Thesis for the Degree of Master of Fisheries Science

Feeding Ecology of the Sand Shrimp *Crangon hakodatei* Rathbun (Decapoda: Crangonidae) in the East Coast of Korea

by

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KOICA-PKNU International Graduate Program of Fisheries Science

The Graduate School

Pukyong National University

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Feeding Ecology of the Sand Shrimp *Crangon hakodatei* Rathbun (Decapoda: Crangonidae) in the East Coast of Korea,

한국 동해안에 서식하는 마루자주새우의 섭이생태 연구

Advisor: Prof. Chul-Woong Oh

by

Islam Maher

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Feeding Ecology of the Sand Shrimp *Crangon hakodatei* Rathbun (Decapoda: Crangonidae) in the East Coast of Korea

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Abstract

The feeding habits of sand the shrimp *Crangon hakodatei* were investigated in the East Coast of Korea based on the analysis of 602 stomach contents, with comparison by season and size class of diet composition and prey diversity. The investigation also took account of the influence of season, sex, size and area variation in the diet composition and prey diversity. The relative degree of stomach fullness, frequency of

occurrence and relative abundance were also determined. Specimens were collected monthly over a period from August 2010 to May 2011 at depths of 30 to 60 m.

The diet of *C. hakodatei* consisted of 17 different prey categories, and belonged mainly to crustaceans (e.g. amphipods, mysids, isopods, cumaceans, decapods and copepods), molluscs (e.g. gastropods and bivalves), polychaetes, nematodes, algae and fishes. The above prey categories consisted of 89.1% of the relative abundance and 92.79% of frequency of occurrence in prey item for males. For females it consisted of 85.9 % of the relative abundance and 91.32% of the frequency of occurrence. Crustaceans were the dominant items of the diet. Molluscs, nematodes and fishes were also memorable prey items, whilst other food categories like polychaetes and algae occurred in low percentages. For small-sized shrimps (< 10 mm carapace length) amphipods and mysids consist of more than 67% of its food items in both relative abundance and frequency of occurrence. Large-sized shrimps (>10 mm CL) tended to be more dependent on amphipods more than mysids. Amphipods and mysids together constituted the dominant prey, accounting for over 50% of the diet in both percent occurrence and relative abundance. The abundance and occurrence composition of food items showed a seasonal variation. Amphipods and mysids were the predominant prey items in autumn (45%), winter (30%) and spring (40%). There was also variation according to area. With amphipods and mysids being conspicuously the predominant prey items in area 1 (40%) and area 2 (45%). Amphipods were the most dominant food item with regard to season, size class, sex or area. The females feeding behaviour differed among the seasons. In spring, decreased feeding activity, highest value of vacuity index and lowest values of stomach fullness have been shown.

Introduction

Malacostraca is the largest subgroup of crustaceans which includes the order decapod. There are more than 22,000 taxa in this group representing two third of all crustacean species and contains all the larger forms (Akbulut et al., 2009). One of the species in this sub group *Crangon hakodatei*. Malacostraca members play an important role in aquatic ecosystems. They are prey for fishes and other aquatic organisms and an important diet in the food web of the aquatic ecosystem (Pechenik, 1996). Decapods such as shrimps, crabs, lobsters and crayfish show much variation within the group of crustaceans, represented about 175 families and 15,000 described taxa. One of these families is family Crangonidae (Bracken et al., 2009). Few years ago, the Crangonidae was one of the most poorly taxonomically progressed groups in the Malacostraca. Until now the approximately 160 species belonging to 20 genera have been recognized within the family Crangonidae (Holthuis, 1993). From East Asian waters eighteen species have been recognized belonging to the genus Crangon (Hayashi and Kim, 1999). The classification of the East Asian species of *Crangon* has always been controversial despite the recent review of its status by Hayashi and

Kim in 1998 and 1999 (Konishi and Kim, 2000). The species are easily confused with each other because the taxonomic status is very unsettled and many taxa in the Crangonidae family are incompletely known as yet (Hayashi, 1999; Kim, 2003). Shrimps of the genus *Crangon* are characterized by one median gastric spine on the carapace, a single arthrobranch on the third maxilliped and one ventral spine on the merus of the first pereopod (Christoffersen, 1988).

Due to the rapid change in environmental factors such as temperature and salinity Crangonid shrimps play an important role in food webs of coastal ecosystems, (Li and Hong, 2006). As other shrimps *Crangon* spp. play a role that is no smaller in the trophic interrelations among mass species of nekton (Chuhukalo and Shebanova, 2008). Members of the family Crangonidae usually called sand or black tailed shrimp (Wicksten, 1980). They are commonly distributed on sandy, muddy or mixed bottoms of littoral and sublittoral areas from cold to temperate regions of the Northern Hemisphere. The sand shrimp is one of the most abundant and most important community components in the estuarine and coastal soft bottom as prey or predator, also can play a role in contributing to human protein need by consumption as food, and have high commercial value

(Price, 1962, Boddeke, 1989 ; Hayashi et al., 1999; Tiews, 1970; Oh et al., 2001; Hanamura et al., 2003). *C. hakodatei* from other related species are recognized by a high blunt median dorsal carina on the third to fifth abdominal somites. *Crangon nigricauda* from Korea (Kim and Park, 1972) was later reidentified as *C. hakodatei* by Kim (1976). From northern China, *Crangon affinis*- Liu, 1955 referred to as *C. hakodatei* (Hayashi et al, 1999; Chen et al, 2006). As family Crangonidae members the *C. hakodatei* are inhabitants on a sandy, muddy or mixed substrata of sublittoral areas from 10 to 250 m depth. The geographical distribution of the species is known as follows; Yellow Sea, Korean coast of the northern part of the East China Sea, Sea of Japan, eastern coast of Korea, northern part of the Pacific coast of Japan and southern part of the Sea of Okhotsk, southern coast of Korea (Hayashi et al., 1999; Cha et al., 2006) .

In fact, there is no information available on the diet composition of *C. hakodatei*. In addition, many studies have been made of the feeding behaviour for other species of the genus *Crangon*, e.g. *C. affinis* De Haan (Hong and Oh, 1989), *C. allmani* (Allen, 1960), *C. crangon* (Tiews, 1968; Oh 2001), *C. septemspinosa* (Wilcox et al., 1974), *C. uritai* (Nakaya et al., 2004). This study was undertaken to describe the diet composition of this species. The results of this investigation will increase our understanding of its feeding strategy and feeding patterns. The study will also provide the knowledge about the relation between this species and other species and their effect in marine ecosystems. This will be useful when we estimate energy flow from the primary producers to the higher trophic level. Trophic interactions are considered as a key element in knowing the ecological role of species in the community of any ecosystem, and one can describe diet composition and assign trophic level by stomach content analyses (Lorman and Magnuson, 1978; Momot et al., 1978). In fact, estimation of prey abundance, frequency of occurrence and relative importance of food items can provide critical ecological information (Espinoza and Wehrtmann, 2008) and provide our information about food contains (Crisp, 1963; Fagade and Olaniyan, 1972).

When animal stomach content analysis is done, often it is difficult to determinate the origins of ingested prey, because some diet components may digest faster than others and the contents may be changed due to different digestibility of tissues. Analysis often shows the items that have been macerated by mouthparts and/or partly digested. In shrimp the identification stomach contains is more difficult, because shrimps do not have the ability to swallow food whole, but pinch off tiny pieces (Foale and Day, 1992; O'Brien 1994; Bird 1997; Chuhukalo and. Shebanova 2008) .

The objective of this study is to investigate the diet and feeding behaviour of *C. hakodatei*. The study was carried out in two parts.

1) The first part involved the comparison of stomach from two different ecological habitats (Area 1 and 2).
2) The second involved the comparison of the stomach contents of shrimp from the third area (Area 3). This was based on seasonal variation (autumn, winter and spring).

In both experiments, the specific objectives were:

First of all get the first data on the feeding ecology of the *Crangon hakodatei*. Secondly the effect of seasonal variations, sex, size and areas differentiation in feeding habits were studied. The third is to provide our knowledge about the relation between this species and their prey and prey preference. As matter of fact, all animals are selective in concerning their prey (Krebs, 1989). All of the above were established by stomach content analysis, laboratory and field observations.

Material and Methods

2.1. Geography of the study area

The Sea of Japan (East Sea) is one of several marginal seas of the western Pacific Ocean. It is a typical mid-latitude marginal sea surrounded by Korea, Japan, and Russia. The Sea has a surface area of about 978,000 km², and it maximum depth exceeds 3,742 m with a mean depth of 1.752. The coastal length is about 7,600 km, The continental shelf of the Japan Sea is relatively narrow (Chough, 1983; Lee, 1987; Kim and Choi, 2006). It has four straits (Korea, Tsugaru, Soya, and Tatar), three major basins (Ulleung, Yamato, and Japan), and one rise (Yamato). The Korea, Tsugaru, Soya, and Tartar Straits comprise only about 5% of the boundary and are relatively shallow, The east coast of Korea is characterized by its monotonous coastline, which faces the open sea directly with almost a continuous swell condition and small tidal range (Boo and Lee, 1986).

2.2. Sampling and preservation

The *C. hakodatei* samples were caught by trawls from three areas from Gijang Costal area – South Korea (Fig. 1, Table 1).

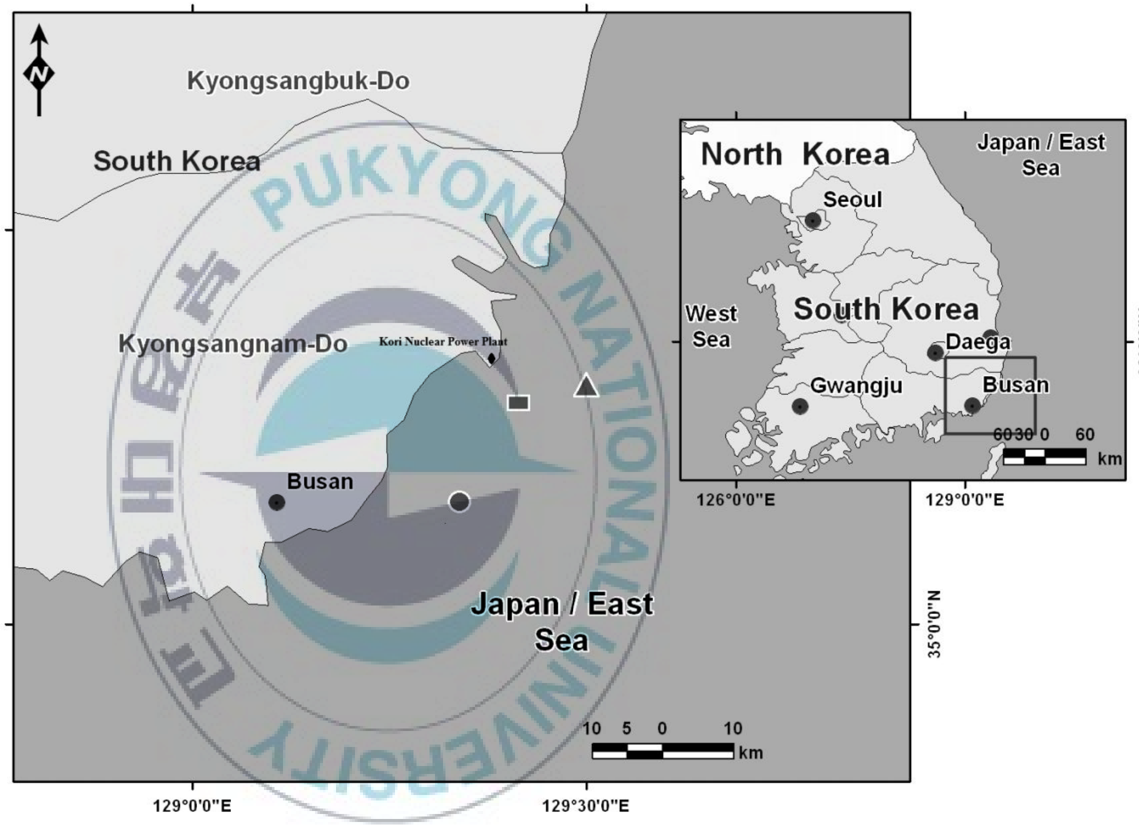


Fig. 1. Sampling areas in this study: area 1, 2 and 3 are those of rectangle, circle and triangle, respectively.

Table 1. Summary of relevant data on the sampling areas for *C. hakodatei* sorted by season and depth range.

Season	Month / years	Area	Coordinat		Depth	Velocity
			Latitude	Longitude	Meter	knot/hour
Summer	August (2010)	01	35°15.382'	129°17.212'	46.8	1.3
		02	35°19.184'	129°19.749'	38.9	1.3
Autumn	September (2010)	01	35°16.323'	129°18.546'	50.6	1.3
		02	35°18.683'	129°19.141'	41.3	1.3
		03	35°15.634'	129°18.034'	49.9	1.3
	October (2010)	01	35°16.579'	129°19.678'	58.3	1.7
		02	35°19.321'	129°20.141'	43	1.2
		03	35°15.622'	129°18.075'	52.6	1.2
	November (2010)	03	35°16.526'	129°17.988'	42.7	1.5
Winter	December (2010)	03	35°16.173'	129°17.741'	42.2	1.5
	January (2011)	03	35°17.571'	129°17.950'	37	1.1
	February (2011)	03	35°17.693'	129°17.709'	33.1	0.9
Spring	March (2011)	03	35°16.169'	129°17.539'	41.7	1.1
	April (2011)	03	35°16.923'	129°18.458'	43.7	1.2
	May (2011)	03	35°17.301'	129°17.216'	30.9	1.2

All individuals were collected at depths between 30 to 60 m, by using small bottom trawl. Samples were collected randomly from each area, and specimens of *C. hakodatei* were fixed in 4% neutralized formalin, after 24 hours storing in 70% alcohol. Samples were taken from area 3 during the period from September 2010 to June 2011, and from area 1 and 2 during period from August 2010 to October 2010.

In area 3 months were grouped as follows: Autumn (September, October, and November), winter (December, January, and February), spring (March, April, and May).

2.3. Laboratory analysis

2.3.1. Carapace length

Carapace length (CL, the shortest distance between the posterior margin of orbit and the mid dorsal posterior edge of the carapace) of all *C. hakodatei* samples was measured using Vernier calipers with an accuracy of 0.01 mm. The samples was grouped into two size classes, small size class (<10 mm CL) and large size class (>10 mm CL).

2.3.2. Sex

Sex of samples was determined based on examination of the endopod of the second pleopods and the presence of the appendix masculine. Sex was determined under a binocular microscope.

2.3.3. Stomach fullness

The relative degree of stomach fullness was assessed visually and each foregut was assigned to 1 of 5 categories derived from the points method described by Wear and Haddon (1987). A category representing 95 to 100% of foregut contents was given 100 points (Full); <95 and >65%, 75 points (Semi Full); <65 and >35%, 50 points (Half Full); <35 and >5%, 25 points (Semi empty); and 5% or less, 2.5 points (Empty). Prey items in the stomachs were determined to the lowest taxonomic level possible. Specimens with < 2.5 points were excluded from the analyses. Sand and mud was excluded as a prey category. Prey was determined as both present or absent, and as a proportion of the number of points assigned for the stomach fullness. Diet was examined for area 1 and 2 for three months and for area 3 for three seasons, autumn, winter and spring.

2.3.4. Identification of stomach contents

The stomach was removed and opened on a microscope slide. The contents were first examined under low power of a dissecting microscope, then examined again under high power of a light microscope. Apparently empty stomachs were also examined. For identification prey items that were found in stomach contents of sand shrimp the flowing criteria was used: Polychaetes: brownish or yellowish stout tapering iridescent chaetae, stout dark brown jaws (Fig. 2A). Fishes: whole bones or pieces of bones of ribs and vertebrae, muscular tissues, scales or fish eggs (Fig. 2B). Crustaceans fragments of chitinous shells, parts of legs, claws or part of telson (Fig. 2C). Molluscs (gastropods-bivalves): parts of shell, part of helical coil (Fig. 2D). Algae (diatoms): parts of blue-green-grey of circular or with radial iridescence (Fig. 2E). Sand and mud particles were found with food items in stomachs (Fig. 3). The same observation was made in other studies involving marine animals, in Menhaden deposit-feeders diet consists of a combination of sediment grains (sand, mud), adsorbed material, detritus, comprising plant substrate and algae (Deegan et al., 1990). Possibly land derived organics can be found (Conkright and Sackett, 1986).

