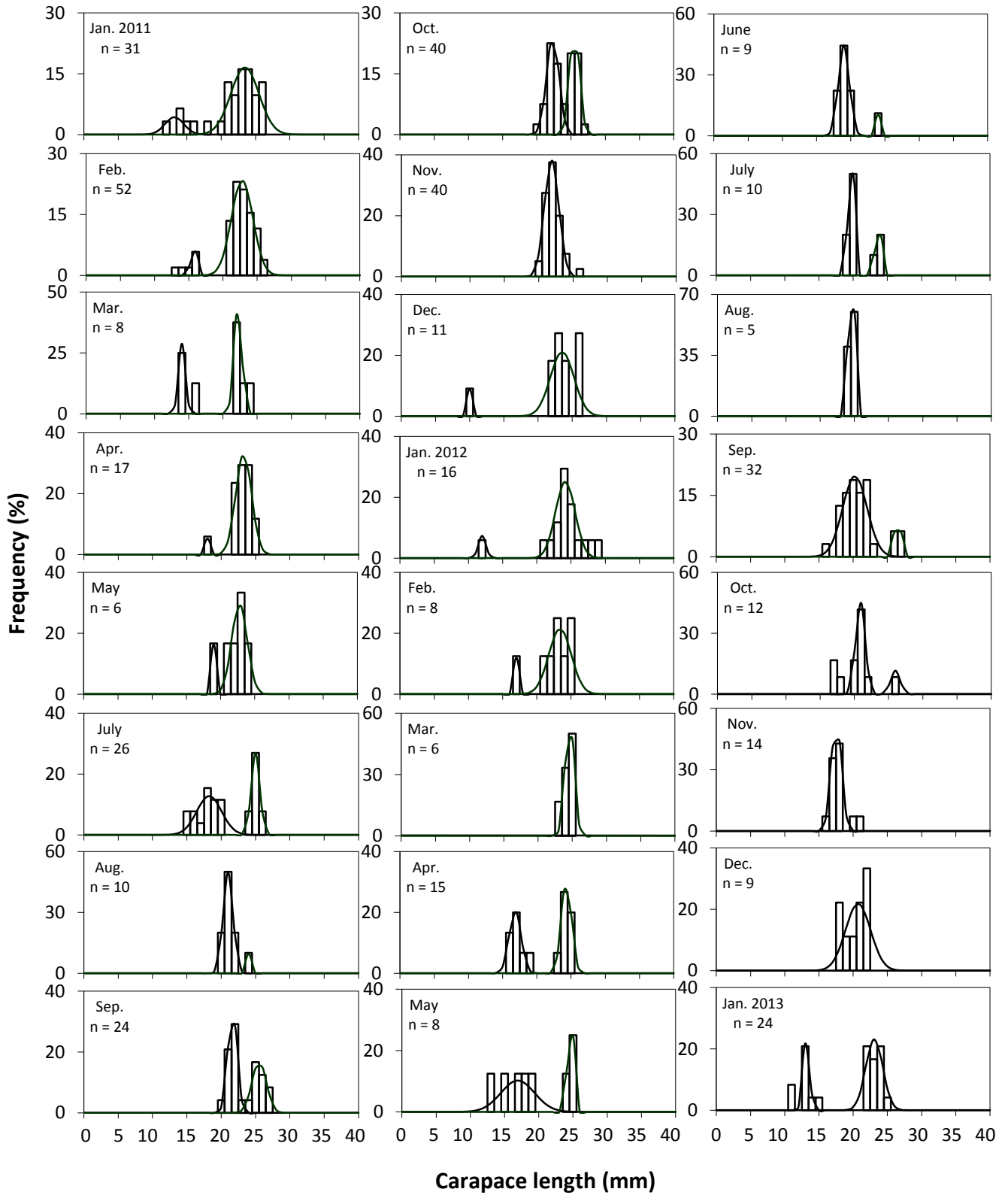
Fig. 5.1. Length-frequency distributions of male *Parapenaeus lanceolatus* Kubo, 1949 in Kagoshima Bay. Curves show the estimated normal distributions of age groups.
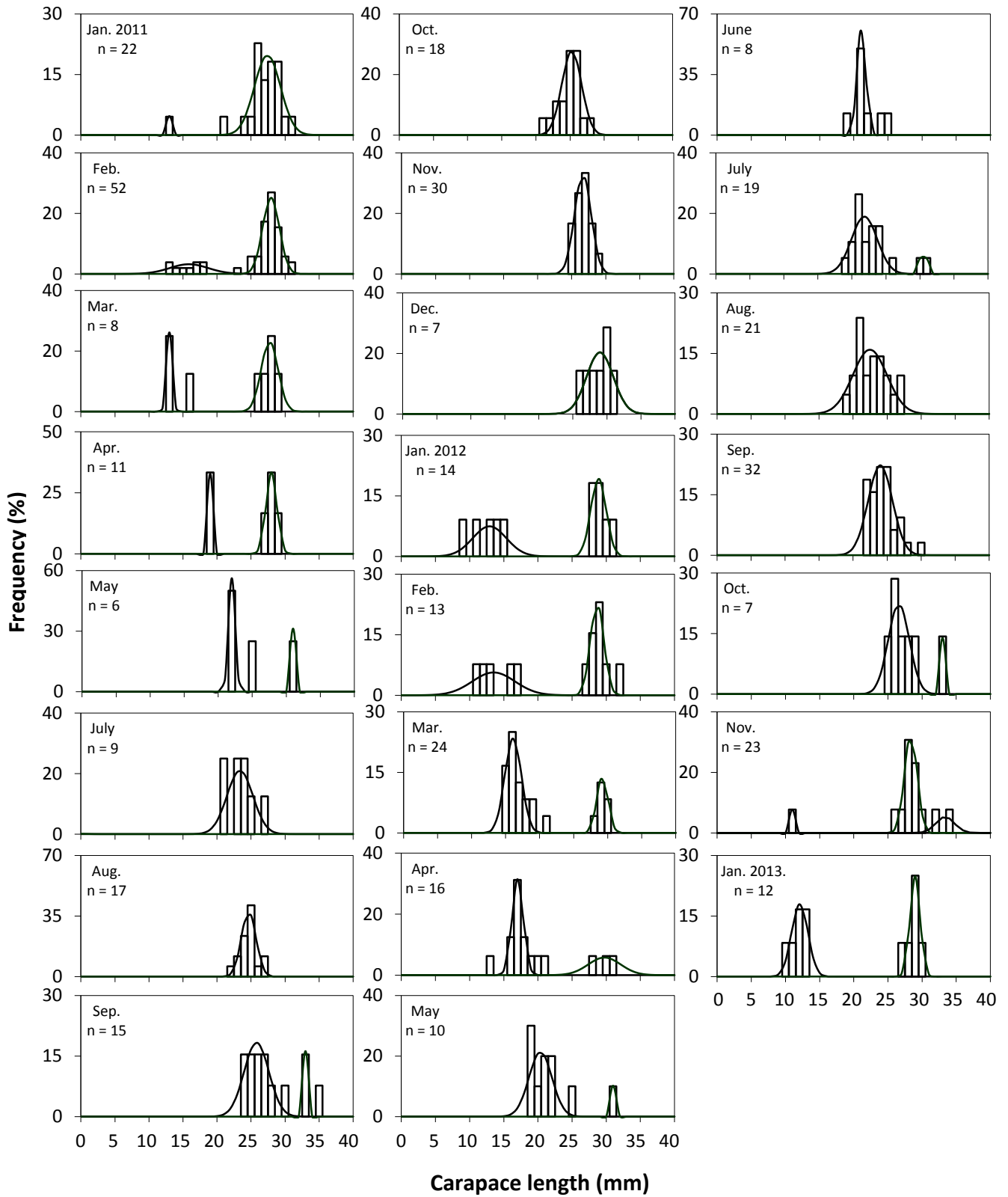
Fig. 5.2. Length-frequency distributions of female *Parapenaeus lanceolatus* Kubo, 1949 in Kagoshima Bay. Curves show the estimated normal distributions of age groups.
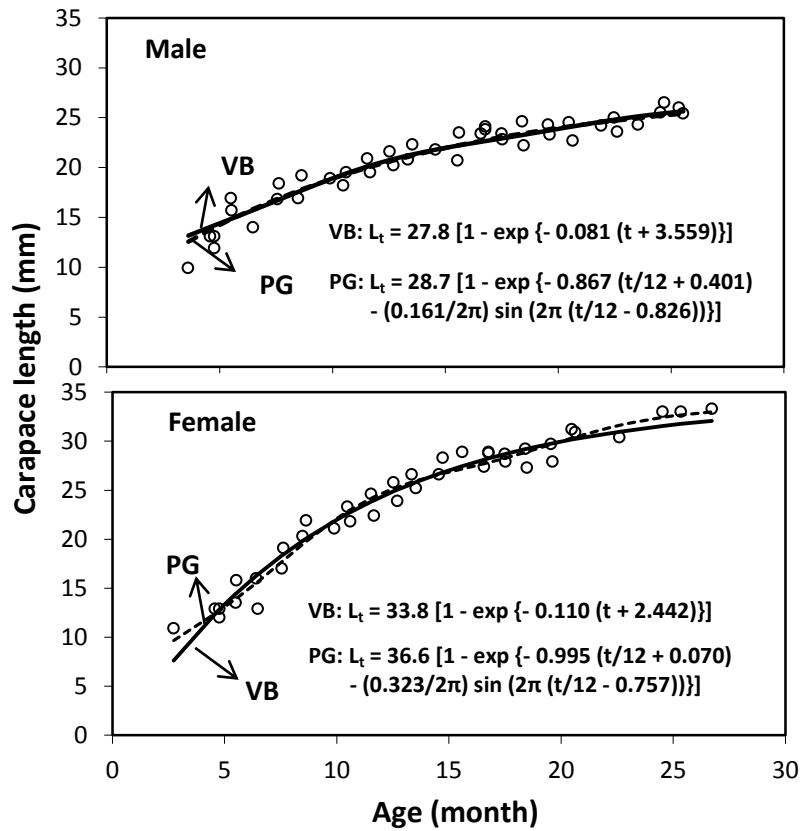
Fig. 5.3. Growth curves for male and female *Parapenaeus lanceolatus* Kubo, 1949 in Kagoshima Bay. Solid circles show the mean carapace lengths of age groups derived from Figs. 5.1 and 5.2. VB and PG indicate von Bertalanffy equation and Pauly & Gaschütz equation, respectively.

5.3.2 Length-Weight Relationship

The estimated *b* value was 2.514 for males and 2.462 for females indicated negative allometric growth for both sexes ($P < 0.05$) (Table 5.1). There was a statistically significant difference in both slope and elevation between sexes (ANCOVA, $P < 0.001$). The estimated W_∞ of males and females were 7.7 g and 15.6 g, respectively.

5.4 DISCUSSION

In the present study, growth pattern and longevity of *P. lanceolatus* were investigated using a time series of large number of specimens from Kagoshima Bay, southern Japan. We were fortunately able to capture a considerable amount of small individuals during their recruitment period, which allowed us to estimate age and growth of this shrimp using length-frequency distributions.

The growth of male and female *P. lanceolatus* was well described by the von Bertalanffy growth equation. The maximum CLs recorded in this study were 26.4 mm for males and 34.3 mm for females. Females attain larger size than males in same age group, indicating sexual dimorphism in size which was also observed for *Parapenaeus fissuroides* in Kagoshima Bay (Farhana & Ohtomi, 2016b). The standard deviations were greater in females than in males. This indicates the growth of females is more variable than in males. Females of *P. lanceolatus* had higher L_∞ and *K* values than males. This indicates females grew faster than males at same age group. These results agree with earlier studies reported for other penaeidae, *P. fissuroides* (Farhana & Ohtomi, 2016b), *Trachysalambria curvirostris* (Hossain & Ohtomi, 2010) in Kagoshima Bay.

Table 5.1 Allometric relationships between body weight (BW in g) and carapace length (CL in mm) of *Parapenaeus lanceolatus* Kubo, 1949 in Kagoshima Bay. The equation is: ln (BW) = ln (*a*) + *b* ln (CL). CL range, sample size (n) and coefficient of determination (r^2) are also given.

Sex	n	CL range (mm)	*a*	*b*	r^2
Male	290	12.31 – 26.42	0.00231	2.514	0.968 ($P < 0.05$)
Female	312	11.79 – 34.32	0.00270	2.462	0.967 ($P < 0.05$)

Based on the time series of length-frequency distributions, the longevity was estimated to be around 27 months for *P. lanceolatus*. According to King & Butler (1985), the difference in the longevity between species might be attributed to the differences in bathymetric distribution and deeper water shrimp exhibit longer life cycle. In comparison with *Parapenaeus longirostris* in European Atlantic and Mediterranean waters, the longevity of *P. lanceolatus* was somewhat shorter, as Sobrino et al. (2005) reported that the longevity of *P. longirostris* there was around 3 years and distributed in comparatively deeper waters.

In the present study, a negative allometry was observed between CL-BW relationships for both sexes of *P. lanceolatus*. The BW of males increased faster with CL after recruitment size than that of females. However, the absolute growth of females was faster than males (Fig. 5.3). Similar observation was reported for *P. fissuroides* by Farhana & Ohtomi (2016b) while studying in Kagoshima Bay. The females are commercially more important because the W_∞ for females is more than twice as large as that of males.

In the present study, the peak date of spawning season was considered as starting point of age for the calculation of growth equations, because the early life history of this species is still unknown. Future research can be done on the planktonic phase and the settlement period of this species.

6. DISTRIBUTION OF *PARAPENAEUS FISSUROIDES* AND

PARAPENAEUS LANCEOLATUS

6.1 INTRODUCTION

Understanding the causes and mechanisms of change in the abundance of species over time and space is a crucial issue in marine ecology. There is a growing interest in describing the spatial distribution of fishery resources by life phase and the habitats essential to complete the resources' life cycle. Research on nursery and spawning areas is essential for effective management of vulnerable stages of the life cycle (FAO, 2003), and knowledge of the spatial structure of a species is essential when the management question involves. However, studies on the distribution of *Parapenaeus fissuroides* and *Parapenaeus lanceolatus* are evidently lacking in Kagoshima Bay and other waters of the world. The present study aimed to provide the information on spatiotemporal distribution and spawning ground of these two species in Kagoshima Bay using large number specimens.

6.2 MATERIALS AND METHODS

6.2.1 Study Site

The present study was conducted in Kagoshima Bay, southern Japan in the eastern East China Sea (Fig. 6.1). Eight stations were established based on oceanographic and bathymetric features of the bay. The bay was demarcated into three areas; bay head, central basin and bay mouth. Eight sampling stations were considered as follows; stations 1, 2, and 3 in the bay head, stations 4, 5, 6 and 7 in the central basin, and station 8 in the bay mouth (Table 6.1).