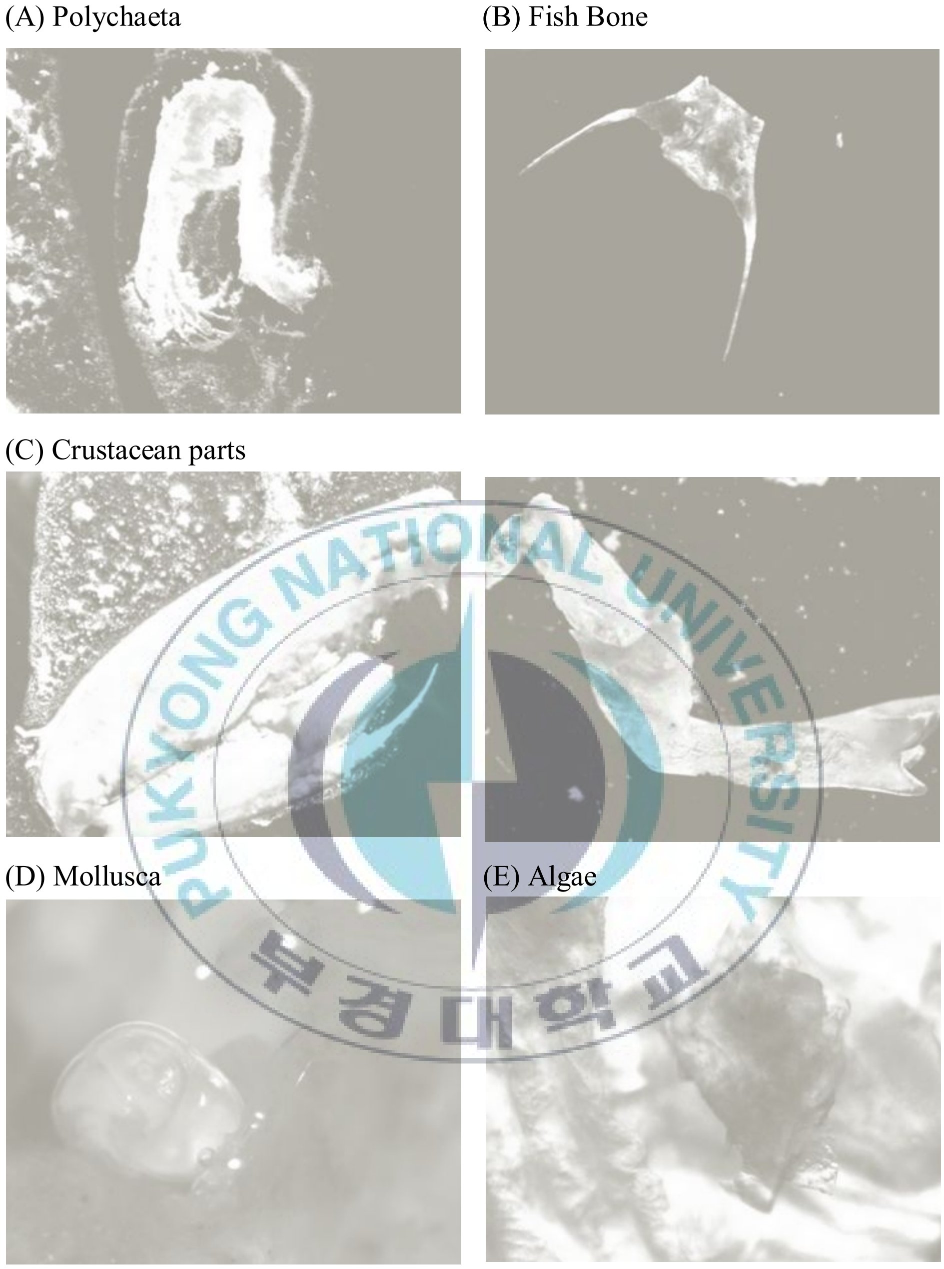


Fig. 2. Some of prey items that are found in stomach of *C. hakodatei*.

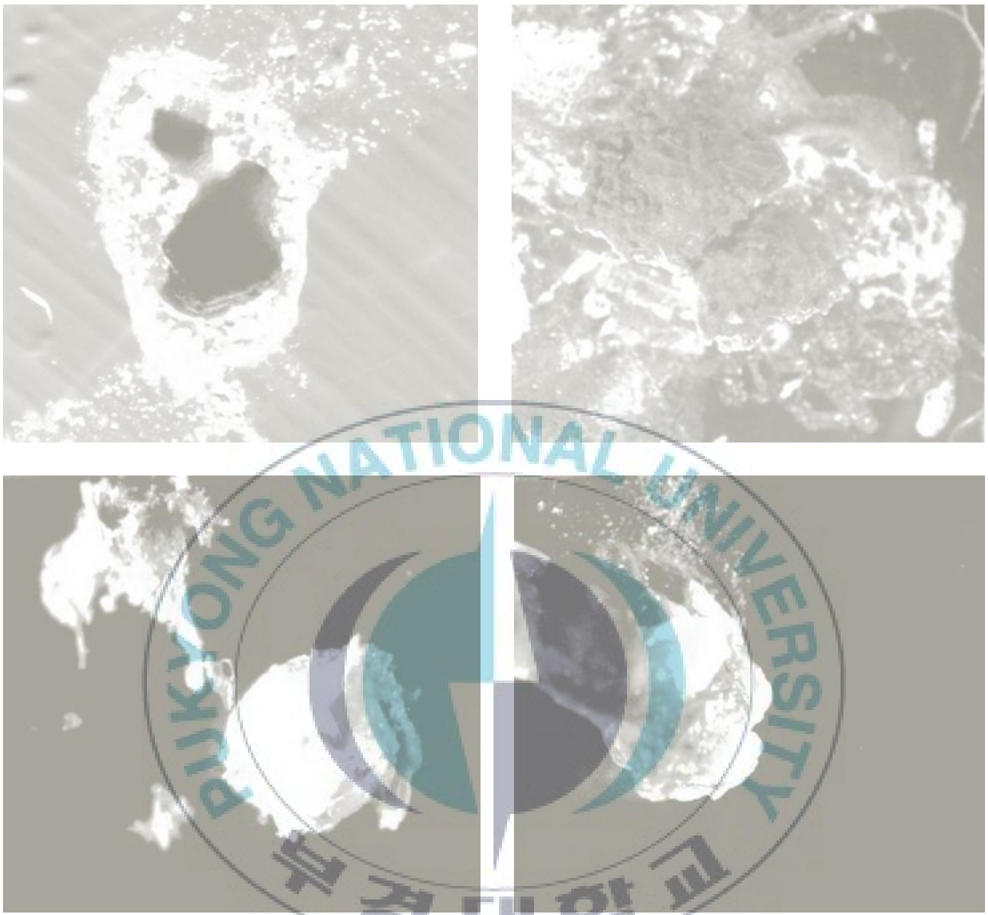


Fig. 3. Some of sand and mud that were found with the food content in stomach of *C. hakodatei*.

2.4. Physical parameters

At each area, during sampling, the temperature and salinity were recorded for surface and bottom sea water using YSI 30, Digital salinity conductivity temperature meter.

2.5. Statistical analysis

2.5.1. Occurrence and abundance

Numerous indices have been used for describing the importance of different prey in the diet of fish (Hynes 1950; Hyslop 1980). The percent frequency of occurrence (F) and relative abundance (A) for each type of prey were estimated by the following formulas:

$$\%F = (n_i / N) \times 100$$

$$\%A = (S_i / S_t) \times 100$$

Where n_i is the number of shrimps with prey i in their stomach.

N the total number of shrimps with stomach contents.

S_i the number of prey i and S_t the total number of prey items.

2.5.2. Vacuity index

The vacuity index (V.I.) was used to characterize feeding state: V.I. = the percentage ratio of the empty and nearly empty stomachs to total number of stomachs analysed (Hyslop, 1980).

2.5.3. Kolmogorov-Smirnov two-sample test

Look at difference in the size distribution among seasons and sex

$$D_{n,n'} = \sup_x |F_{1,n}(x) - F_{2,n'}(x)|$$

Where $\boldsymbol{F_{1,n}}$ and $\boldsymbol{F_{2,n}}$ are the empirical distribution functions of the first and the second sample respectively

2.5.4. Shannon-Wiener index

Trophic diversity (H') in the diet for season and size class were calculated according to the Shannon-Wiener index (Cody and Diamond, 1975)

$$H' = -\sum_{i=1}^{S} (p_i \ln p_i)$$

Where S is the total number of species p_i is the frequency of the ith species.

2.5.5. Pielou's evenness index

Diet equality was also calculated for the different size classes and seasons, using Pielou's evenness index (Pielou 1975):

$$J' = \frac{H'}{H'_{max}}$$

Where H' is the number derived from the Shannon diversity index, and H'_{max} is the maximum value of H'.

2.5.6. Kruskal-Wallis test

The obtained data were subjected to Kruskall-Wallis to compare difference between the Vacuity index values and area, in both sexes and season for area 3 according to Conover (1971) and Daniel (1974).

$$T = \frac{12}{N(N+1)} \sum_{i=1}^{K} \frac{R_i^2}{n_i} - 3\,(N+1)$$

This test indicates whether a difference exists or not, but not the cause of the difference.

2.5.7. The χ^2 test

In some observations of feeding parameters, the observed and expected frequencies may differ greatly. The common test employed for this purpose is the χ^2 (Qui square). To determine whether the observed number is consistent with the expected one, a χ^2 value can be estimated using the equation:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where: O and E are the observed and the expected numbers, respectively.

Statistical analyses were accomplished in SPSS Statistical V.19 and SAS Version 9.1.3.

Result

3.1. Physical characteristics

3.1.1. Temperature

The surface water temperature ranged from a maximum of 21.3ºC to minimum of 16.3ºC at area 1, while bottom water temperatures decrease and ranged from a maximum of 19.2ºC to a minimum of 15.5ºC, temperature recorded highest values during Sept at the surface and bottom, and lowest values during August. At area 2 the surface water temperature ranged from a maximum of 23.8ºC to a minimum of 15.5ºC, whilst bottom water temperatures increased and ranged from a maximum of 24.2ºC to a minimum of 16ºC. The maximum temperature was recorded in September at surface and bottom, while minimum temperatures were recorded in August. During investigation it was realized that bottom water temperature was higher than the surface water temperature in area 2 .The temperature for each area is shown in (Fig. 4). At area 3**,** the surface water temperature ranged from a maximum of 22.7ºC to minimum of 11.2ºC**,** while bottom water temperatures decreased and ranged from a maximum of 20.9ºC to a minimum of 10.9ºC. The highest value of temperature was recorded during

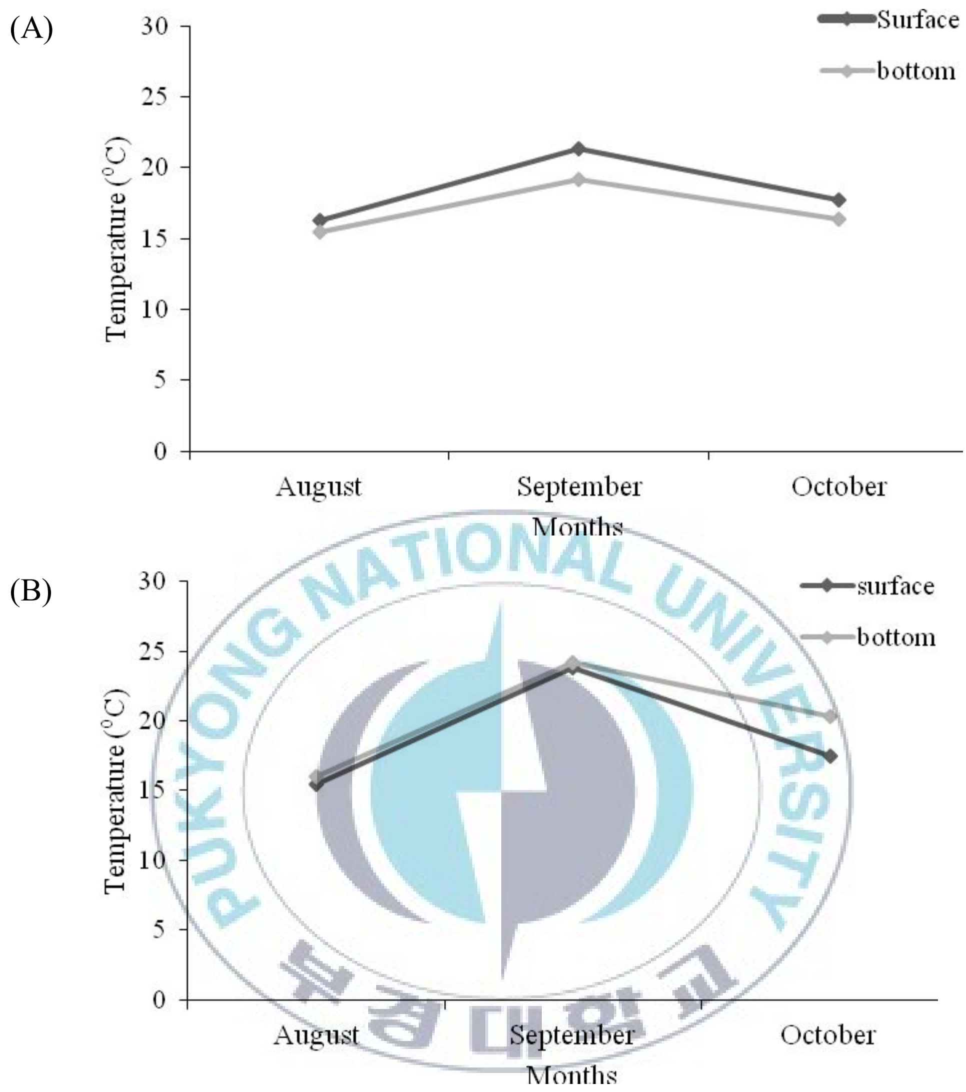


Fig. 4. Surface and bottom temperature values at (A) area 1 and (B) area 2.

September at the surface and bottom, lowest value during November at the surface and during December at the bottom (Fig. 5)

3.1.2. Salinity

The bottom water salinity ranged from a maximum of 35.4‰ to a minimum of 34.9‰ at area 1. Maximum salinity was recorded in October, while a minimum salinity was recorded in August. At area 2, the salinities were slightly different. The bottom water salinity varied between a maximum of 34.2‰ to a minimum of 33.3‰. The highest salinity value was recorded in October, while lowest value was recorded in September (Fig. 6).

At area 3 the bottom water exhibited a salinity range between 36.3 ‰ and 33.9‰**.** The highest value of salinity was recorded in December and lowest in May (Fig. 7)

3.2. Sex and size range

During the present investigation 602 individuals of *C. hakodatei* were collected and analyzed. 304 individuals from areas 1 and 2 were examined to known the effect of area differentiation on feeding habits. 298 individuals from area 3 were examined to known the effect of seasonal variation in feed

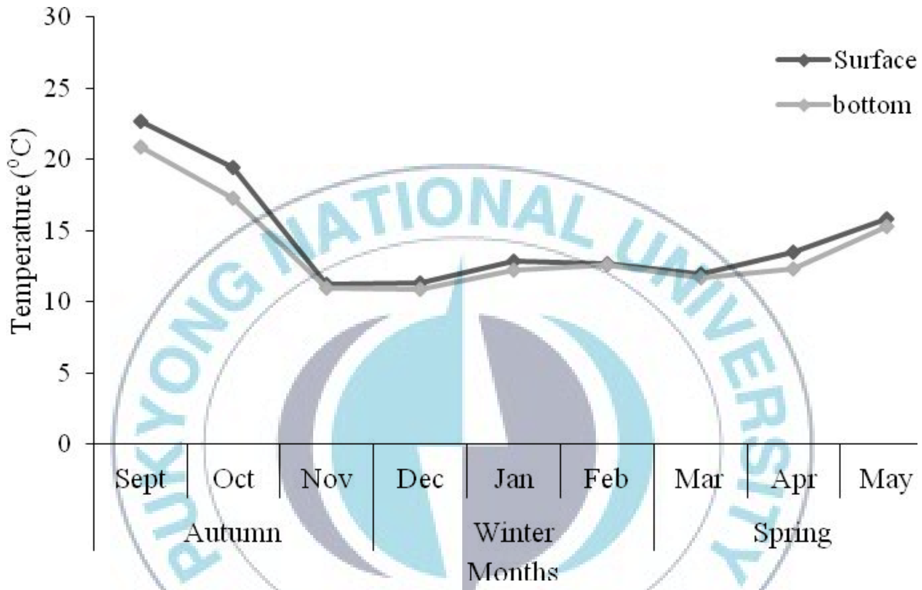


Fig. 5. Surface and bottom temperature values at area 3 during three seasons (autumn, winter and spring).