6.2.2 Sampling Protocol and Data Analysis

Seasonal samplings were carried out in eight established sampling stations of Kagoshima Bay, southern Japan during 2006-2015. Experimental trawl surveys were conducted in central area with 10 m depth interval ranging from 110-150 m during February, 2012. In the present study, seasons were considered as winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). The samples were collected during day time on board of *Nansei Maru*, a training vessel of the Faculty of Fisheries, Kagoshima University. This ship was equipped with a simple trawl net carrying canvas kites on tip of the wings (Ohtomi et al., 2004) and a split-beam quantitative echo sounder (KFC-3000; KAIJO, Hamura, Japan). The dimensions of the net were, 23.5 m long, 6.7 m wide, 37.9 mm and 20.2 mm mesh size of net body and cod end respectively (Fig. 6.2). The mouth opening height of the net was 2.5 ± 0.3 m (Fuwa et al., 2010). Towing was conducted at 2.0 kt for 10 mins. preset duration. The bottom depth was recorded from the echo sounder at 1 min. intervals. Water depth was also recorded at 1 min. intervals using submersible data loggers (Compact-TD ATD-HR; JFE Advantech, Nishinomiya, Japan) attached to the head rope of the net. Effective tow duration was estimated by plotting echo sounder data and logger data (depth). Effective tow duration is the time between initial and final contact of the trawl net to bottom according to Fulanda and Ohtomi (2011) (Fig. 6.3). Trawl net contact with sea bottom was assumed when the difference between the depth readings on the echo sounder and TD logger reached to ≤ 2.8 m.

All collected specimens were sorted into species level and chilled immediately in ice on board. In the laboratory, the numbers and wet weight of these specimens were recorded at each haul. The catch in numbers and weight per haul then standardized to 10 mins. preset tow duration by following formula (Fulanda & Ohtomi, 2011):

$$\text{CPUE/weight} = \text{No. of individuals} \times \frac{\text{Preset tow duration}}{\text{Effective tow duration}}$$

All specimens of *Parapenaeus fissuroides* and *Parapenaeus lanceolatus* were sexed according to the presence of petasma in males and thelycum in females. Carapace length (CL) was measured with a digital slide calipers (CD-15PS, Mitutoyo, Kawasaki, Japan) to the nearest 0.01 mm. Individual body weight (BW) of each specimen of these two species was measured by an electronic balance (EB-430DW, Shimadzu, Kyoto, Japan) to the nearest 0.01 g. Distribution pattern with age progression of both species was investigated using each component normal distributions explained in growth analysis. In case of overlapping two age groups in the CL-frequency distributions, individuals were considered into age groups using the following discriminant function:

$$Z_i = (L_m\sigma_n + L_n\sigma_m) / (\sigma_m + \sigma_n) - L_i$$

Where L_m is the mean CL and σ_m is the standard deviation at age m; L_n and σ_n is the mean CL and standard deviation at age n; L_i is CL of individual i. If $Z_i > 0$, i belonged to m age group; if $Z_i < 0$, i belonged to n age group.
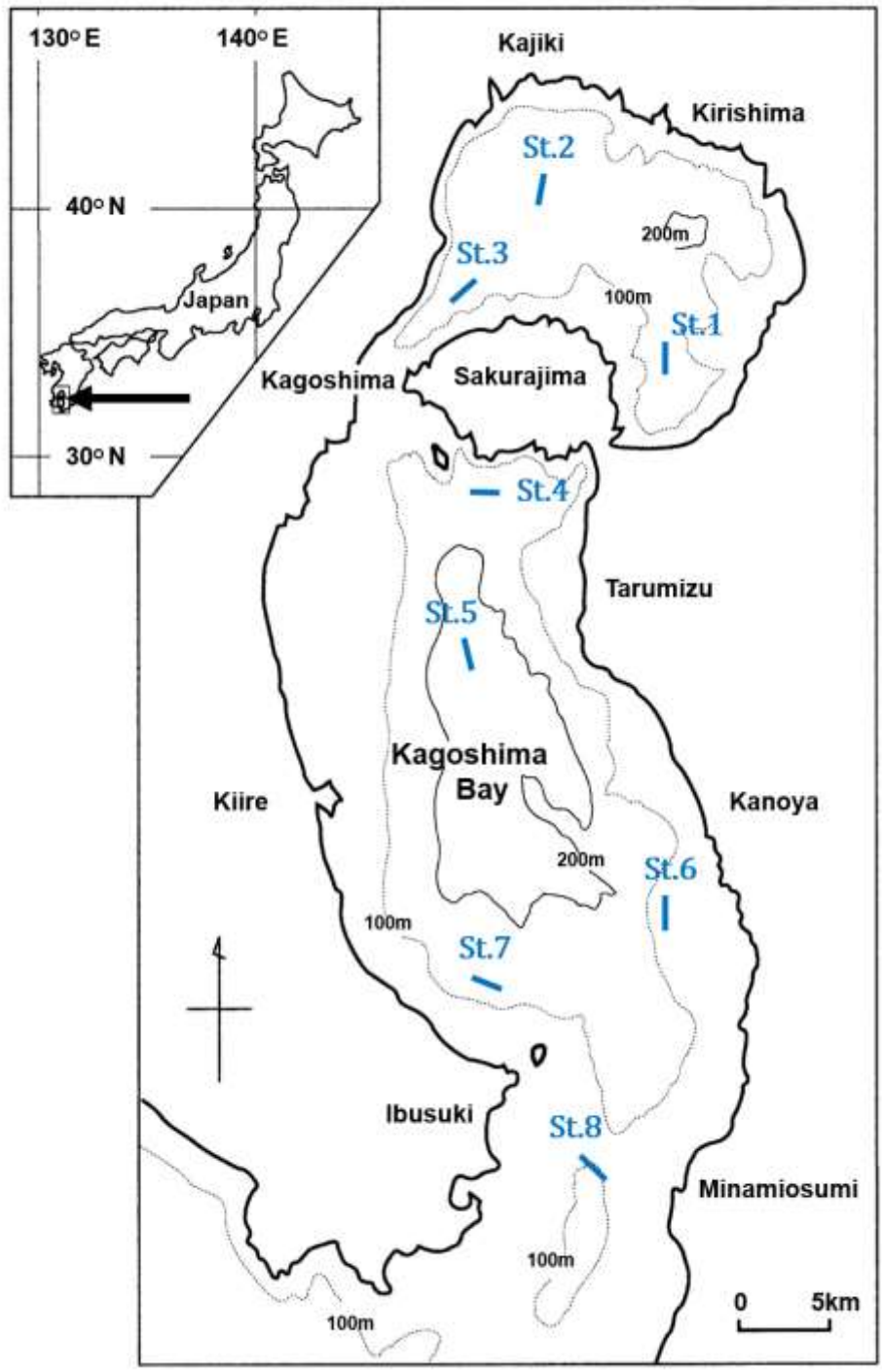
Fig. 6.1 Sampling sites in Kagoshima Bay, southern Japan.