(A)

(B)

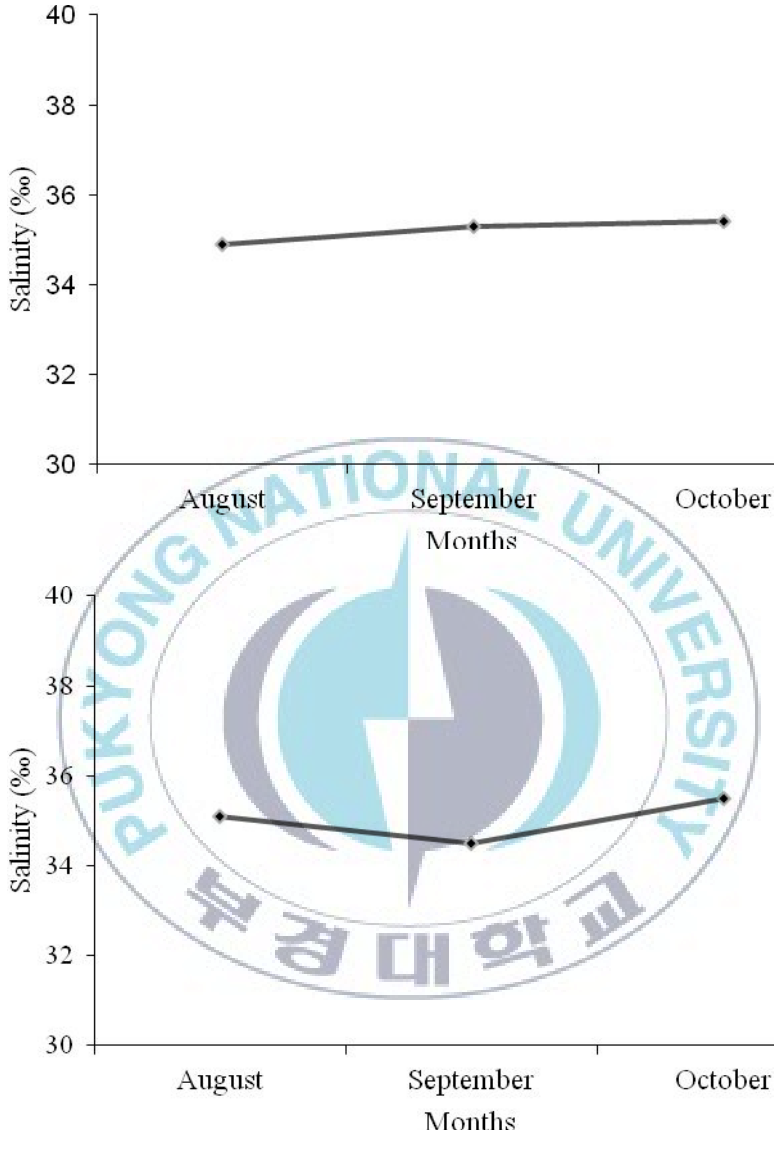


Fig. 6. Bottom salinity values at (A) area 1 and (B) area 2.

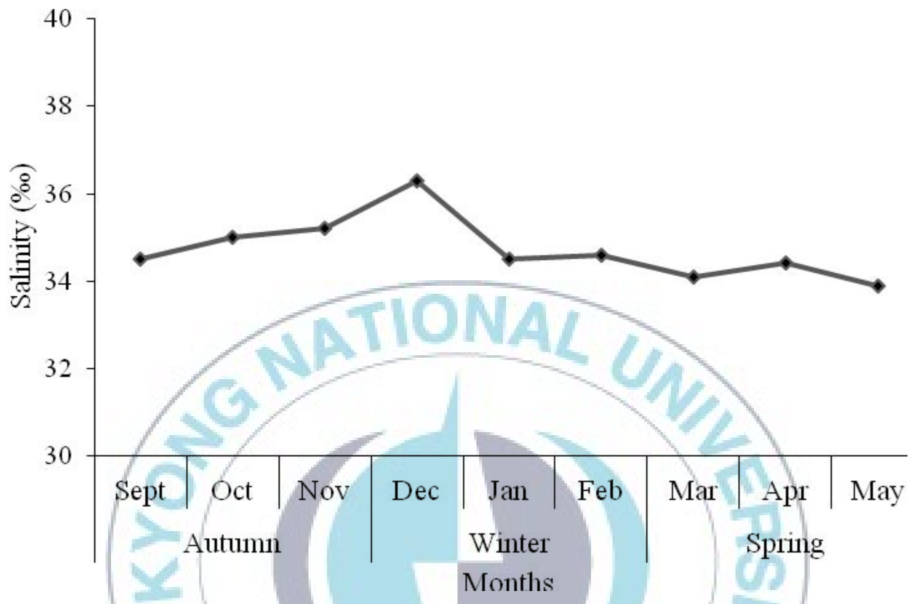


Fig. 7. Surface and bottom temperature values at area 3 during three seasons (autumn, winter and spring).

The length range of samples caught was 6.24 to 15.8mm CL during study period. The maximum length of *C. hakodatei* species 19mm CL (Choi et al., 2002; Hong et al., 2006)

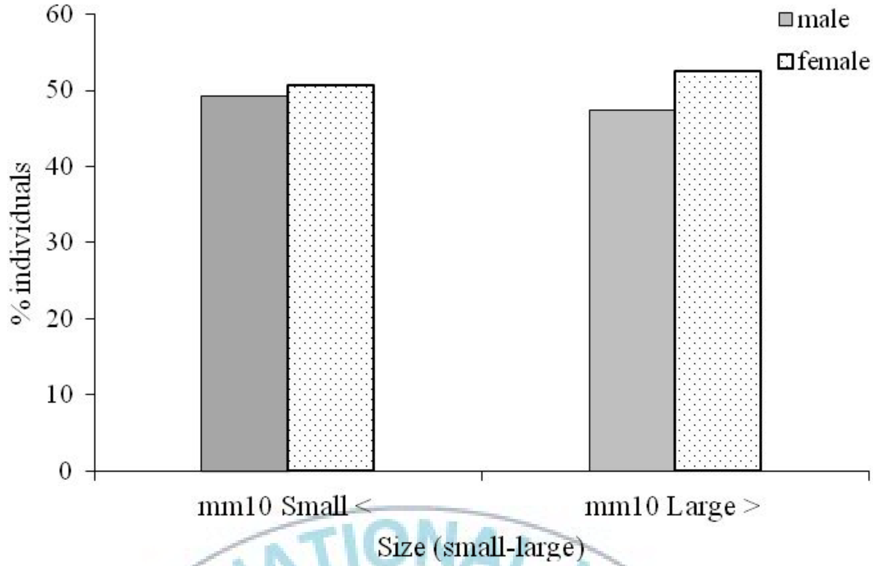
3.2.1. Variance in sex and size range according to areas

In areas 1 and 2, the proportions of females (52%) were larger than that of males (48%). In area 1, males represented about 48.2% of total individual analyzed from this area, while the females represented about 51.8%. In area 2, males represented about 46.6% and females represented about 53.4%. Large size class (>10mm CL) represent 51.3% and small size class (<10mm CL) (48.7%). In area 1, females were slightly more than males in large size group, whilst in area 2, females were slightly more than males in the small size group (Fig. 8).

3.2.2. Variance in sex and size range according to seasons (area 3)

During the three seasons (autumn, winter and spring), the proportion of males (51%) were higher than females (49%) in all seasons. The proportion of males in autumn, winter and spring comprised 50%, 54%, 51% and that of females 50%, 46%, 49%, respectively.

(A)



(B)

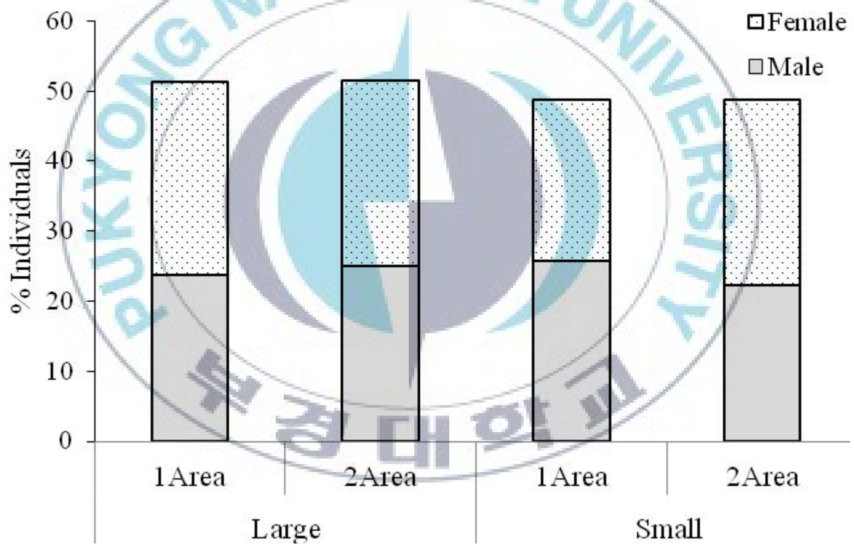
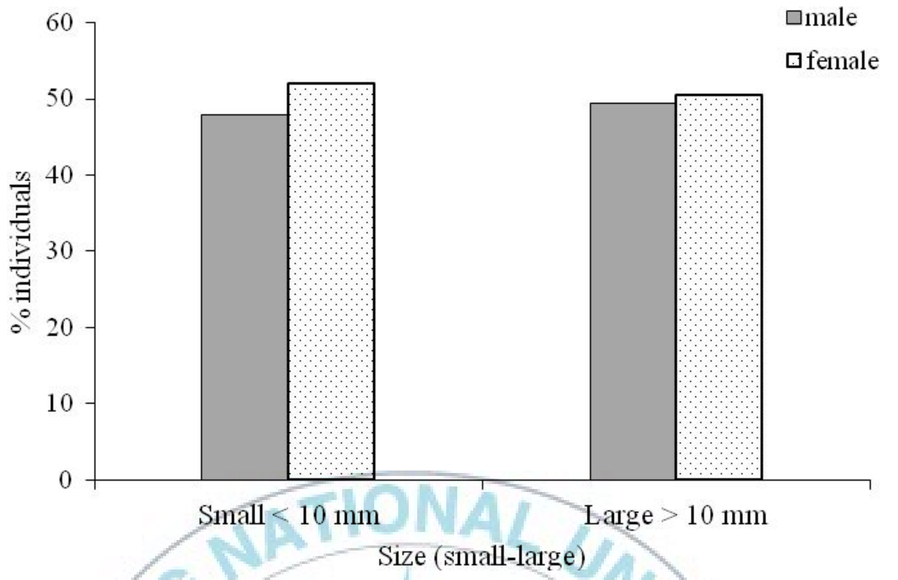


Fig. 8. Size range of *C. hakodatei* (A) for males and females, (B) for both area.

Large size class (>10mm CL) represented 55% and 45% for the small size class (<10mm CL). In autumn males were the most occupied a large size group than females, also same in winter, while in spring females were the most occupied a large size (Fig. 9).

(A)



(B)

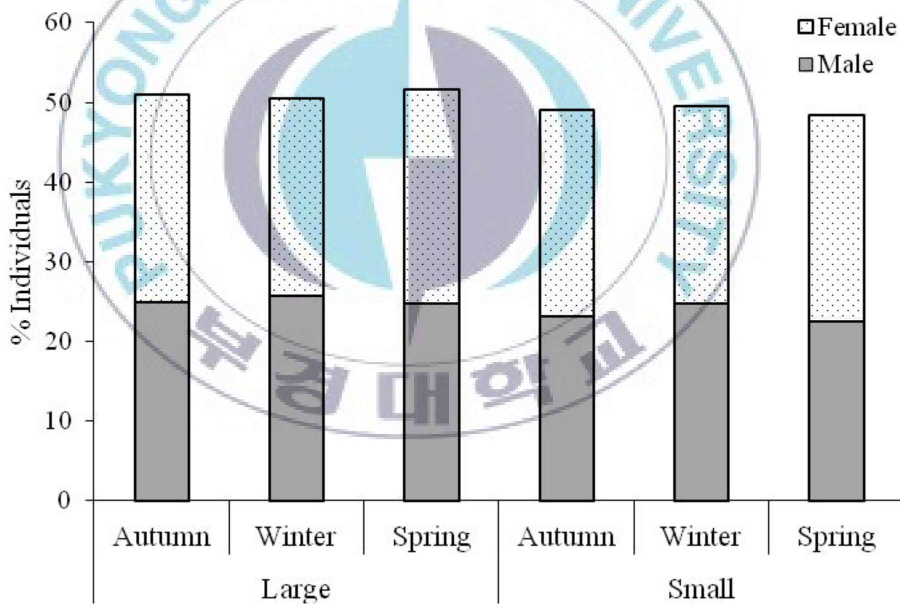


Fig. 9. Size range of *C. hakodatei* (A) for males and females at area 3 and (B) for seasons.

3.3. Size composition

CL distribution of C. hakodatei was used for the analysis of diet and also to evaluate the effects of season, sex and area differentiation on feeding behaviour.

3.3.1 Area size composition

Of all the 304 individuals collected from area 1 and 2, 270 individuals were used for this analysis (individuals whose stomachs registered > 2.5 points on stomach fullness scale). Statistical analysis showed that there were no significant differences in size distribution among area (Kolmogorov-Smirnov 2-sample test, $p=0.993$). The largest numbers of individuals were collected from area 1 for both sexes were mostly in the size class of 9mm CL, The smallest number of individuals occurred in the size class of 16mm CL (Fig. 10A). In area 2 the maximum and the minimum Individuals were in both size classes of 8mm and 16mm CL (Fig. 10B). On the other hand the highest of males number and of females were found in the class size of 9mm CL. The smallest number of males was in the class sizes of 14 mm and 15 mm CL. For females the smallest number was in the class sizes of 14mm, 15mm and 16mm CL in area 1 (Fig. 11A).