Table 6.1 Latitude-longitude coordinates, mean depths, and warp lengths for sampling stations in Kagoshima Bay, southern Japan.

| Area | Station | Location | | Mean water depth (m) | Warp length (m) |
		Latitude	Longitude		
Bay head	1	$31^0 36.0'$	$130^0 45.0'$	136.2	620
	2	$31^0 40.2'$	$130^0 41.4'$	143.4	650
	3	$31^0 37.8'$	$130^0 37.2'$	127.9	600
Central basin	4	$31^0 31.8'$	$130^0 39.0'$	179.2	700
	5	$31^0 27.0'$	$130^0 37.2'$	228.5	900
	6	$31^0 20.4'$	$130^0 45.0'$	78.9	430
	7	$31^0 18.6'$	$130^0 39.0'$	135.7	600
Bay mouth	8	$31^0 12.6'$	$130^0 43.2'$	99.1	500
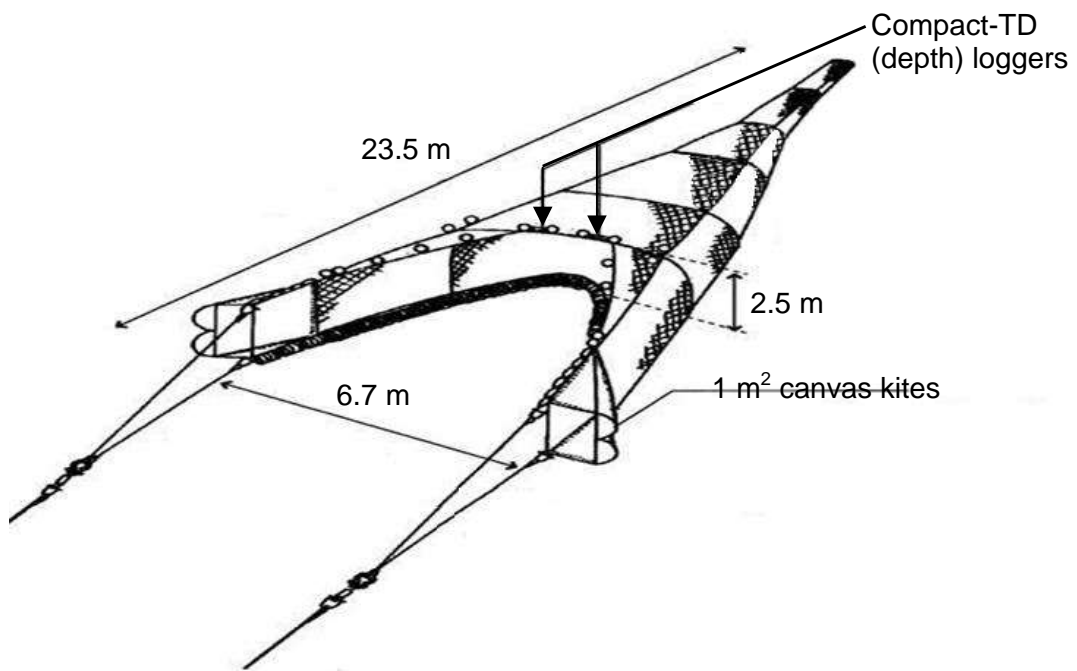
Fig. 6.2 The trawl net carrying canvas kites on the tip of the wings used for samplings.
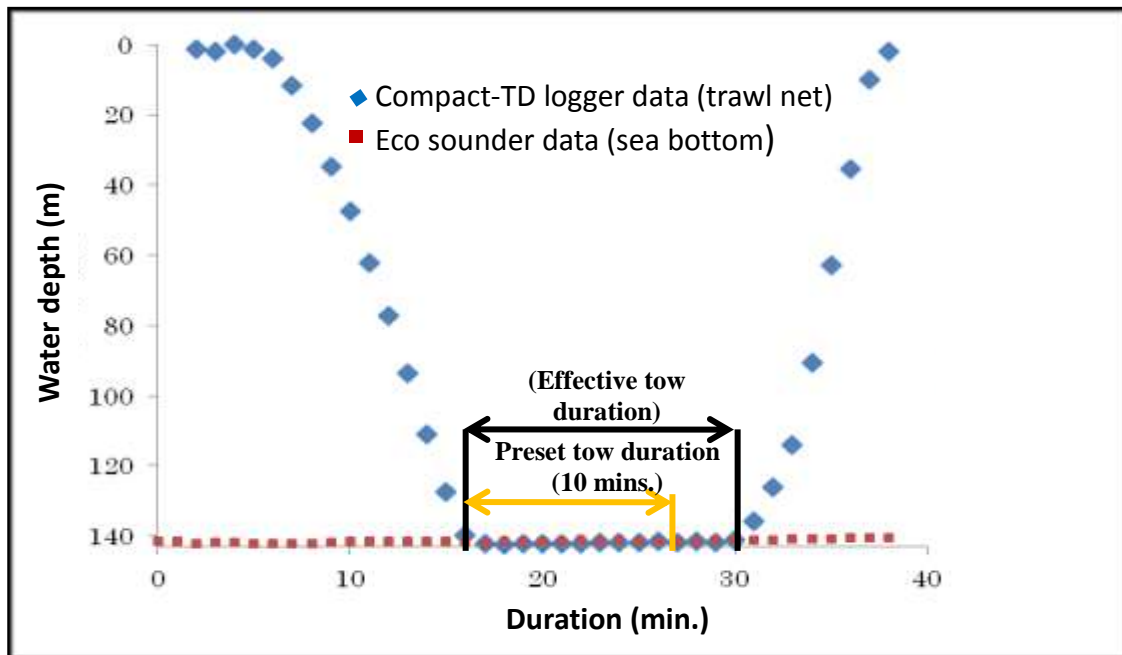
Fig. 6.3 Estimation of effective tow duration plotting logger data (depth) and echo sounder data (depth).
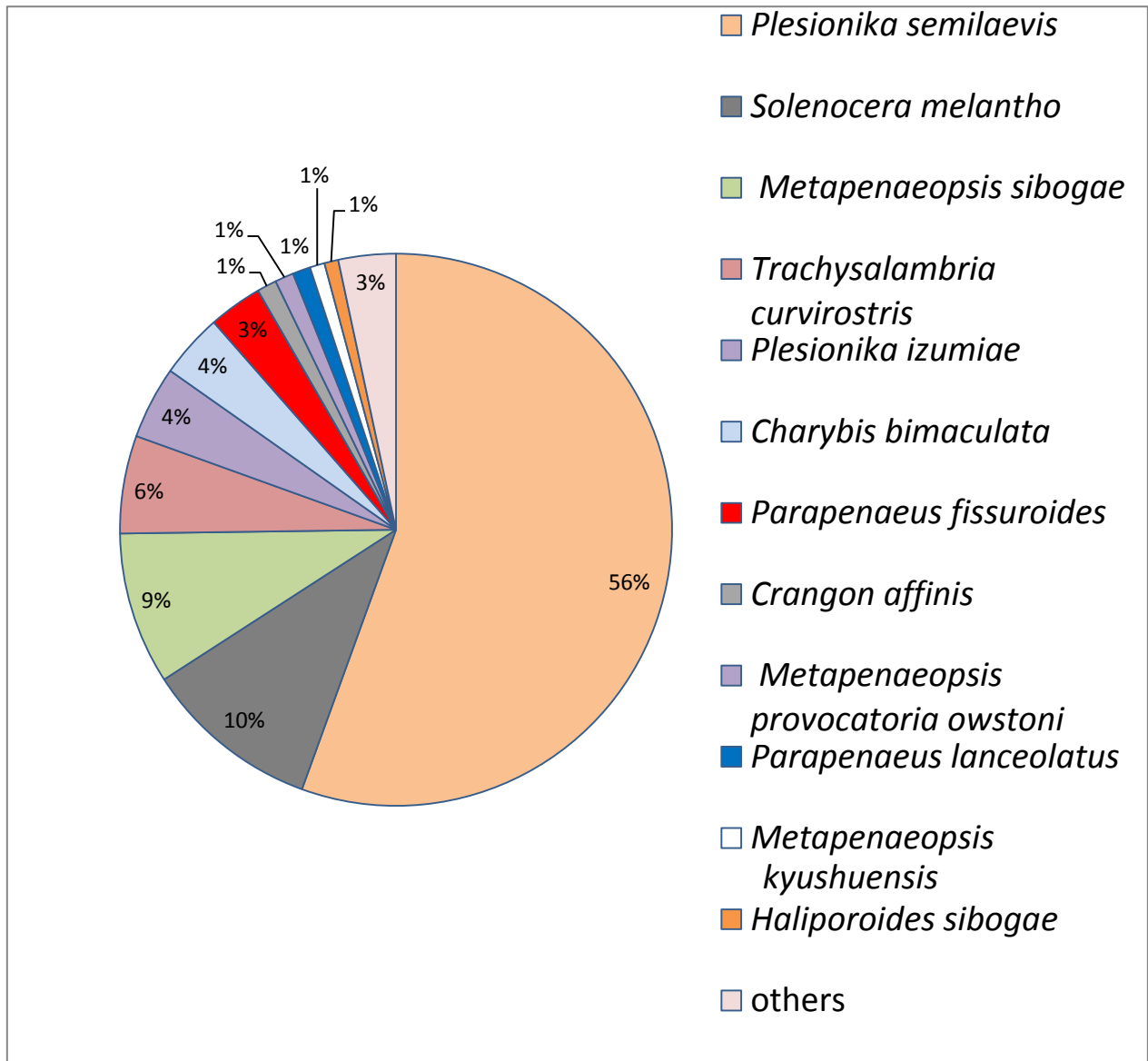
Fig. 6.4 Species composition in total weight (g) of benthic community in Kagoshima Bay during 2006-2013.
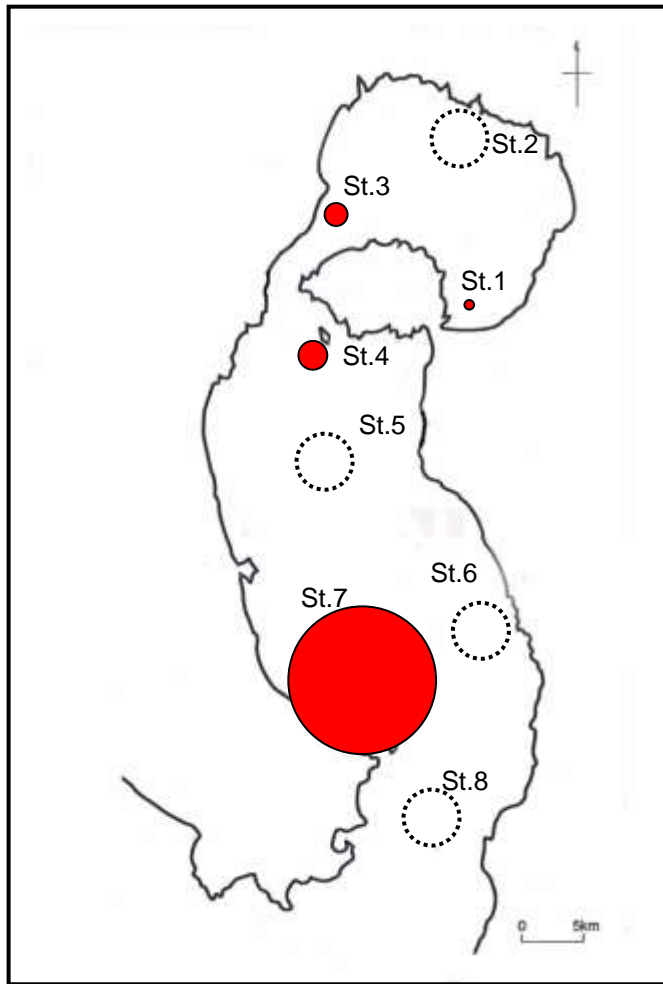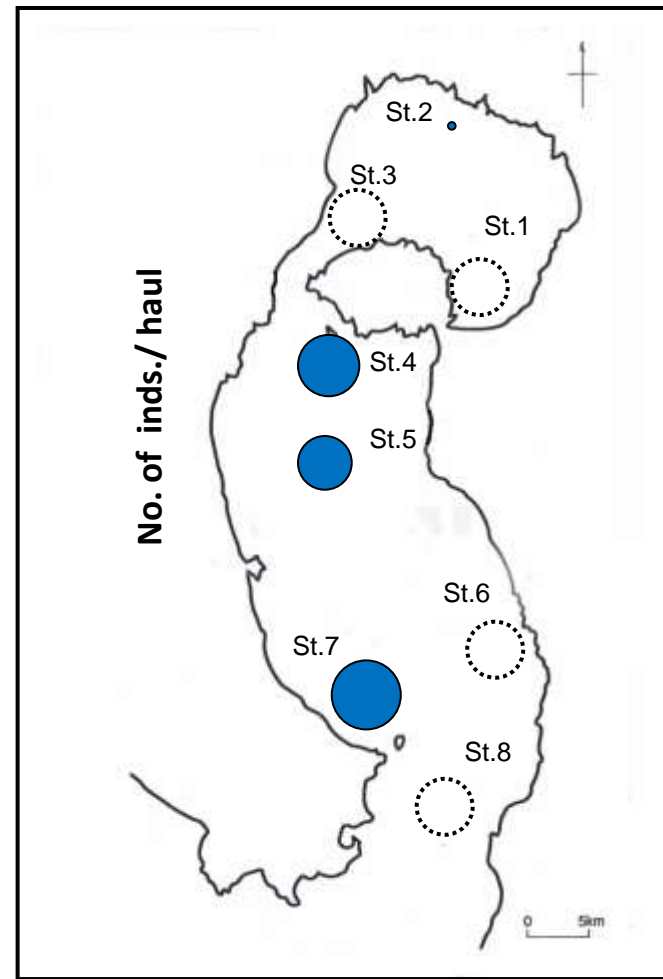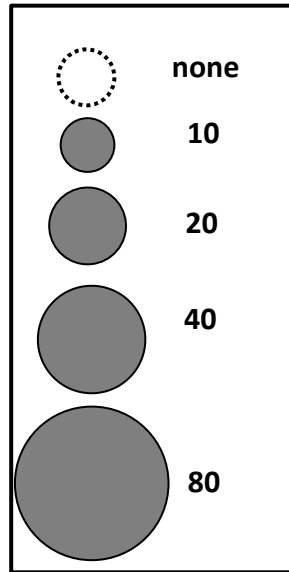
Fig. 6.5 Mean CPUE of *Parapenaeus fissuroides* Crosnier, 1985 and *Parapenaeus lanceolatus* Kubo, 1949 at each station from 2006 to 2015