(A)

(B)

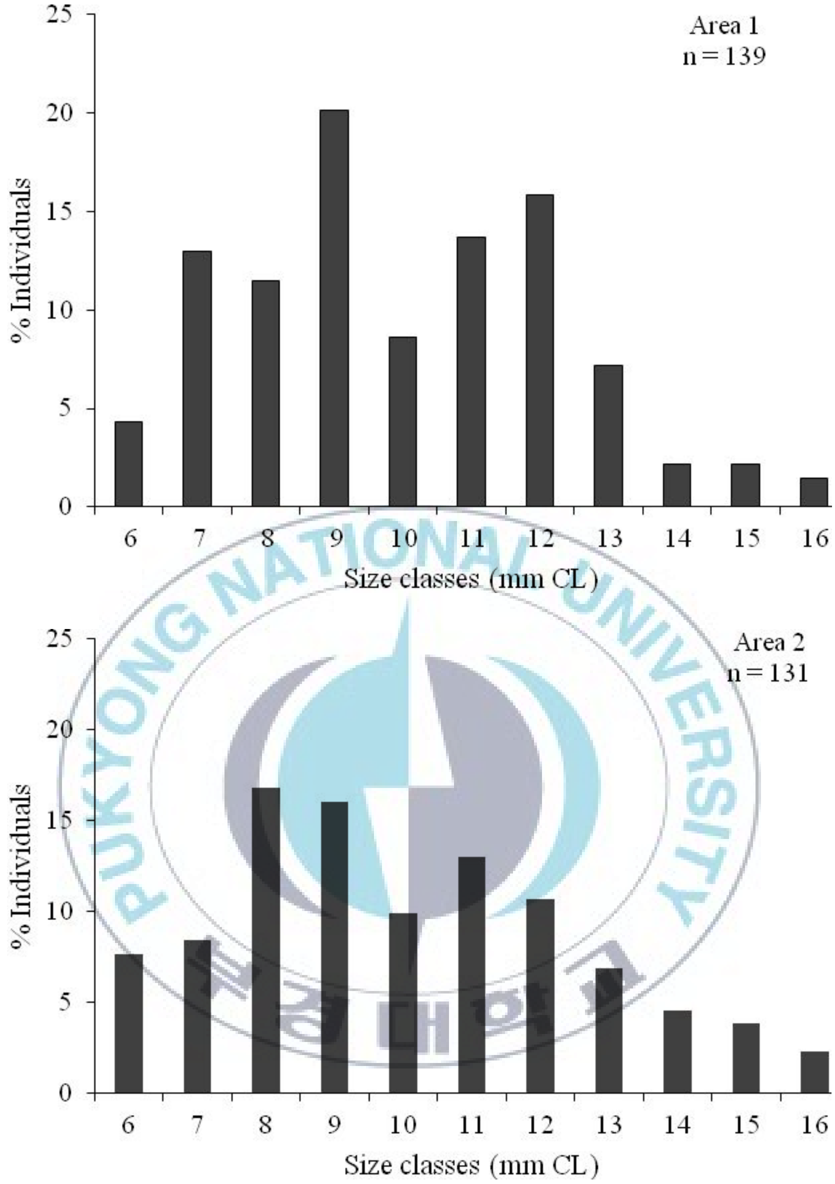
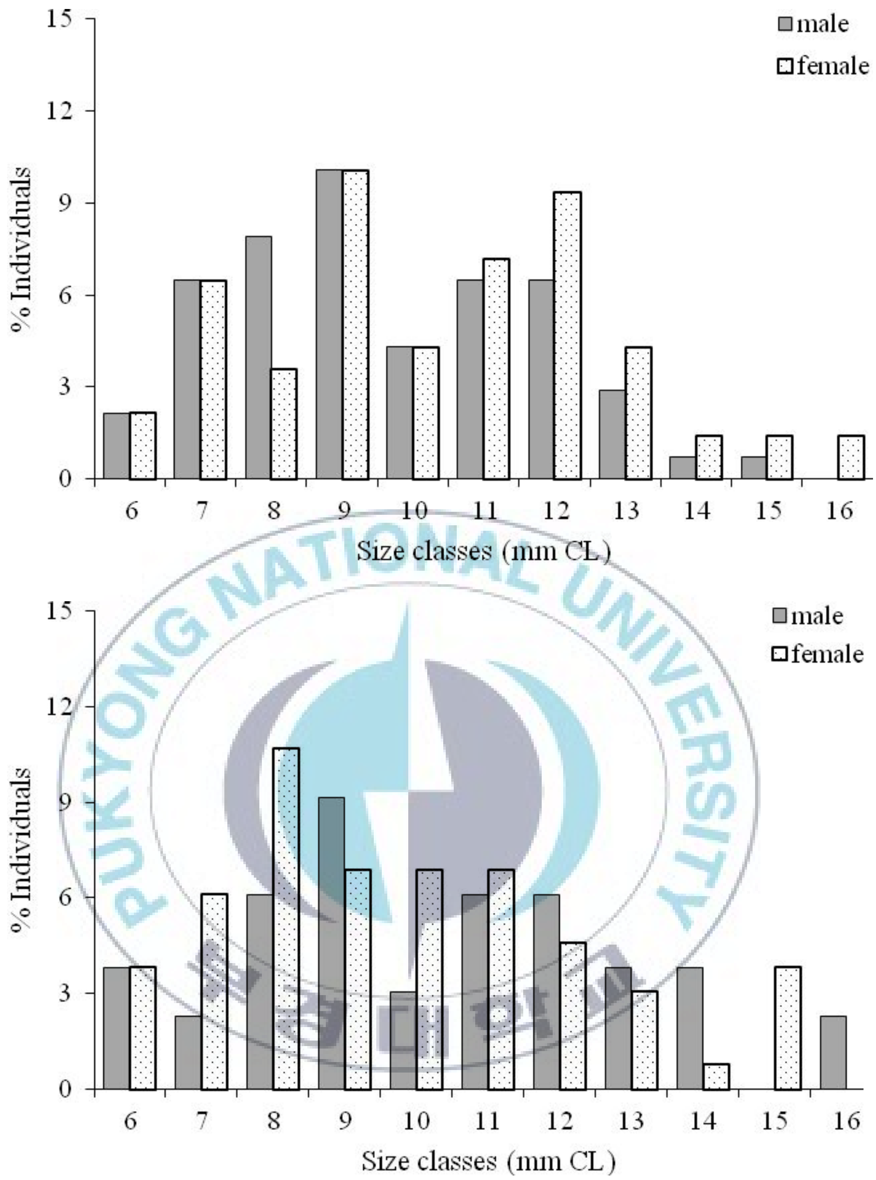


Fig. 10. Size structure of *C. hakodatei* individuals examined for stomachs contents analysis for (A) area 1 and (B) area 2.

(A)



(B)

Fig. 11. Size structure of males and females in *C. hakodatei* individuals examined for stomachs contents analysis for (A) area 1 and (B) area 2.

From area 2 the highest number of males was in size class of 9mm CL, in female it was in the class size 9mm CL, while the smallest number for males and females was in the class sizes of 7mm and 14mm CL (Fig. 11B).

3.3.2. Seasonal size composition

Of the 298 stomachs examined from area 3, 267 were used for the analysis (that's registered > 2.5 points on the stomach fullness scale) Statistical analysis showed that there were no significant differences in size distribution among seasons (Kolmogorov- Smirnov 2-sample test) autumn and winter ($p = 0.808$), autumn and spring ($p =0.641$) winter and spring ($p =0.993$). The highest numbers of individuals were collected during autumn season were mostly in the size class of 9mm CL, the smallest was in the size class of 16mm CL (Fig. 12A). The maximum and the minimum Individuals were in the size classes of 8mm and 6mm CL in winter season (Fig. 12B). In spring season size class 8mm CL represent highest number and size class 13mm CL represent smallest number. According to sex, in autumn season the highest males and females number were in the size classes of 7 mm and 6mm CL, the smallest for males were In size rang class of 15mm CL, for females were in the size class of 6mm CL (Fig. 13A).

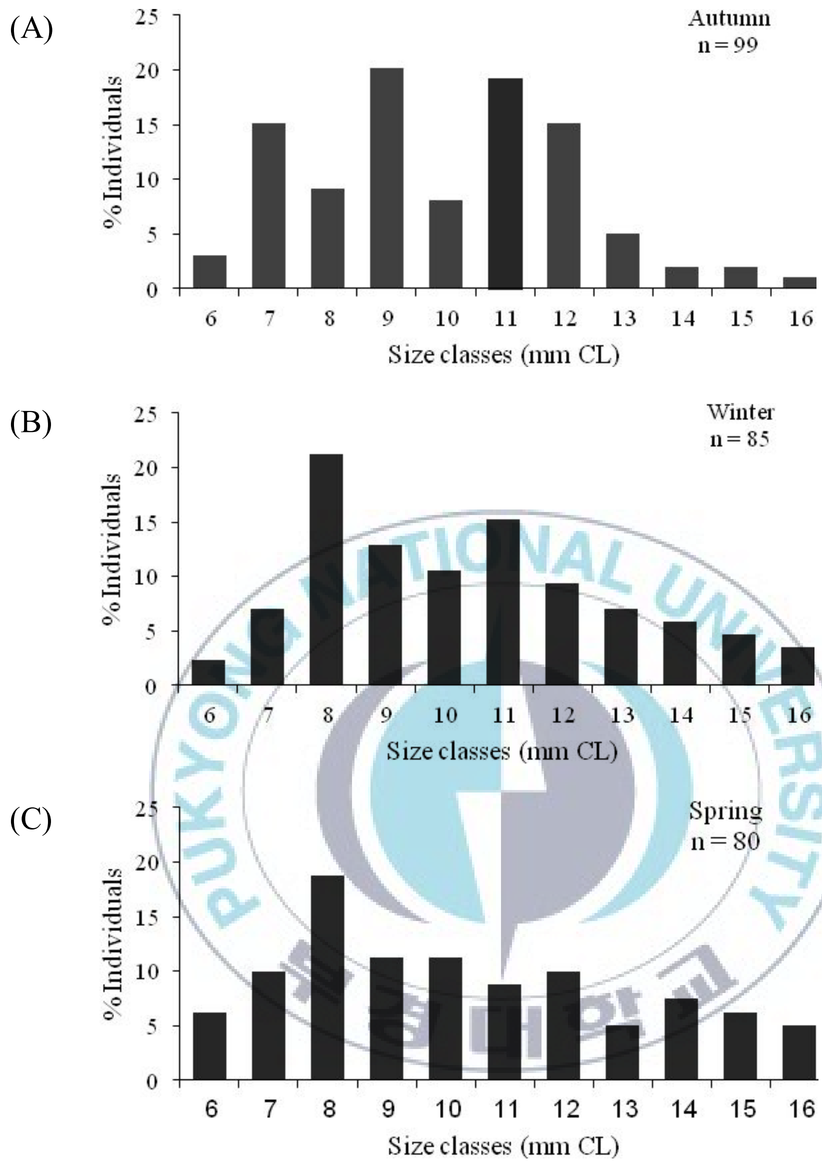


Fig. 12. Seasonal size structure of *C. hakodatei* individuals examined for stomachs contents analysis.

In winter the highest numbers of males were in the size class 9mm CL, in female was in the class size 8mm CL, the smallest number for males and females were in the size classes 15mm and 6mm CL (Fig. 13B). The highest males and females number occurred in spring season in the class size of 8mm and 7mm CL, the smallest for males were in the size class of 7mm CL, and for females in the size classes of 13mm CL (Fig. 13C).

3.4. Feeding activity

Of the all stomachs that were examined from area 1 and 2 about 12% of stomachs from males and about 9% of those for females were found to be empty, or contained trace amount of food, sand or mud, while the proportion of empty stomach for males and females in area 3 comprised 10%, 11%, respectively (Table 2).

3.4.1. Vacuity index for area

The mean vacuity index for both areas (area 1 and 2) during study period was (VI = 6.25) for males, and that in females was a slightly lower (VI = 4.93). The V.I. was highest in area 1 (VI = 13.1) and lowest in area 2

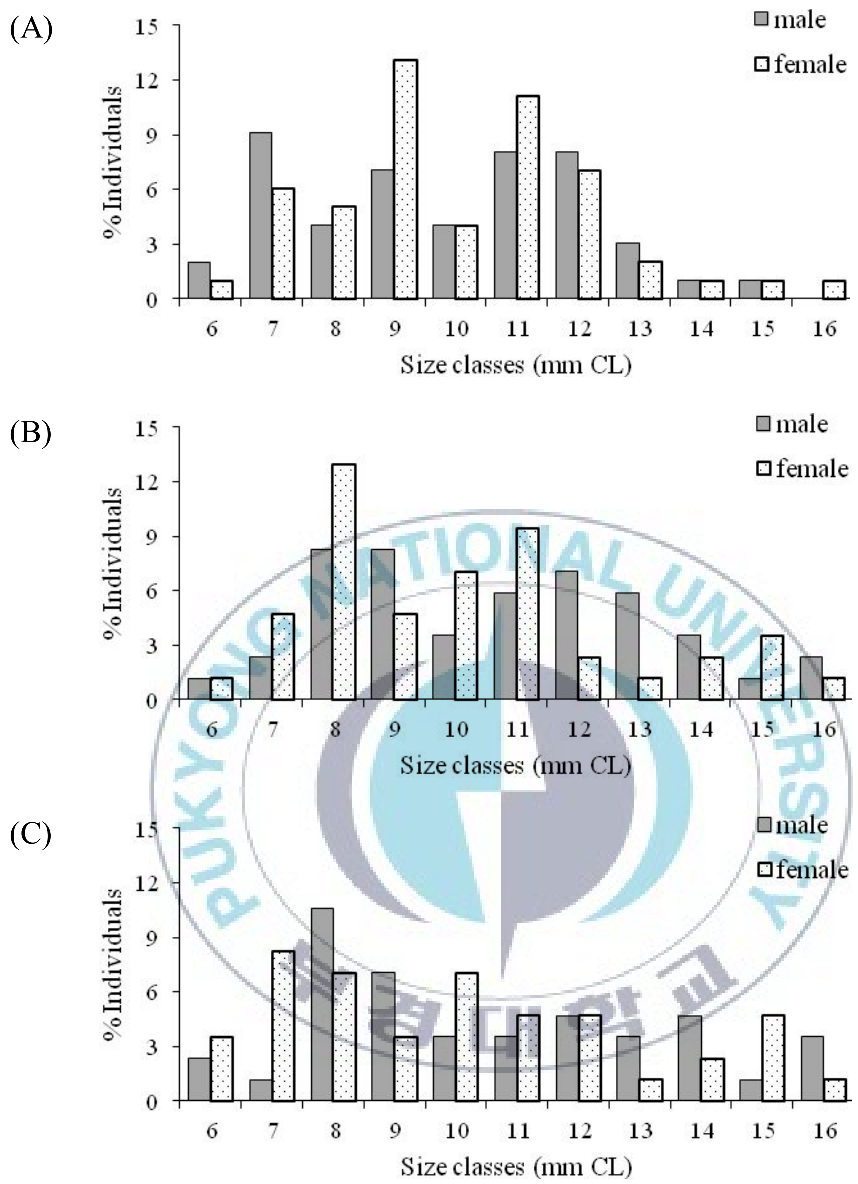


Fig. 13. Seasonal structure of males and females in *C. hakodatei* individuals examined for stomachs contents analysis,(A) autumn, (B) winter, (C) spring.

Table 2. Size rang, stomachs examined, and number of empty stomachs of males and females of *C. hakodatei*.

Area	Sex	Size range	No. of examied stomach	No. of empty stomach	precent of empty stomach
Area 1 & 2	Males	Large	74	11	7.48
		Small	73	8	5.44
	Femals	Large	82	7	4.46
		Small	75	8	5.10
Area 3 (Seasons)	Males	Large	75	6	4.14
		Small	70	9	6.21
	Femals	Large	77	9	5.88
		Small	76	8	5.23

(VI = 9). The V.I. in area 1 for males (VI = 7.5) was higher than for females (VI = 5.63). The same was observed in area 2 where the V.I for males (VI = 4.86) was higher than that for females. According to the size class, the V.I. for large size class (VI = 6.88) in area 1 was higher than the small size class (VI = 6.25). Also, in area 2, the V.I. for large size class (VI = 4.86) was higher than that for small size class (VI = 4.17). In general, the V.I. for males was higher than that for females in both areas. Also the V.I. for large size class was higher than for small size class (Fig. 14).

Kruskal-wallis test showed that there were no significant difference between V.I. values and areas in both sexes, also was no pronounced significant difference between V.I. values and areas in both sizes (Kruskal–Wallis test, P =0.121, at the 95% confidence level).

3.4.2 Vacuity index for season

The mean V.I. for all season during study period (autumn, winter and spring) was (VI = 5.03) for males, and in that in females was slightly higher (VI = 6.04). The V.I. was lowest in autumn (VI = 8.3), in winter was (VI = 11.3) and highest value was recorded in spring (VI = 12.9). The V.I. in autumn for males (VI = 4.63) was higher than that for females (VI = 3.7).