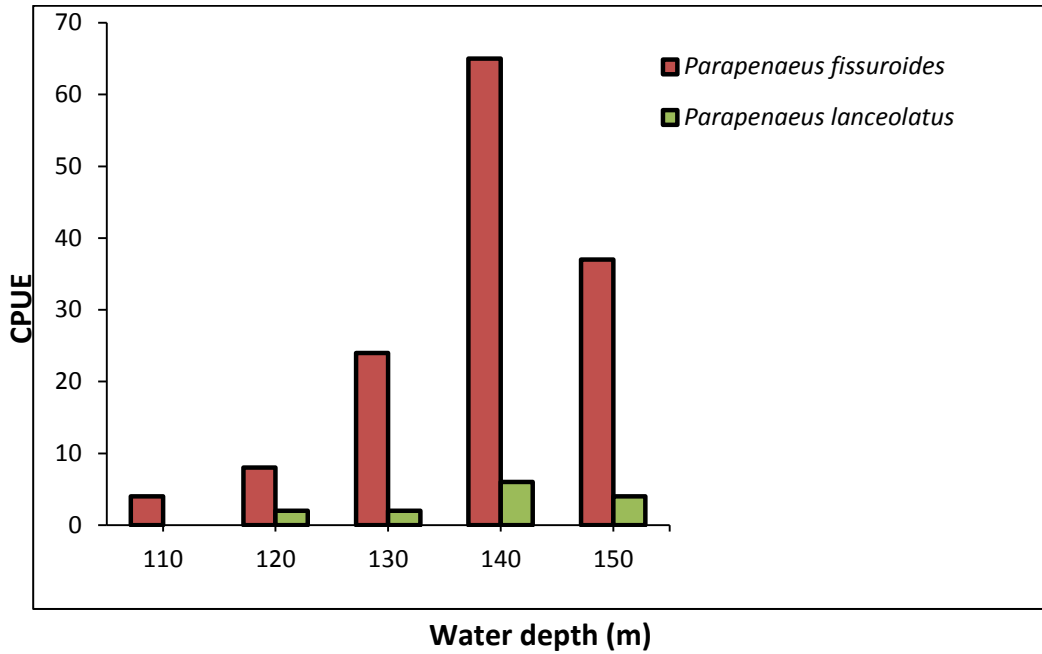
Fig. 6.6 CPUE in relation to water depth in the central area of Kagoshima Bay during February, 2012 (Experimental trawl survey).
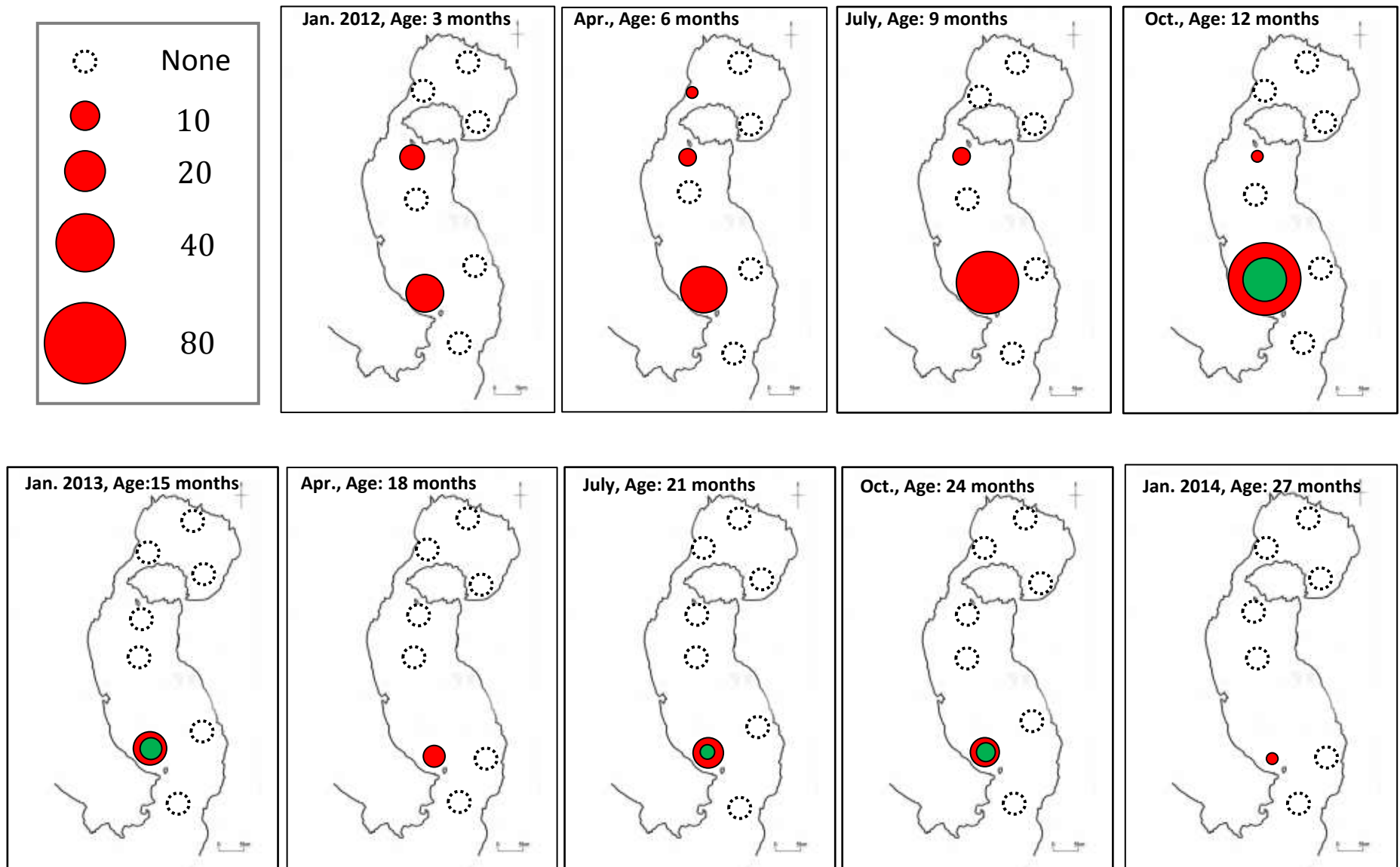
Fig. Distribution pattern of *Parapenaeus fissuroides* Crosnier, 1985 at each station with progression of age in Kagoshima Bay. The green circles indicate the CPUE of mature females.
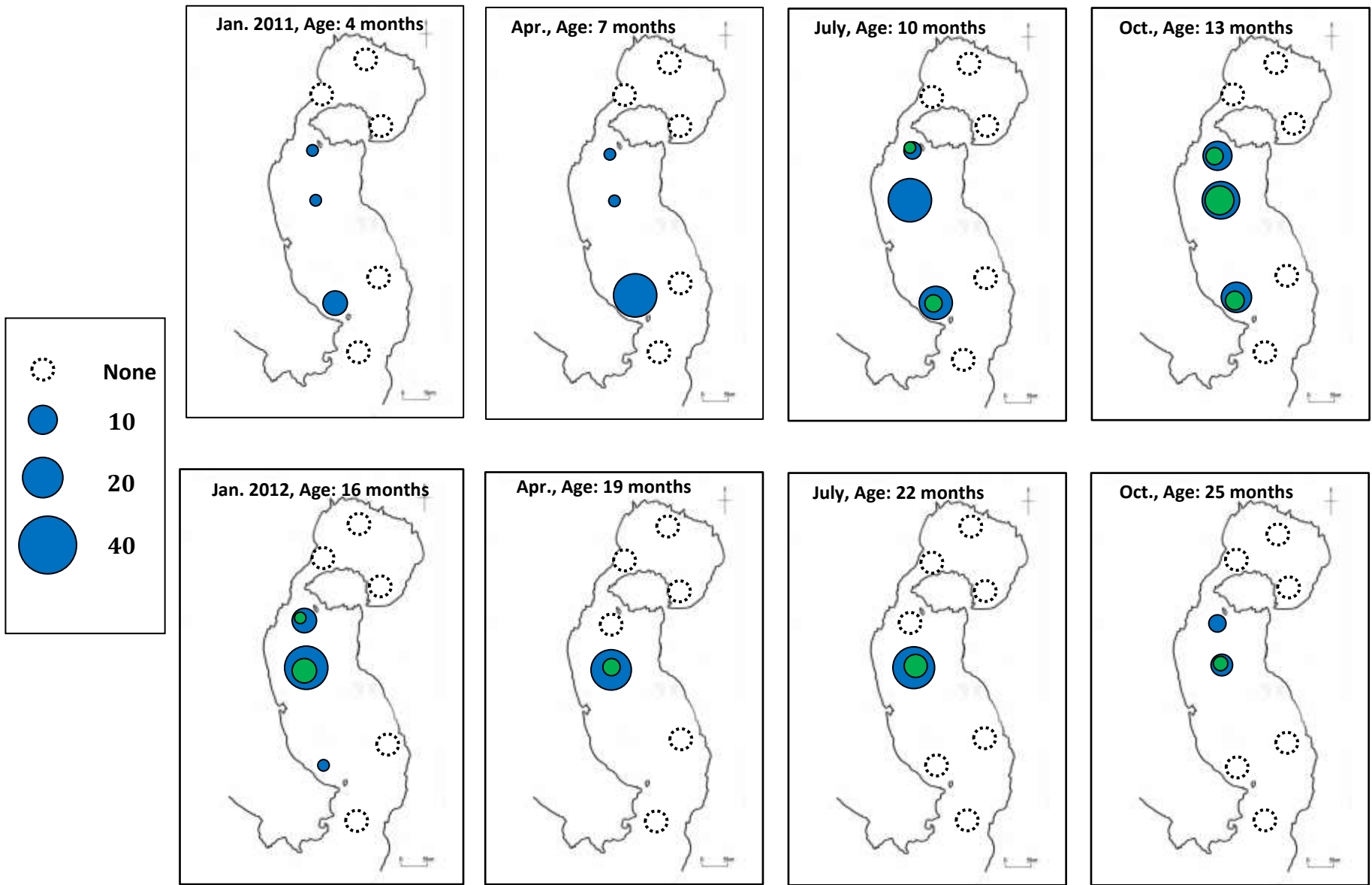
Fig. Distribution pattern of *Parapenaeus lanceolatus* Kubo, 1949 at each station with progression of age in Kagoshima Bay. The green circles indicate the CPUE of mature females.

6.3 RESULTS

6.3.1 Species composition

Species composition in total weight (g) of benthic community in Kagoshima Bay is shown in Fig. 6.4. *Plesionika Semilaevis* is the most dominant species followed by *Solenocera melantho* and *Metapenaeopsis sibogae* in the benthic community of Kagoshima Bay. *P. fissuroides* and *P. lanceolatus* are 7th and 10th dominant species in the benthic community of the bay.

6.3.2 Spatial distribution

The catch from the present study revealed that *P. fissuroides* was distributed in the central basin area (Sts. 7 & 4); whereas Sts. 1 and 3 in the bay head recorded only lower number of specimens (Fig. 6.5) in Kagoshima Bay. The results showed that *P. fissuroides* was distributed in depths from around 130-180 m, while highest individuals were recorded around 130 m depth (St. 7). The number of specimens per haul at this station ranged from 5 to 231 with an average of 78, and the weight ranging from 3 to 1292 g with an average of 276 g.

P. lanceolatus was distributed in the central basin area at Sts. 4, 5 and 7 and St. 2 in bay head area (Fig. 6.5). This species was distributed at depths ranging from around 130-230 m in the bay. The number of specimens per haul ranged from 0 to 96 with an average of 16 at St. 7, 14 at St. 4 and 10 at St. 5. Few individuals were recorded at St. 2. The weight per haul ranged from 4 to 475 g and the average was 68 g at St.7, 56 g at St. 4 and 41 g at St. 5.

In the experimental trawl surveys, *P. fissuroides* obtained from 110-150 m water depth and the maximum CPUE was observed at 140 m water depth (Fig. 6.6). Few specimens of *P. lanceolatus* caught from 120-150 m water depth.

6.3.3 Temporal distribution

Distribution pattern of *P. fissuroides* and *P. lanceolatus* with progression of age at each station in Kagoshima Bay are shown in Figs. 6.7 and 6.8. Small individuals of *P. fissuroides* were observed in central basin during winter. With the progression of age, they were observed at same distributed areas mainly southern shallower part of central basin. In case of *P. lanceolatus* young individuals appeared almost entire central basin and older individuals appeared only in deeper parts of central bay.

6.3.4 Spawning ground

Distribution pattern with the age progression of mature females indicate the main spawning ground of *P. fissuroides* was in the southern shallower central basin (Fig. 6.7). In case of *P. lanceolatus*, different spawning grounds were detected for young and older individuals. Young mature females obtained from almost entire central basin while older mature females obtained only in deeper areas of central bay (Fig. 6.8).

6.4 Discussion

Collecting samples of shrimp population inhabiting deep waters are quite difficult. Few studies were focused on distribution of *Parapenaeus* species including *P. fissuroides* and *P. lanceolatus* in world waters. The information on spatiotemporal distribution of these species is indispensable to understand the population dynamics and appropriate fisheries management strategies. This study described the spatiotemporal distribution of these two species in Kagoshima Bay using a long-term survey data.

According to the number of individuals per haul, both species are mainly distributed in the central area of the bay (Fig. 6.5). The present study revealed that *P. fissuroides* is mainly inhibit in relatively shallower part of central bay, while *P. lanceolatus* is distributed in almost entire central bay. The quantitative distribution of *P. fissuroides* was studied in East China Sea by Song et al. (2002). He obtained this species in shallower area with 60 m depth in eastern areas ($26^0$00´-$30^0$00´). Higher density areas were around 100 m depth near Taiwan. The experimental trawl surveys and seasonal samplings revealed that the depth range of *P. fissuroides* was around 110-180 m and mainly distributed in around 130 m in Kagoshima Bay (Figs. 6.5 & 6.6). Several studies suggested local water environment play important role in partitioning fishes and other aquatic animals (Schoener 1974; Gatz, 1979). The bottom water temperature of main distributed area of *P. fissuroides* tended to be stable throughout the year (Farhana & Ohtomi, 2016). Song et al., 2002 also reported that higher density of *P. fissuroides* obtained where the bottom water temperature was relatively stable without obvious seasonal changes. The depth range of *P. lanceolatus* was reported from 300 to 350 m by Holthuis (1980). The present study confirmed the presence of this species in relatively shallower water in Kagoshima Bay. The depth of this species ranged from around 120-230 m in the bay (Figs. 6.5 & 6.6). Depth is considered one of the major factors influencing the spatial distribution of penaeid shrimps (Dall et al., 1990; Somers, 1994). Several authors reported bottom sediment characteristic is one of the key factors influencing spatial distribution of crustaceans (Wenner et al., 1983; Abelló et al., 1988). The type of sediment in the central areas of Kagoshima Bay is muddy (Hossain and Ohtomi, unpublished). *Parapenaeus longirostris* was reported to live on muddy bottoms in the Mediterranean Sea and the western and eastern northern Atlantic Ocean (Heldt, 1954; Holthuis, 1980). Water depth and

sediment type can be the factors influencing the spatial distribution of these two species in Kagoshima Bay.

Distribution pattern of *P. fissuroides* with the progression of age revealed that both young and older individuals of this shrimp occurred in their distributed areas in central basin (Fig. 6.7). Lu et al. (2007) also reported that no apparent migration was observed for *P. fissuroides* in east of East China Sea. In case of *P. lanceolatus*, Young individuals appeared almost entire central basin while older individuals appeared only deeper parts of central bay (Fig. 6.8). The reason can be migration, predation or death. A migratory movement of *P. longirostris* was reported in the central Mediterranean Sea (Ardizzone et al., 1990).

In the present study, Environmental variables such as current flows, temporal distribution of food availability, predations were not investigated. In addition, further detailed studies on migration of these shrimps are needed to clarify the distribution pattern of these shrimps in Kagoshima Bay.