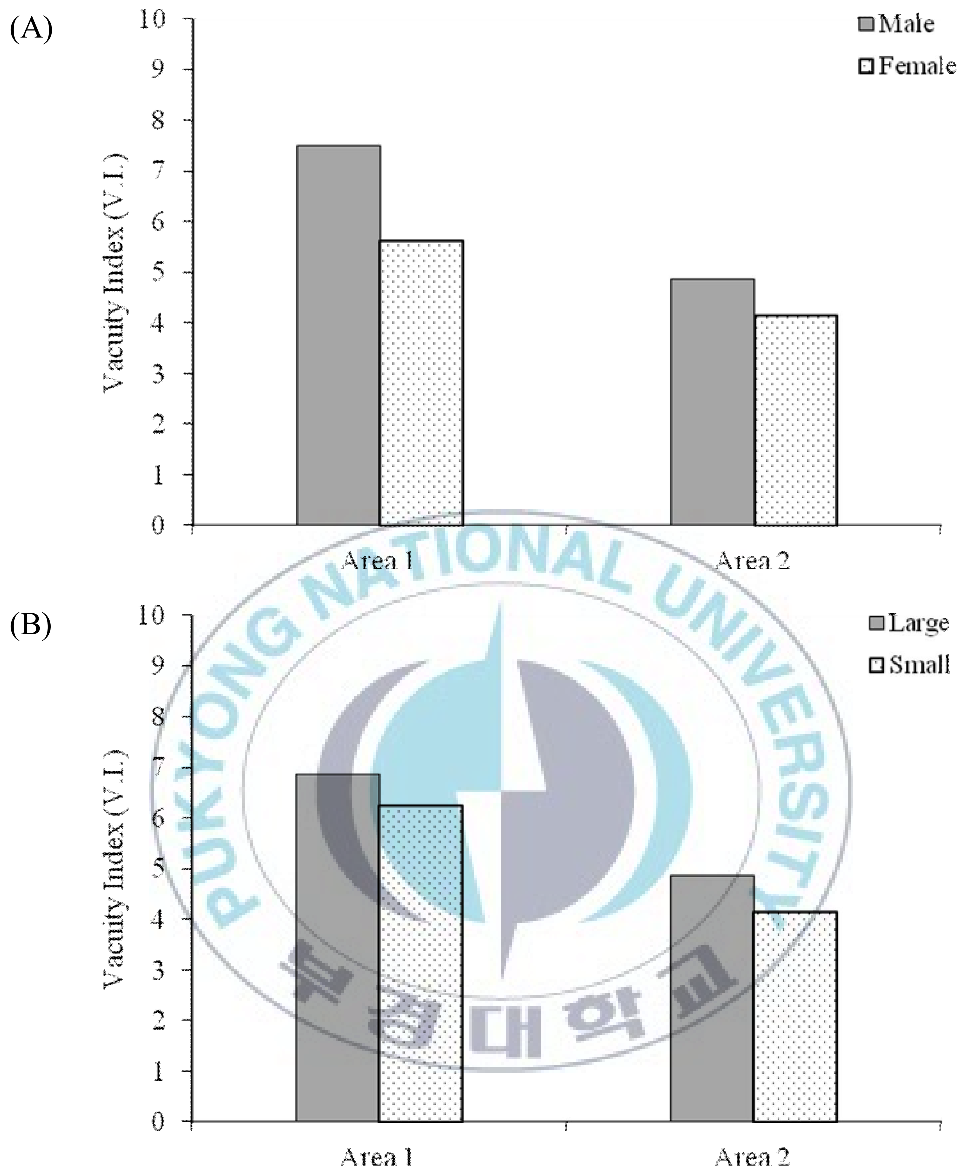


Fig. 14. Area variation in percentage of empty stomachs (vacuity index, V.I.) of *C. hakodatei* by (A) sex, and (B) size.

In winter the V.I for males (VI = 5.15) was lower than that for females (VI = 6.19). The same was observed in spring where the V.I for males (VI = 5.38) lower than that for females (VI = 7.53). According the size class, the V.I. for large size class (VI = 2.78) in autumn was lower than that in the small size (VI = 5.56). In winter the V.I. for large size class (VI = 5.15) was lower than that in small size class (VI = 6.19). While in spring the V.I. for large size class (VI = 7.22) was higher than that for small size class (VI = 5.38). In general the V.I. for males was lower than that for females during all seasons. The V.I. for large size class was lower than that for small size class (Fig. 15).

Kruskal-wallis test showed that there was no significant difference between V.I. values and season in both sexes (Kruskal–Wallis test, P = 0.565, at the 95% confidence level), also was no pronounced significant difference between V.I. values and season in both sizes class at 95% confidence level (Kruskal–Wallis test, P = 0.156, at the 95% confidence level).

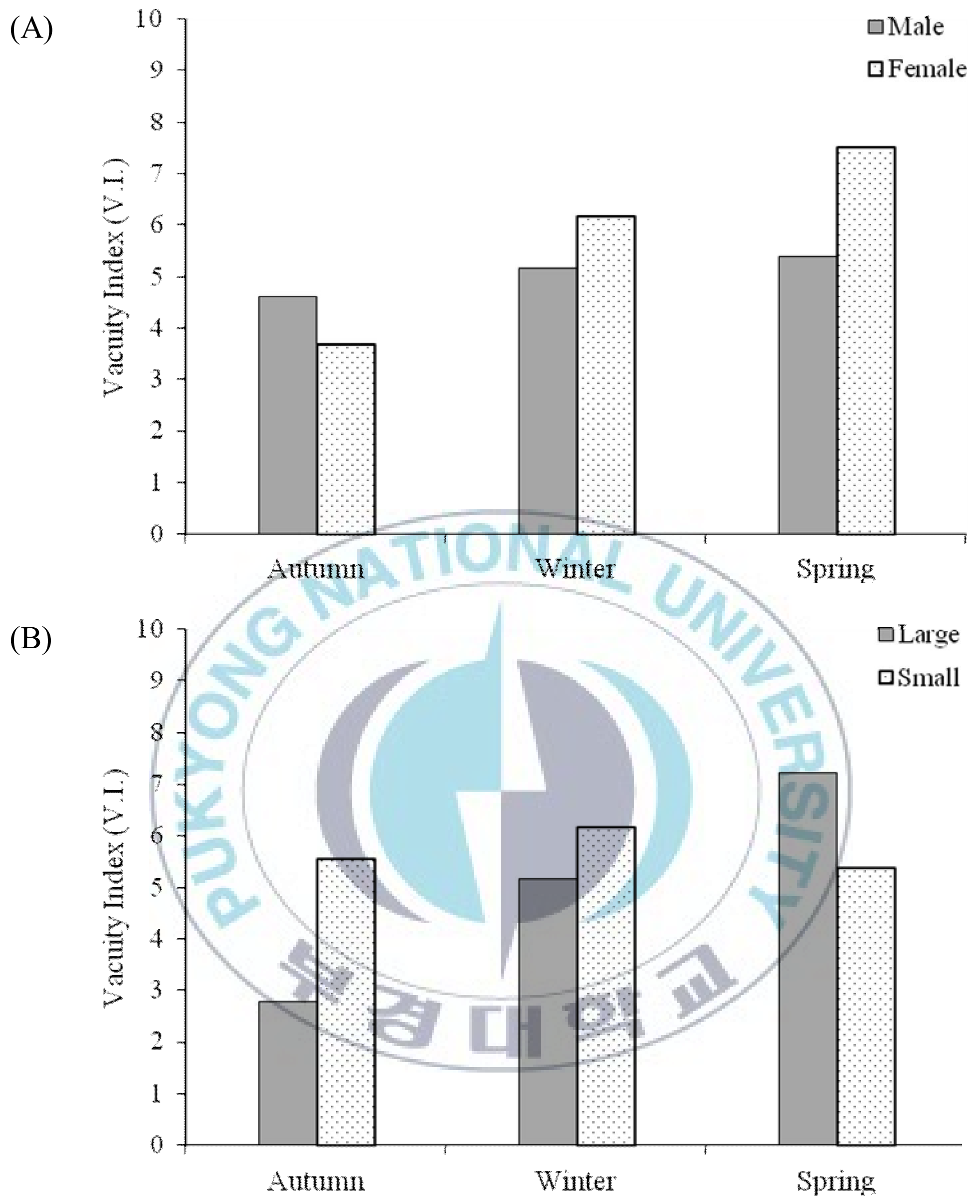


Fig. 15. Seasonal variation in percentage of empty stomachs (vacuity index, V.I.) of *C. hakodatei* by (A) sex, and (B) size.

3.5. Stomach fullness

The relative degree of stomach fullness was assessed visually and each foregut was assigned to 1of 5 categories (100, 75, 50, 25 and 2.5point).

3.5.1. Stomach fullness by area

Stomach fullness percentages for all samples of *C. hakodatei* for area 1 and 2 are given in (Fig. 16A). Of all the stomachs examined about 89% of the stomachs registered > 2.5 points on the stomach fullness scale. 13.82% of stomachs were very full (100 point), 24.34 % were full (75 point). Half full represented the highest proration of 26.97% (50 point), and 23.68% for moderately full (25 point). Males and females showed different proportions with the stomachs fullness. Half full stomachs were highest in males (14.14%), whilst full stomachs were highest in females. The lowest proportion of males had empty stomach (6.25%). A similar result occurred in females with a slightly lower in proportion (4.93%). The proportion of moderately full, half full, full, very full in males comprised 10.86%, 14.14%, 9.21%, 7.89%, and that in females 12.83%, 12.83%, 15.13%, 5.92%, respectively (Fig 16B). Half full and full showed the same highest proportion for large sizes, while moderately full was the highest proportion

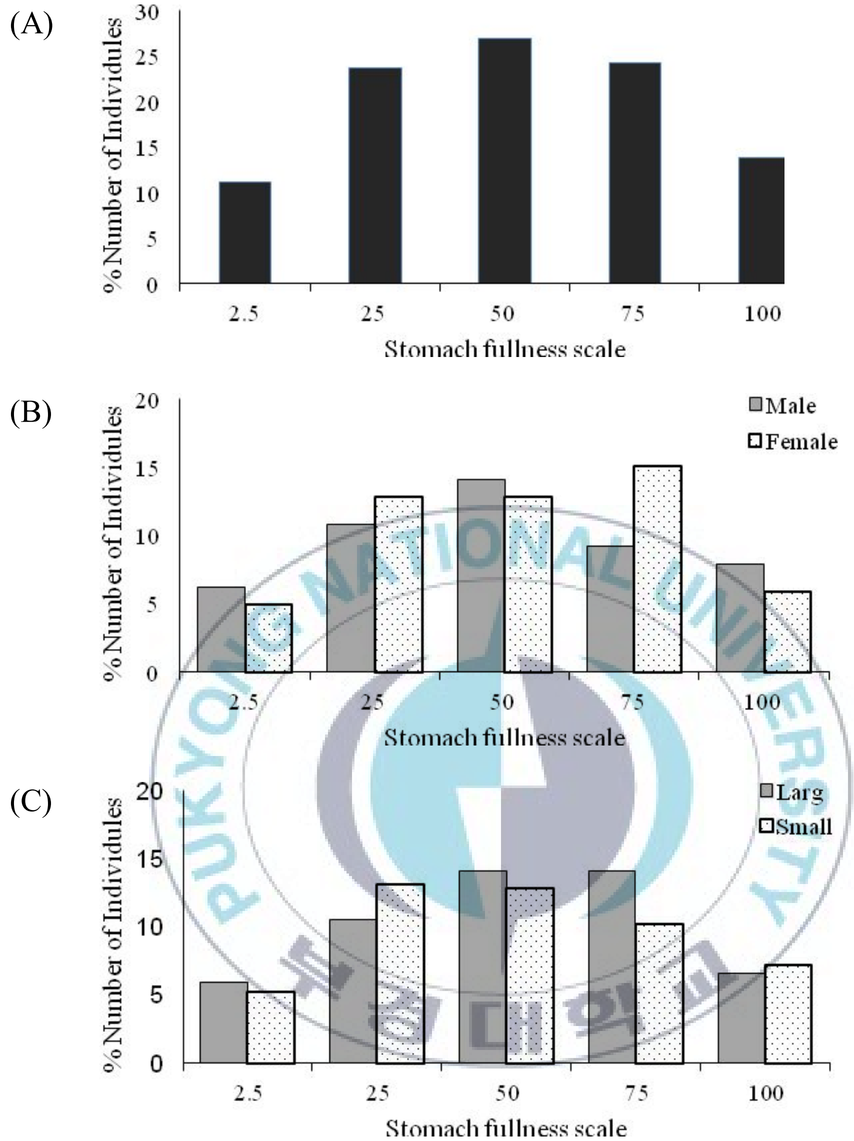
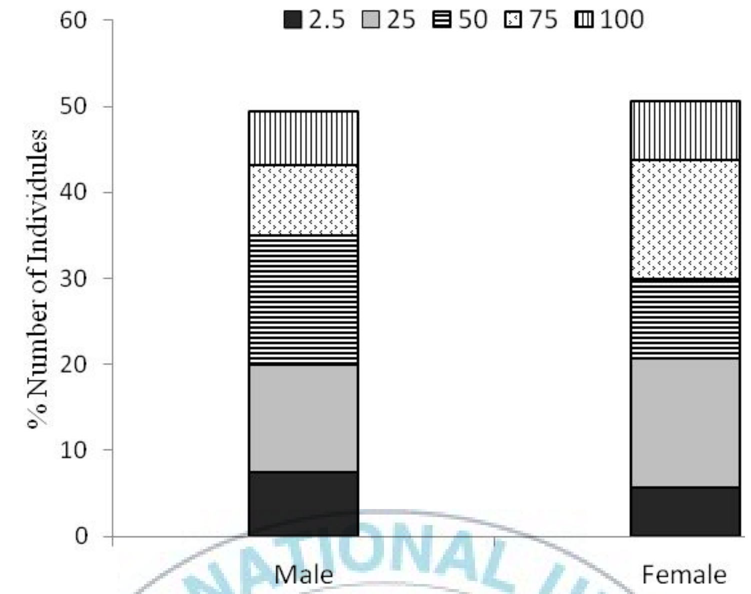


Fig. 16. Proportion of stomach fullness scale of *C. hakodatei* by (A) total, (B) sex, and (C) size (2.5< 5%, 25= 5~35%, 50= 35~65%, 75= 65~95%, 100= 95~100%).

for the small size class. Empty stomach was the lowest proportion for large size class (5.92%) as well as small sizes class (5.26%). The percentage of large size class was 10.53% in moderately full, 14.14% in half full, 14.14% in full, 6.58 in very full, while in small size class the proportion of moderately full, half full, full, very full comprised 13.76%, 12.83%, 10.20%, 7.24%, respectively (Fig. 16C).

On the other hand, there was no significant difference between stomachs fullness proportion and areas in both sexes (Kruskal–Wallis test, $P > 0.05$, at the 95% confidence level). There was also no pronounced significant difference between stomachs fullness proportion and areas in both sizes (Kruskal–Wallis test, $P > 0.05$, at the 95% confidence level). For area 1 the proportion of stomach fullness was moderately full (12.50%), half full (15.0%), full (13.0%), and very full (6.25%) in males, and that in females was 15.0%, 9.38%, 13.75%, 6.88%, respectively. In area 2 the proportion of moderately full, half full, full, and very full in males comprised 9.03%, 13.19%, 10.42%, 9.72% and that in females was 10.42%, 16.67%, 16.67%, 4.86%, respectively (Fig. 17). The proportion of large size class was 10.63% in moderately full, 12.50% in half full, 14.38% in full, 6.88% in very full for area 1, and that in the small size class was 16.88%,

(A)



(B)

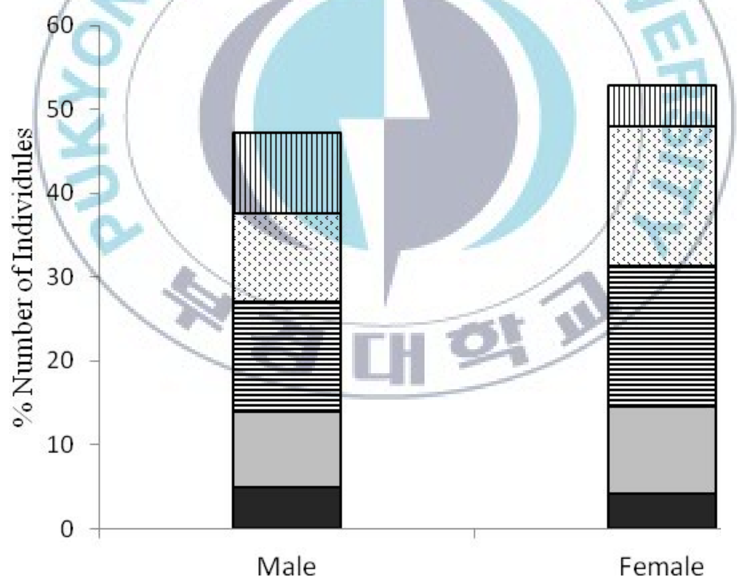


Fig. 17. Proportion of stomach fullness scale of *C. hakodatei* by sex for (A) area 1 and (B) area 2, see Fig. 16 for key to abbreviation.