Parapenaeus are well distributed in Indo-west Pacific and Atlantic regions (Holthuis, 1980). In spite of their economic importance, few biological studies have been reported for *Parapenaeus* species including *P. fissuroides* and *P. lanceolatus*. The present study conducted in Kagoshima Bay, southern Japan which is a semi enclosed deep water body. Though four species of *Parapenaeus* were recorded in the bay, *P. fissuroides* and *P. laneolatus* are two of the dominant species in the benthic community of the bay. This study provides the information on the fisheries biology of these two species in Kagoshima Bay that would be helpful for sustainable management of these fisheries in the Pacific region.

P. fissuroides and *P. lanceolatus* are mainly distributed in the central area of Kagoshima Bay. The majority of *P. fissuroides* was distributed in around 130 m depth in the central bay, while *P. lanceolatus* was distributed both in relatively shallower (around 130 m) and deeper (180-230 m) area of the central bay (Fig. 6.5). Their different bathymetric distribution was also reported in world waters. *P. fissuroides* was caught in 60-200 m water depth in East China Sea (Song et al., 2002) and *P. lanceolatus* was recorded in 300-350 m water depth in Pacific region (Holthuis, 1980). *P. lanceolatus* inhabits a wider range of water depths in comparison to *P. fissuroides* in Kagoshima Bay. In comparison to other closely related species in world waters, *Parapenaeus longirostris* was captured between 100-508 m isobaths and the highest abundances were observed mainly between 150-350 m isobaths in central Mediterranean (Ardizzone et al., 1990). In Kagoshima Bay, other penaeidae, *Trachysalambria curvirostris* is well distributed in the bay head area with an around 130 m water depth (Hossain & Ohtomi, 2010). Several authors reported the correlation between body size of the shrimp and water depth. Larger shrimps are likely to inhibit in deeper water areas (King and Butler, 1985, Ardizzone et al., 1990, Company

and Sardá, 2000). The maximum carapace length of *P. fissuroides* and *P. lanceolatus* are larger than *T. curvirostrs*. Sediment type can be influencing factor for spatial distribution. *T. curvirostris* is mostly living on sandy-mud bottoms in Kagoshima Bay and eastern Mediterranean Sea (Hossain and Ohtomi, 2010; Galil, 2000). *P. fissuroides* and *P. lanceolatus* are mostly inhibit in the central bay which is consists of muddy bottoms (Hossain & Ohtomi, unpublished). In addition, Ohtomi et al. (2008) reported that the sediment composition of Kagoshima Bay is strongly influenced by current flows. Environmental variable such as food availability was not considered in the present study.

From the analysis of distribution of *P. fissuroides* and *P. lanceolatus* with the progression of age revealed different distribution pattern for these shrimps in the bay. *P. fissuroides* recruited, spawned and spent their life mainly in southern central bay with around 130 m water depth (Fig. 6.7). This analysis suggested that main spawning grounds were different for young and older individuals of *P. lanceolatus*. Young individuals spawned in almost entire central bay, while older individuals spawned only deeper central bay (Fig. 6.8).

The size at sexual maturity for *P. fissuroides* was 23 mm in CL (Fig. 2.3) and 22 mm in CL for *P. lanceolatus* (Fig. 4.3). Transforming these CLs to ages using the estimated growth equations, the mature females of both species belong to 1 year old group. A prolonged spawning season was observed for *P. lanceolatus* ranging from July to April (Fig. 4.4), while the estimated spawning season of *P. fissuroides* in Kagoshima Bay was during July to February (Fig. 2.4). The spawning season of *P. lanceolatus* was more extended than *P. fissuroides*. Several authors reported that deeper water species exhibit a longer reproductive period (Harrison, 1988; Gage & Tyler, 1991; Bishop & Shalla, 1994). *P. lanceolatus* is distributed in deeper areas of the bay

compare to *P. fissuroides* (Fig. 6.5). Another deep-water shrimp *P. longirostris* spawn throughout the year reported by Kasalica et al. (2011) in southern Adriatic Sea.

The Pauly and Gaschütz equation provided the best fitting model for describing the growth for both sexes of *P. fissuroides* (Fig. 3.3) suggested that growth rates of this shrimp followed a seasonal oscillation, while the growth of *P. lanceolatus* for both sexes was well described by von Bertalanffy equation (Fig. 5.3). The growth oscillation of *P. fissuroides* was correlated with their spawning season in Kagoshima Bay (Farhana & Ohtomi, 2016a). In comparison with *P. lanceolatus*, the shorter spawning period of *P. fissuroides* may influence their seasonal oscillation in growth rate, while the longer reproductive period of *P. lanceolatus* might not have any influence on their growth rate. *P. fissuroides* had higher K and L_∞ values than *P. lanceolatus* for both sexes. This indicate higher growth rate in *P. fissuroides* than *P. lanceolatus*. Females had a lower K value but reached larger sizes at each age and larger asymptotic size than males in *P. fissuroides*. For *P. lanceolatus*, females had a higher L_∞ and K value and larger asymptotic size in comparison to males.

The present study revealed the different bathymetric distribution and different temporal distribution of these closely related species in Kagoshima Bay, which was quite interesting. This study provides a lot of important information on their biology as biological information of *P. fissuroides* and *P. lanceolatus* is evidently lacking in world waters.

8. CONCLUSION

Parapenaeus fissuroides and *Parapenaeus lanceolatus* are two of the dominant species in the benthic community of Kagoshima Bay, southern Japan. They are mainly distributed in the central area of Kagoshima Bay. *P. fissuroides* recruited, spawned and spent their life mainly in southern central bay with around 130 m water depth. The main spawning grounds were different for young and older individuals of *P. lanceolatus*. The spawning grounds for young individuals were almost the entire central bay and older individuals spawned only in deeper part of the central bay. *P. lanceolatus* is a deeper water species compare to *P. fissuroides*.

The ovaries of *P. fissuroides* and *P. lanceolatus* were observed as asynchronous type, suggesting that these species are multiple spawners. Cortical granules in the peripheral region of the oocytes were considered as spawning sign to define the mature females of both species. The size at sexual maturity of female *P. fissuroides* and *P. lanceolatus* was estimated to be 23 mm and 22 mm in carapace length, respectively. The spawning season was estimated during July to February for *P. fissuroides* and July to April for *P. lanceolatus*. The spawning season of *P. lanceolatus* was more extended than *P. fissuroides*.

In the present study, age and growth of *P. fissuroides* and *P. lanceolatus* were estimated using monthly length-frequency distribution. For *P. fissuroides*, CL in males ranged from 7.7 - 27.1 mm and 6.4 - 36.1 mm in females. And for *P. lanceolatus*, males ranged from 9.9 - 26.4 mm in CL and females 8.3 - 34.3 mm in CL. *P. fissuroides* and *P. lanceolatus* both were recruited in late autumn to winter (November to January) with modal size of around 11 mm CL and 10 mm in CL respectively. Growth was best described by Pauly and Gaschütz growth equation for *P. fissuroides* and von Bertalanffy equation for *P. lanceolatus*. The monthly growth rate (%) of *P.*

fissuroides was the highest during July to August (summer point) and the lowest during January to February (winter point). This suggests that the growth of this shrimp slows down during the reproductive period from summer to winter. Females grew faster and reached larger sizes than males of the same age group in these shrimps. The longevity of *P. fissuroides* was estimated to be around 24 months for males and 30 months for females. The longevity for male and female *P. lanceolatus* was around 27 months.

The present study provided biological information on distribution pattern, size at sexual maturity, spawning season, asymptotic length, growth pattern, growth performance and longevity of *P. fissuroides* and *P. lanceolatus* in Kagoshima Bay. These data will be helpful for designing a fishing management strategy to ensure a sustainable exploitation of these shrimp in Kagoshima Bay.

9. ACKNOWLEDGEMENT

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