11.88%, 7.50%, 6.25%, respectively. In area 2 the proportion of moderately full, half full, full, and very full in large size class comprised 10.42%, 15.97%, 13.89%, 6.25% and that proportion in small size class 9.03%, 13.89%, 13.19%,8.33%, respectively (Fig. 18).

3.5.2. Stomach fullness by season

Of all the stomachs that were examined during seasons in area 3, about 88% of the stomachs registered > 2.5 points on the stomach fullness scale. Stomach fullness percentages for all samples of *C. hakodatei* for the seasons are shown in Fig. 19A. 17.11% of stomachs were very full (100 point), full represented the highest proration (24.50%) (75 point), while 23.49% were half full (50 point), 23.83% for moderately full (25 point), and empty (11.07%). When males and females showed different proportion with the stomachs fullness, half full stomachs were the highest (12.42%) in males, full stomachs were highest in females (14.77%). The males recorded the lowest proportion with empty stomach (5.03%). A similar occurred in the females with proportion of 6.04%. The proportion of moderately full, half full, full, very full in males comprised 11.41%, 12.42%, 9.06%, 10.74%, that in the females 13.09%, 11.07%, 14.77%, 6.38% (Fig. 19B).

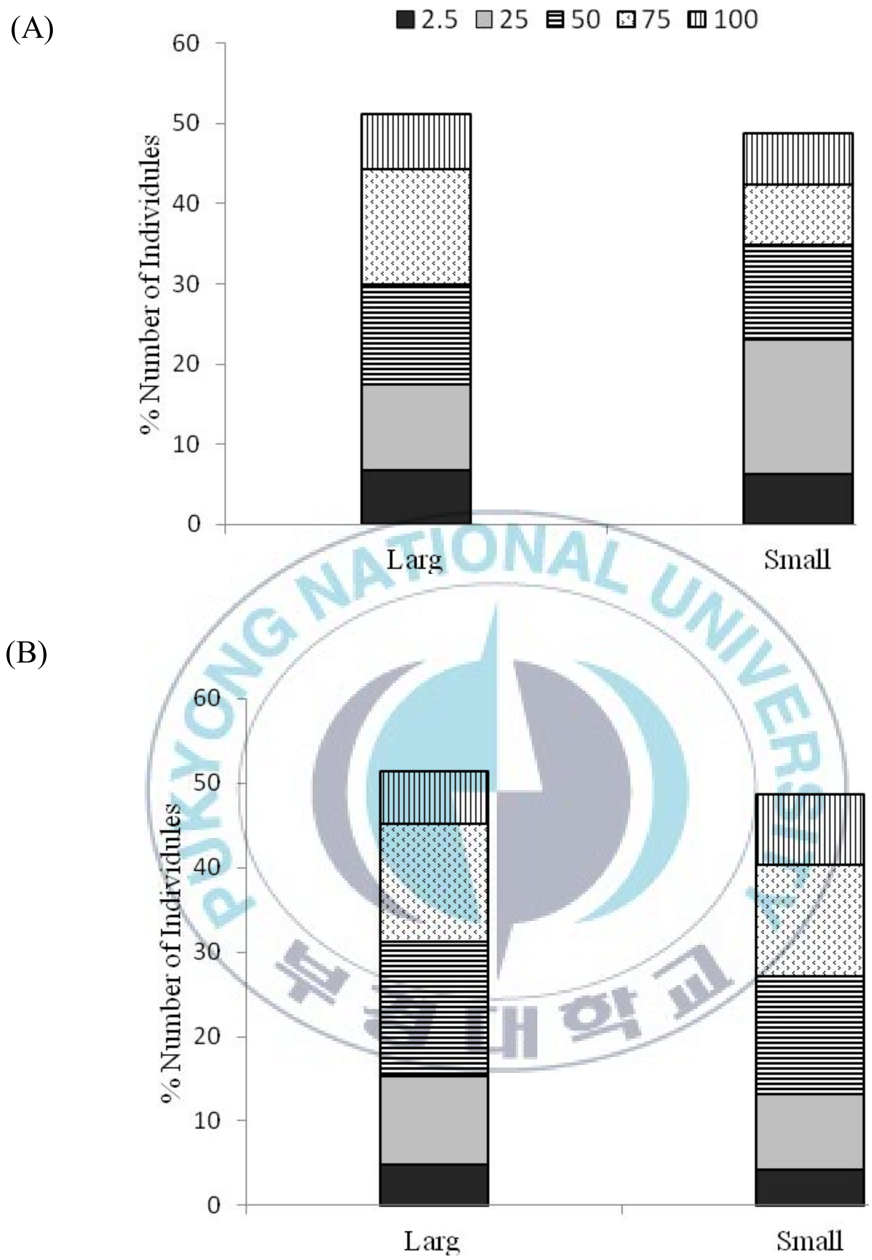


Fig. 18. Proportion of stomach fullness scale of *C. hakodatei* by size for (A) area 1 and (B) area 2, see Fig. 16 for key to abbreviation.

(A)

(B)

(C)

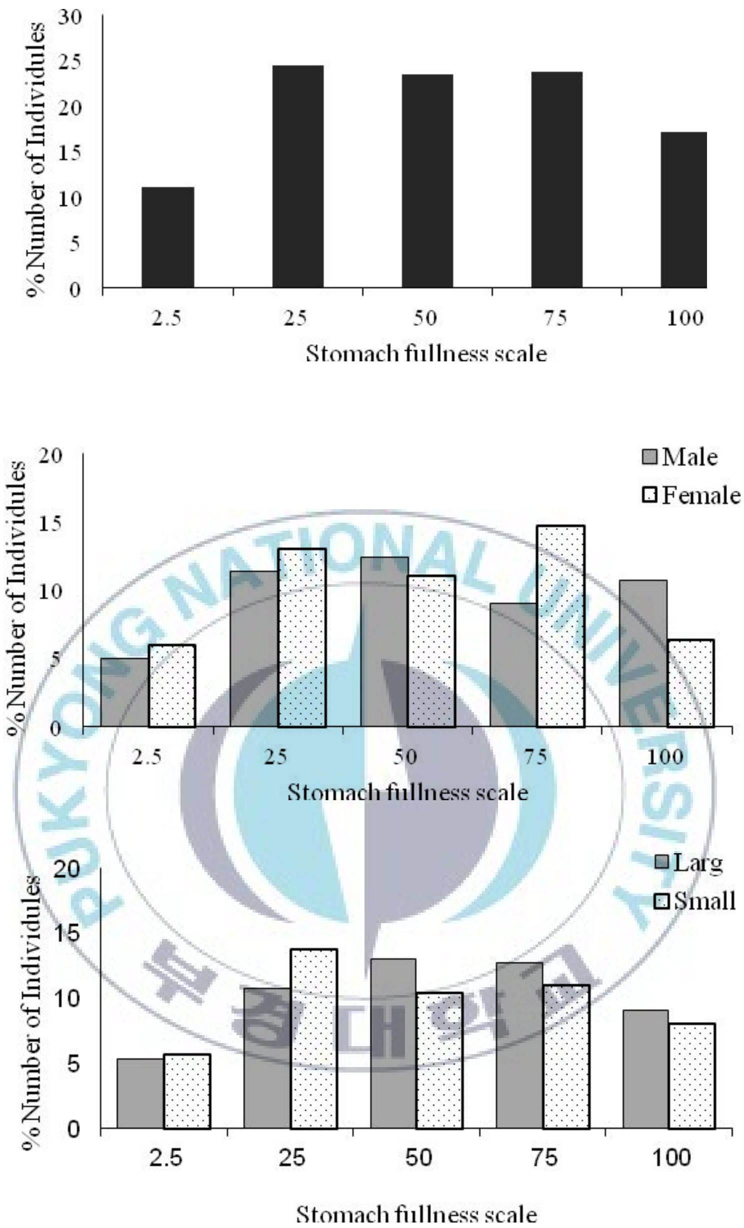


Fig. 19. Seasons, proportion of stomach fullness scale of *C. hakodatei* by (A) total, (B) sex, and (C) size, see Fig. 16 for key to abbreviation.

According to size class, half full showed the highest proportion for large size class, while moderately full was the highest proportion for the small size class. Empty stomach showed the lowest proportion (5.37%) for large sizes class and small sizes class (5.70%). The proportion of large size class was 10.74% in moderately full, 13.09% in half full, 12.75% in full, 9.06 % in very full, while in the small size class the proportion of moderately full, half full, full, very full comprised 13.76%, 10.40%, 11.07%, 8.05%, respectively (Fig. 19C).

There was no significant difference between stomachs fullness proportion and seasons in both sexes (Kruskal-wallis test, $p > 0.05$). There was also no pronounced significant difference between stomachs fullness proportion and seasons in both sizes (Kruskal-wallis test, $p > 0.05$). For autumn the proportion of stomach fullness was moderately full 8.33%, half full 14.81%, full 10.0 %, and very full 11.11 % in males, and that in females 17.59%, 7.41%, 17.59%, 5.56%, respectively. In winter the proportion of moderately full, half full, full, and very full in males comprised 11.34%, 11.34%, 11.34%, 7.50% and that in females 9.28%, 15.46%, 12.37%, 12.50%, respectively. In spring the proportion of moderately full, half full, full, and very full in males comprised 13.98%, 10.75%, 9.68%, 8.60% and that in females 12.90%, 10.75%, 10.75%, 8.60%, respectively (Fig. 20).

The percentage of large size class was 9.26% in moderately full, 12.96% in half full, 16.67% in full, 9.26% in very full for autumn, and that in the small size class 16.67%, 9.26%, 1019%, 7.41%, respectively. In winter the proportion of moderately full, half full, full, and very full in large size class comprised 9.28%, 15.46%, 11.34%, 9.28% and that in the small size class 11.34%, 11.34%, 12.37%, 8.25%, respectively. In spring percentage of large size was 13.95% in moderately full, 10.75% in half full, 9.68% in full, 8.60 in very full for, and that in small 12.90%, 10.75%, 10.75%, 8.60%, respectively (Fig. 21).

(A)

(B)

(C)

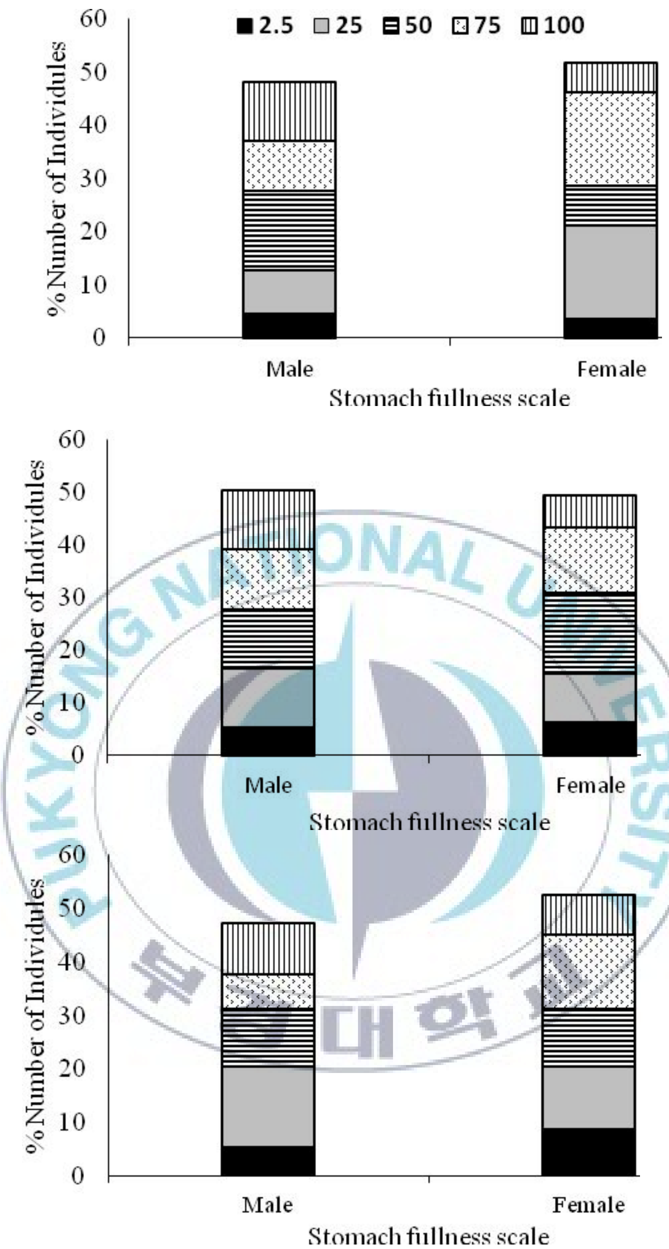


Fig. 20. Proportion of stomach fullness scale of *C. hakodatei* by sex for (A) autumn, (B) winter and (C) spring.

(A)

(B)

(C)

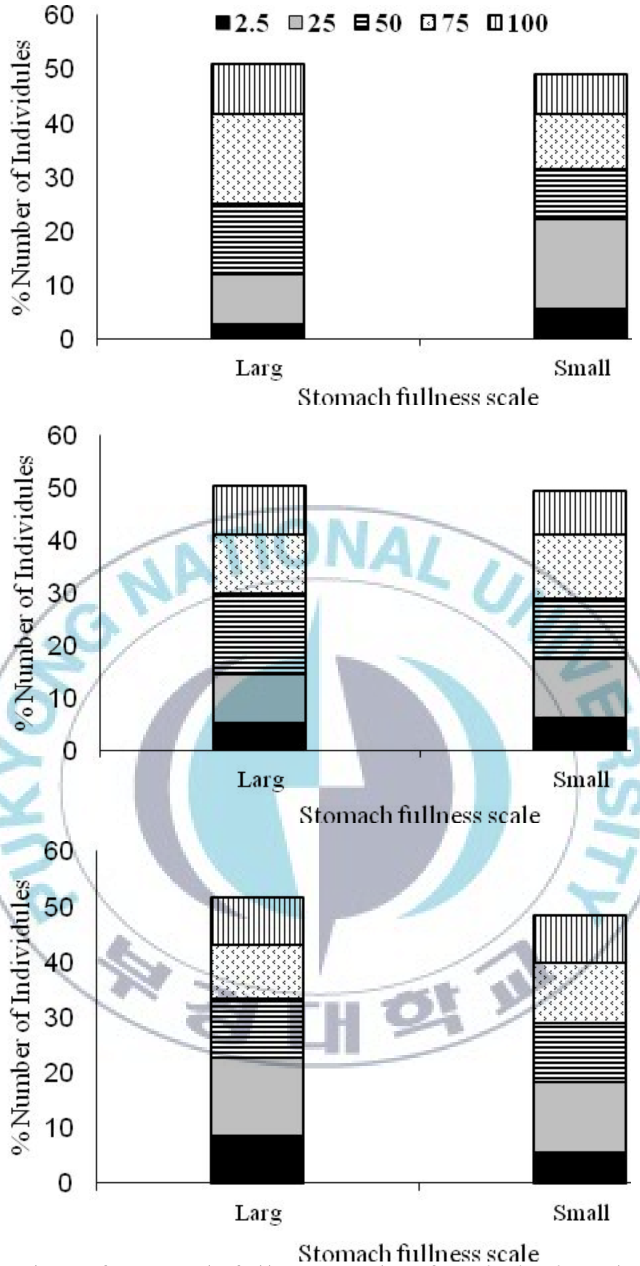


Fig. 21. Proportion of stomach fullness scale of *C. hakodatei* by size for (A) autumn, (B) winter and (C) spring.

3.6. Diet composition

Mysids and amphipods were the most important food items, over both area (areas 1 and 2) and seasons (area 3). The prey importance and predator feeding strategy was determined by size and sex, according to the Costello method (1990)

3.6.1. Diet composition by area

The most components of the stomach contents of *C. hakodatei* consisted of polychaetes, crustaceans (e.g. mysids, amphipods, isopods, decapods, copepods) or shells of molluscs primarily gastropods, bivalve, fishes vertebrae, nematodes and algae (Table 3).

The above prey categories consisted of 89.1% of the relative abundance and 92.79% of total occurrence for males, and 85.9 % of the relative abundance and 91.32 % of the total occurrence in females (Table 4)

Mysids and amphipods were the dominate food items overall, both being present in the foreguts examined. The other prey categories contributed only small proportions to the diet. The two categories accounted for over 40% of the relative abundance, while other crustaceans (isopods, cumaceans, copepods, other) represented 19.6%. Molluscs and fishes in

Table 3. Diet composition of *C. hakodatei* in the two area groups and two size groups (%F, frequency of occurrence; %N, Percentage abundance).

Area	Area 1				Area 2			
Size Class	Small		Large		Small		Large	
No. Examined	68		71		64		67	
Prey item	%F	%N	%F	%N	%F	%N	%F	%N
POLYCHAETA	5.88	4.35	4.23	2.36	6.25	4.59	4.48	3.54
CRUSTACEA								
Mysidacea	18.3	13.0	33.8	25.2	25.0	17.4	28.4	17.7
Amphipoda	39.4	27.0	31.0	18.9	32.8	23.9	41.8	31.0
Isopoda	7.0	4.35	7.0	4.72	6.25	3.67	4.48	2.65
Cumacea	5.63	3.48	5.63	3.15	4.69	4.59	3.0	2.65
Decapoda	1.41	0.87	4.23	2.36	4.69	2.75	7.46	5.31
Copepoda	4.23	4.35	7.0	4.72	6.25	5.5	7.46	4.42
Pices	9.86	6.09	5.63	3.94	12.5	7.34	4.48	2.65
Other crustacean	7.0	6.09	8.45	6.3	4.69	2.75	6.0	3.54
MOLLUSCA								
Bivalvia	1.41	0.87	7.0	4.72	3.13	1.83	7.46	4.42
Gastropoda	2.82	2.61	7.0	4.72	3.13	1.83	10.4	6.19
FISHE								
Pices	2.82	2.61	4.23	2.36	6.25	3.67	4.48	2.65
Backbone	4.23	2.61	1.41	0.79	1.56	0.92	6.0	3.54
Eggs	2.82	1.74	5.63	3.15	4.69	2.75	0	0
ALGAE	7.0	5.22	0	0	0	0	0	0
OTHER	11.3	7.0	9.86	7.09	20.3	11.9	9.0	6.19
NEMATODA	9.86	7.83	9.86	5.51	7.81	4.59	6.0	3.54

Table 4. Diet composition *C. hakodatei* in the two area groups and sex groups (%F, frequency of occurrence; %N, Percentage abundance).

Area	Area 1				Area 2			
Sex	Males		Females		Males		Females	
No. Examined	67		72		61		70	
Prey item	%F	%N	%F	%N	%F	%N	%F	%N
POLYCHAETA	6.0	3.4	4.17	3.25	4.92	2.52	5.71	5.0
CRUSTACEA								
Mysidacea	28.4	20.2	25.0	18.7	26.2	15.1	26.4	17.1
Amphipoda	37.3	23.5	34.7	22.0	32.8	23.5	40.3	26.8
Isopoda	9.0	5.9	5.56	3.25	4.92	2.52	5.56	3.3
Cumacea	3.0	1.68	8.33	4.88	3.28	2.52	4.17	4.07
Decapoda	3.0	1.68	2.78	1.63	4.92	3.36	6.94	4.07
Copepoda	4.48	3.36	6.94	5.69	13.1	7.56	1.39	1.63
Pices	7.46	5.0	8.33	4.88	9.84	5.0	6.94	4.07
Other crustacean	10.4	7.56	5.56	4.88	6.56	3.36	4.17	2.44
MOLLUSCA								
Bivalvia	6.0	3.36	2.78	2.44	6.56	3.36	4.17	2.44
Gastropoda	7.46	5.0	2.78	2.44	3.28	1.68	9.72	5.69
FISHE								
Pices	3.0	2.52	4.17	2.44	1.64	0.84	8.33	4.88
Backbone	1.49	0.84	4.17	2.44	3.28	1.68	4.17	2.44
Eggs	3.0	1.68	5.56	3.25	3.28	1.68	1.39	0.81
ALGAE	1.49	0.84	5.56	4.07	0	0	0	0
OTHER	9.0	5.88	12.5	8.13	13.1	7.56	15.3	8.94
NEMATODA	10.4	7.56	9.72	5.69	8.2	4.2	5.56	3.25

the stomach contents comprised 6.9% and 6.7% of the total abundance of prey in the stomach contents, respectively. The others including polychaetes, nematodes, and algae comprised 10.3 % of the stomach contents (Fig. 22). In area 1 amphipods and mysids were the predominate prey items and these two items combined accounted for over 40% of the diet according to relative abundance, while algae and cumaceans which were less important food items overall, occupied 2.48% and 3.31% of the total abundance of prey in the stomach contents, respectively. Other items, such as polychaetes, nematodes, molluscs, fish and other crustaceans varied in relative importance. Also mysids and amphipods were the most important food items in area 2 and these two items combined accounted for over 45% of the diet according to relative abundance, while the other items declined in relative importance. No algae were found in food items (Fig. 23)

3.6.1.1. Difference of diet by size class in different areas

Diet composition in the two size classes in both areas, small and large size classes are shown in (Fig. 24). For small size amphipods were clearly dominant in both areas and occupied more than 39% of prey item, in both relative abundance and frequency of occurrence in area 1.

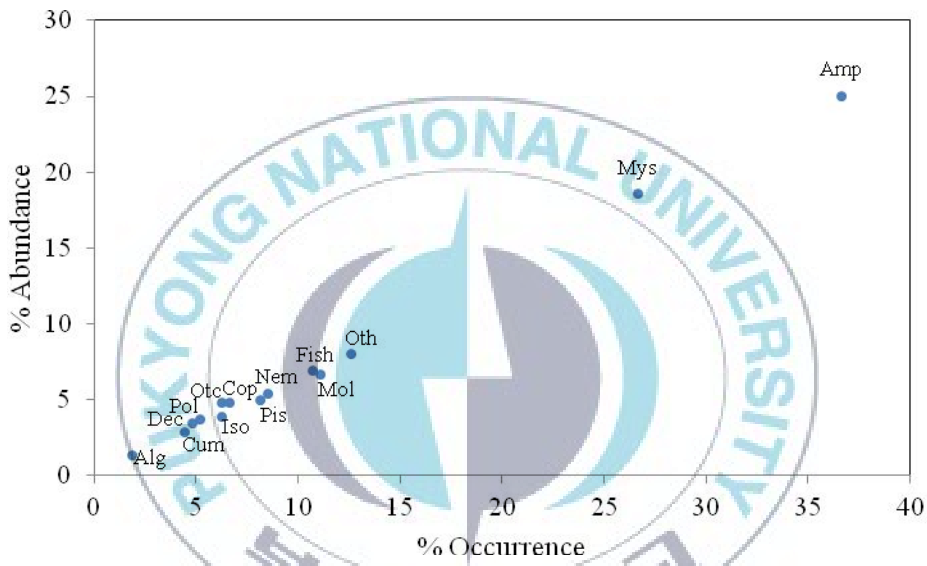
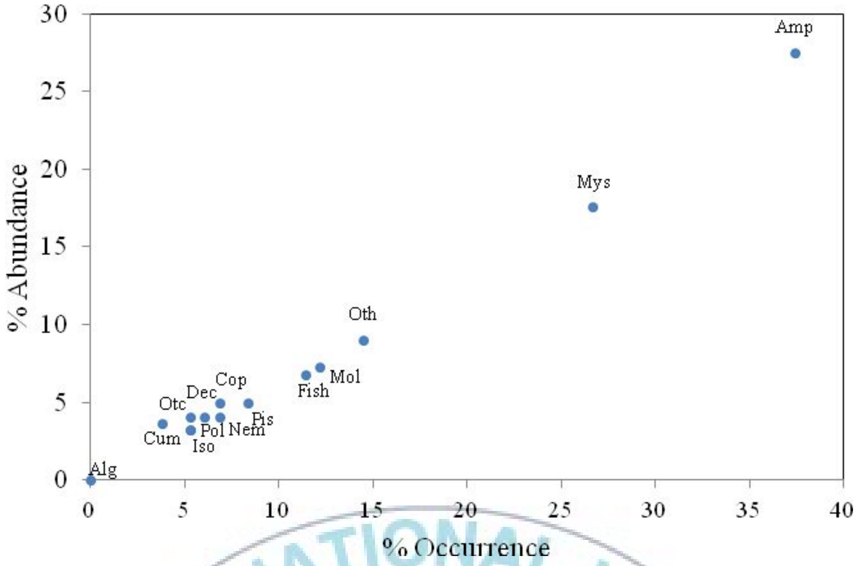


Fig. 22. Relative importance of major stomach contents of *C. hakodatei* in overall diets for all combined samples irrespective of areas (Alg, algae; Amp, amphipods; Cum, cumaceans; Dec, decapods; Iso, isopods; Mol, molluscs; Mys, mysids; Pis, pieces; fishes; Pol, polychaets; Otc, other crustaceans; Oth, other species; Nem, nematodes).

(A)



(B)

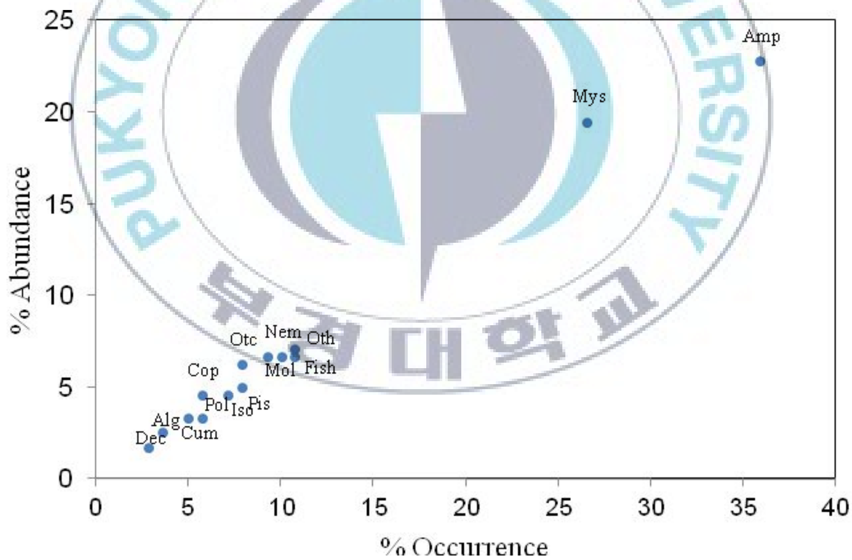


Fig. 23. Relative importance of major stomach contents for *C. hakodatei* samples pooled by (A) area 1 and (B) area 2.

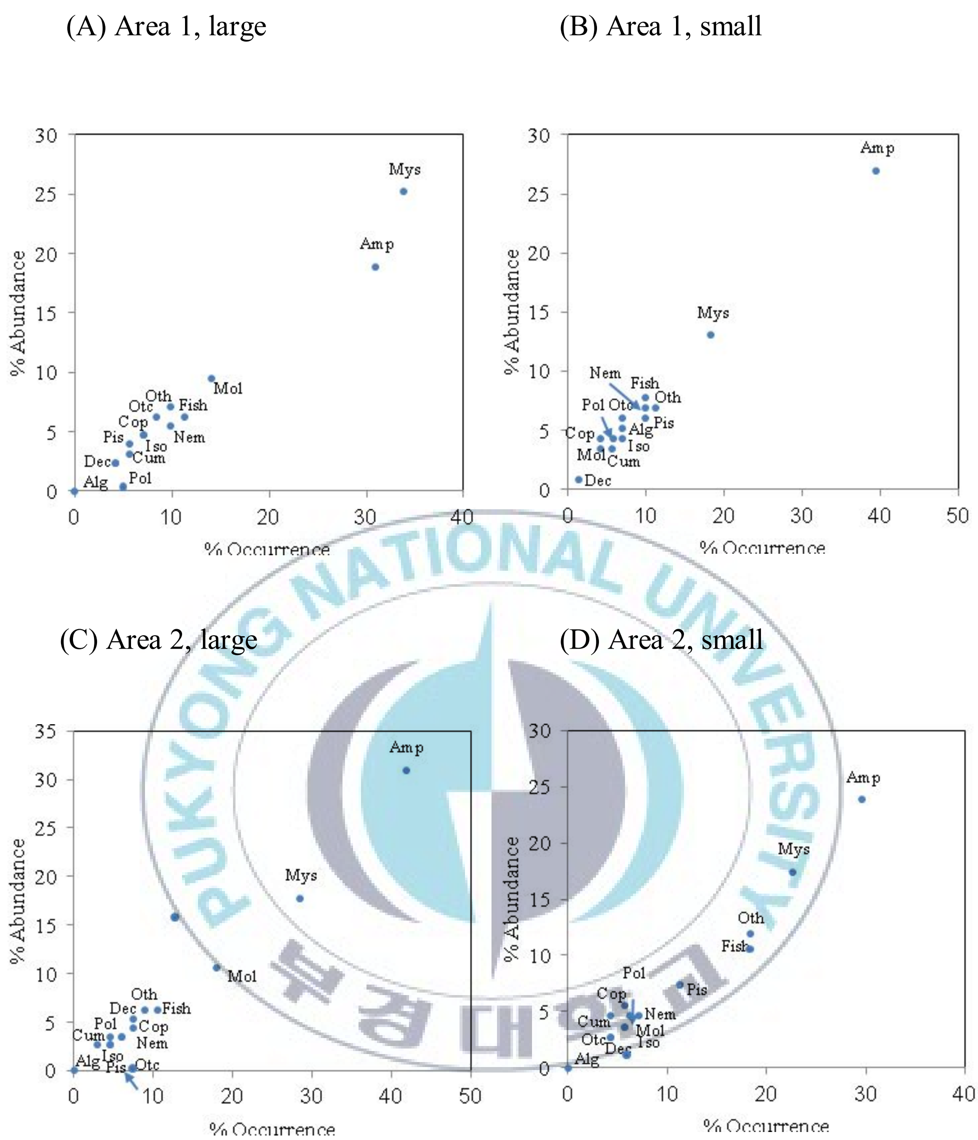


Fig. 24. *C. hakodatei.* Relative importance of major stomach content items for area 1 and 2 samples pooled by size classes: small (<10 mm CL) and large size (>10 mm CL).

In area 2 amphipods occupied more than 30% of prey item, in frequency of occurrence. In area 1 mysids, other species and nematodes ranked as the second, third and fourth important prey items, respectively by relative abundance and frequency of occurrence, respectively. These prey categories comprised 18%, 11% and 9.9% of the frequency of occurrence, respectively. In area 2 mysids, other species and fishes comprised 23%, 18% and 11% of prey item, in frequency of occurrence. For large size shrimps mysids and amphipods were clearly dominant in both areas. In area 1 mysids and amphipods comprised more than 65% of prey item, in both relative abundance and frequency of occurrence. The two combined comprised more than 70% of prey item, in both relative abundance and frequency of occurrence in area 2. In large shrimps, molluscs and fishes ranked as the third and fourth most important prey items respectively, by relative abundance and frequency of occurrence, with different proportions in both areas. Comparisons were made to detect qualitative differences in the diets of the various size classes for both areas, but in area 1 there was no significant difference (df= 13, $p > .05$) in the proportions of prey consumed by the two size classes. Among prey types, the main source of variation came from mysids (χ^2 = 29.43) and amphipods (χ^2 = 27.45) (Table. 5).

Table 5. Contingency table analysis of the size class variation of 14 different categories of food items found in the stomachs of *C. hakodatei*, in area 1. Values are total number of prey observed in each size, with expected values given in parentheses.

Prey	Large	Small	Ni	χ^2
Polychaeta	3 (4)	5 (4)	8	0.72
Mysidacea	32 (13)	15 (12)	47	29.43
Amphipoda	24 (15)	31 (14)	55	27.45
Isopoda	6 (3)	5 (3)	11	4.86
Cumacea	4 (2)	4 (2)	8	3.55
Decapoda	3 (1)	1 (1)	4	3.32
Copepoda	6 (3)	5 (3)	11	4.86
Pices	5 (3)	7 (3)	12	6.35
Other crustacean	8 (4)	7 (4)	15	6.59
Mollusca	12 (4)	4 (4)	16	13.26
Fish	8 (4)	8 (4)	16	7.10
Algae	0 (2)	6 (1)	6	15.34
Other	9 (5)	8 (4)	17	7.46
Nematoda	7 (4)	9 (4)	16	7.96
Ni	127	115	242	
				138.25

In area 2 there was no significant difference (df = 13, p > .05) in the proportions of prey types consumed by the two size classes. The main source of variation were molluscs (χ^2 = 3.26) and pieces (χ^2 = 2.67) among prey types (Table. 6).

3.6.1.2. Difference of diet by sex in different areas

Males and females presented a mixed feeding strategy, with varying degrees of specialization (Fig 25). In both sexes, *C. hakodatei* indicated that amphipods and mysids were the principal food item in both areas. In area 1 amphipods and mysids were clearly dominant in both sexes, the proportion of amphipods and mysids in males comprised 37%, 28%, and that in females 35%, 25% of prey item, in relative of abundance and frequency of occurrence, respectively. In area 2 these prey categories in males comprised 33%, 26% and that in females 41%, 27% of prey item, in relative of abundance and frequency of occurrence, respectively. In terms of prey importance, molluscs and other crustaceans seemed to be the third and fourth most important for males, while fishes and other species for females in area 1. In area 2, copepods and other species ranked as the third and fourth important prey items for males, while the same occurred molluscs

Table 6. Contingency table analysis of the size class variation of 14 different categories of food items found in the stomachs of *C. hakodatei*, in area 2. Values are total number of prey observed in each size, with expected values given in parentheses.

Prey	Large	Small	Ni	χ^2
Polychaeta	4 (5)	5 (4)	9	0.15
Mysidacea	20 (21)	19 (19)	39	0.04
Amphipoda	35 (33)	26 (30)	61	0.68
Isopoda	3 (4)	4 (3)	7	0.24
Cumacea	3 (4)	5 (4)	8	0.68
Decapoda	6 (5)	3(4)	9	0.74
Copepoda	5 (6)	6 (5)	11	0.20
Pices	3 (6)	8 (5)	11	2.67
Other crustacean	4 (4)	3 (3)	7	0.07
Mollusca	12 (9)	4 (8)	16	3.26
Fish	7 (8)	8 (7)	15	0.19
Algae	0 (0)	0 (0)	0	0.00
Other	7 (11)	13 (10)	20	2.32
Nematoda	4 (5)	5 (4)	9	0.22
Ni	113	109	222	
				11.47

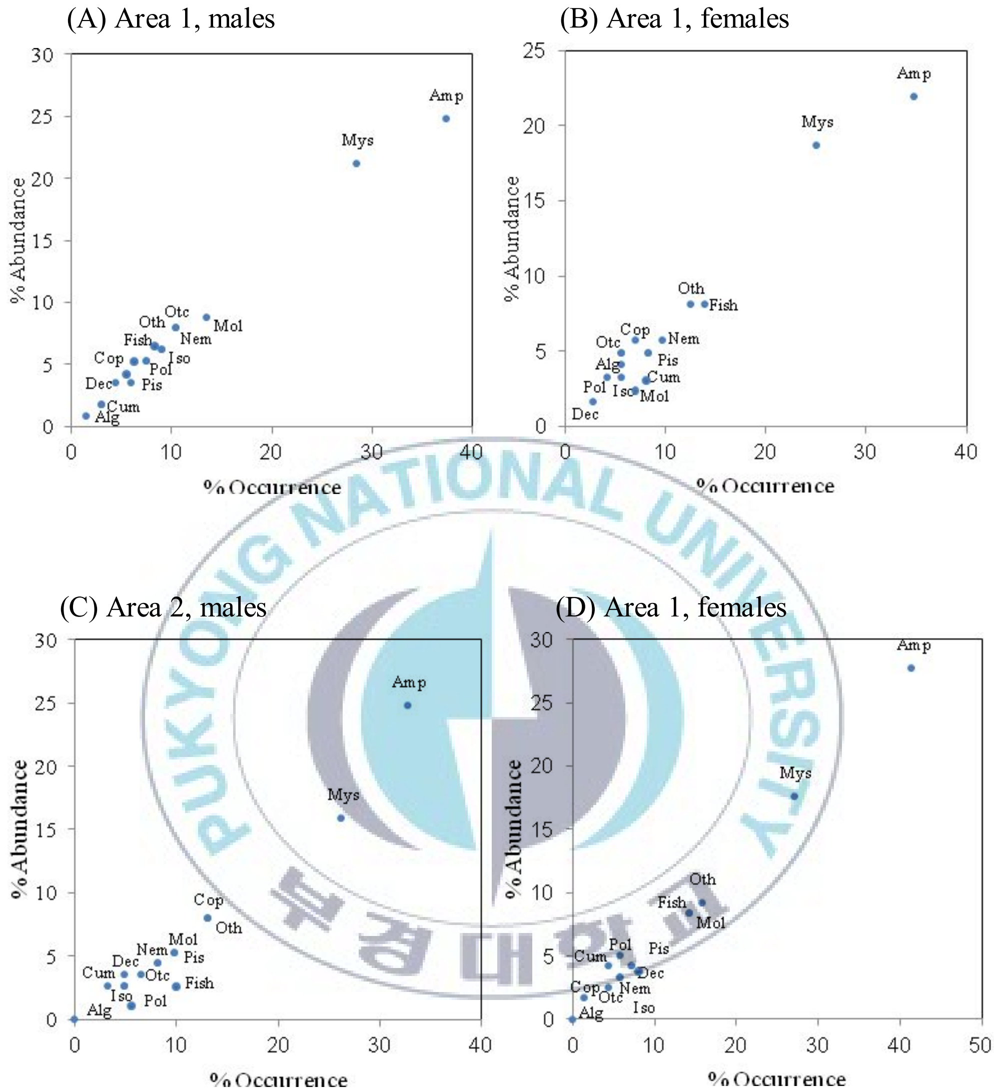


Fig. 25. *C. hakodatei*. Relative importance of major stomach content items for area 1 and 2 samples pooled by sex.

and other species for females. There was not a generally clear separation among the monthly values of the relative abundance of the prey (%N) eaten by *C. hakodatei* males and females. There was also no significant difference (df = 13, p>.05, at the 95% confidence level) in the proportions of prey types in area 1, and the main source of variation coms from amphipods (χ^2= 24.2) and mysids (χ^2= 20.76) (Table 7). In area 2 there was no significant difference (df = 13, p > .05) in the proportions of prey types consumed by males and females. The main source of variation were copepods (χ^2 = 5.55) and fishes (χ^2 = 1.03) among prey types (Table 8).

3.6.2. Seasonal variation in diet composition

The abundance and occurrence composition of food items showed seasonal fluctuation (Table 9). Mysids and amphipods were the predominant prey items in the three seasons. These two food items combined accounted 40% of the diet according to relative abundance and frequency of occurrence in autumn, while in winter it was30 %, and 41% in spring. Other items, such as molluscs, nematodes, polychaetes and other crustaceans (copepods, decapods), declined in relative importance (Fig. 26).

Table 7. Contingency table analysis of the sex variation of 14 different categories of food items found in the stomachs of *C. hakodatei*, in area 1. Values are total number of prey observed in both sex, with expected values given in parentheses.

Prey	Male	Female	Ni	χ^2
Polychaeta	4 (4)	4 (4)	8	0.00
Mysidacea	24 (12)	23 (12)	47	20.76
Amphipoda	28 (14)	27 (15)	55	24.27
Isopoda	7 (3)	4 (3)	11	6.59
Cumacea	2 (2)	6 (2)	8	7.10
Decapoda	2 (1)	2(1)	4	1.76
Copepoda	4 (3)	7 (3)	11	6.21
Pices	6 (3)	6 (3)	12	5.27
Other crustacean	9 (4)	6 (4)	15	7.93
Mollusca	10 (4)	6(4)	16	9.20
Fish	6 (4)	10 (4)	16	8.70
Algae	1 (2)	5 (2)	6	7.50
Other	7 (4)	10 (5)	17	8.30
Nematoda	9 (4)	7 (4)	16	7.64
Ni	119	123	242	
				121.22

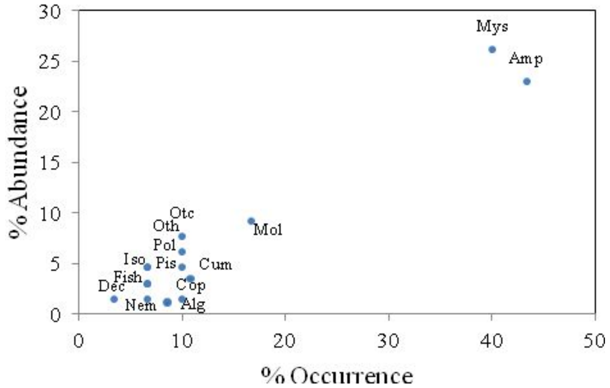
Table 8. Contingency table analysis of the size class variation of 14 different categories of food items found in the stomachs of *C. hakodatei,* in area 2. Values are total number of prey observed in both sex, with expected values given in parentheses.

Prey	Large	Small	Ni	χ^2
Polychaeta	3 (4)	6 (5)	8	0.62
Mysidacea	18 (18)	21 (21)	47	0.00
Amphipoda	28 (28)	33 (33)	55	0.01
Isopoda	3 (3)	4 (4)	11	0.04
Cumacea	3 (4)	5 (4)	8	0.25
Decapoda	4 (4)	5 (5)	4	0.01
Copepoda	9 (5)	2 (6)	11	5.55
Pices	6 (5)	5 (6)	12	0.29
Other crustacean	4 (3)	3 (4)	15	0.33
Mollusca	6 (7)	10 (9)	16	0.51
Fish	5 (7)	10 (8)	16	1.03
Algae	0 (0)	0 (0)	6	0.00
Other	9 (9)	11 (11)	17	0.02
Nematoda	5 (4)	4 (5)	16	0.30
Ni	103	119	222	
				8.95

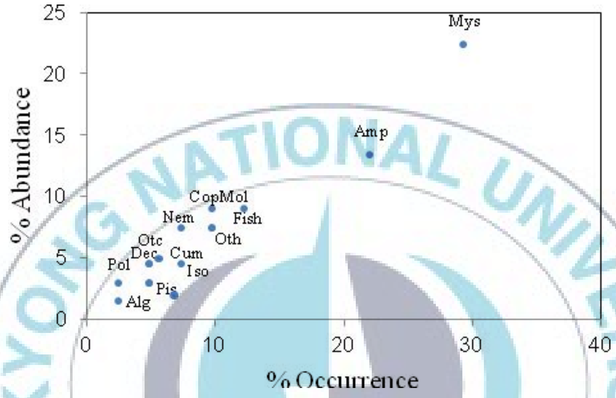
Table 9. Diet composition of *C. hakodatei* in the three seasonal groups and two size groups (%F, frequency of occurrence; %N, percentage abundance).

Area	Autumn				Winter				Spring			
Size Class	Small		Large		Small		Large		Small		Large	
No. Examined	47		52		42		42		40		41	
Prey item	%F	%N	%F	%N	%F	%N	%F	%N	%F	%N	%F	%N
POLYCHAETA	1.89	1	9.09	5.38	8.33	6.25	2.04	1.23	21.4	12	6.25	1.7
CRUSTACEA												
Mysidacea	23.6	18.0	21.8	17.2	25.0	16.3	26.5	18.5	21.4	20.0	12.5	13.0
Amphipoda	38.2	22.0	32.7	21.5	37.5	27.5	32.7	23.5	42.9	24.0	31.3	16.0
Isopoda	7.3	5	9.1	5.38	6.25	3.75	2.04	1.23	0	0	6.25	1
Cumacea	9.09	5	1.82	1.08	6.25	5	4.1	4.94	7.14	4	18.8	3.2
Decapoda	1.82	1	5.45	3.23	6.25	3.75	10.2	7.41	14.3	8	5.1	4
Copepoda	3.64	3	9.1	7.53	2.08	1.25	10.2	6.17	2.2	1.8	1.2	5
Pices	14.5	8	3.64	3.23	10.4	6.25	6.12	3.7	7.1	4	3.7	2.1
Other crustacean	3.6	3	9.09	6.45	6.25	3.75	6.1	3.7	7.14	4	12.5	3
MOLLUSCA												
Bivalvia	1.82	1	5.5	4.3	6.25	3.75	4.08	2.47	7.5	3.2	6.25	6
Gastropoda	5.45	4	1.8	1.08	4.17	2.5	8.2	4.94	7.14	4	6.3	6
FISHE												
Pices	5.45	4	1.82	1.08	6.25	3.75	4.08	2.47	0	0	0	0
Backbone	5.45	3	1.82	1.08	0	0	8.2	4.94	7.14	4	5.2	4.6
Eggs	3.64	2	5.45	3.23	4.17	2.5	0	0	7.14	4	1.1	0.4
ALGAE	5.5	4	3.64	2.15	0	0	0	0	3.4	2.8	0.9	0
OTHER	5.5	3.0	20	14	12.5	7.5	18.4	12.3	14.3	8.0	6.3	5.2
NEMATODA	20	13	3.64	2.15	10.4	6.25	4.1	2.47	0	0	6.3	0

(A)



(B)



(C)

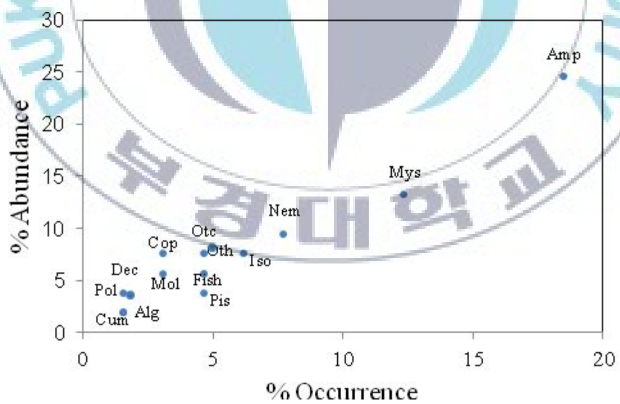


Fig. 26. Relative importance of major stomach contents for *C. hakodatei* samples pooled by seasons, (A) autumn, (B) winter and (C) spring.

3.6.2.1. Difference of diet by season and size class

For both size classes mysids and amphipods were the predominant prey items in all seasons. For small size class they were more than 45% in both relative abundance and frequency of occurrence in autumn. In winter they constituted more than 30% of food prey item, and in spring accounted for 25% of the diet according to both relative abundance and frequency of occurrence. In autumn mollusca, other species and other crustaceans ranked as the second, third and fourth important prey items, respectively, by relative abundance and frequency of occurrence. These prey categories comprised 17%, 11% and 10% of the frequency of occurrence, respectively. In winter fishes, other species and molluscs ranked as the second, third and fourth important prey items they comprised 12%, 10% and 9.8% of prey item, in frequency of occurrence, respectively. In spring the second, third and fourth important prey items comprised nematodes, other crustaceans and molluscs, respectively. For large size shrimps, mysids and amphipods were also clearly dominant in all seasons. In autumn they comprised more than 55% of prey item, in both relative abundance and also. They comprised more than 70% of prey item, in both relative abundance and also in winter, and more than 65% of prey item in spring. In large shrimps, mollusca and fishes ranked as the third and fourth most important prey items, respectively, by relative abundance and also, with different proportion in both areas.

3.6.2.2. Difference of diet by season and sex

Both genders presented a mixed feeding strategy, with varying degrees of specialization and generalization on different prey types. The relative abundance and frequency of occurrence of food items showed the diets of males and females are relatively similar, Both indices highlighted their increasing importance through the seasons, dominating the diet in, autumn (45% males; 40% females), winter (41% males; 32% females), and spring (43% males; 39% females). Other items, such as molluscs, cumaceans and other crustaceans (copepods, isopods), declined in relative importance during the seasons (Fig. 27).

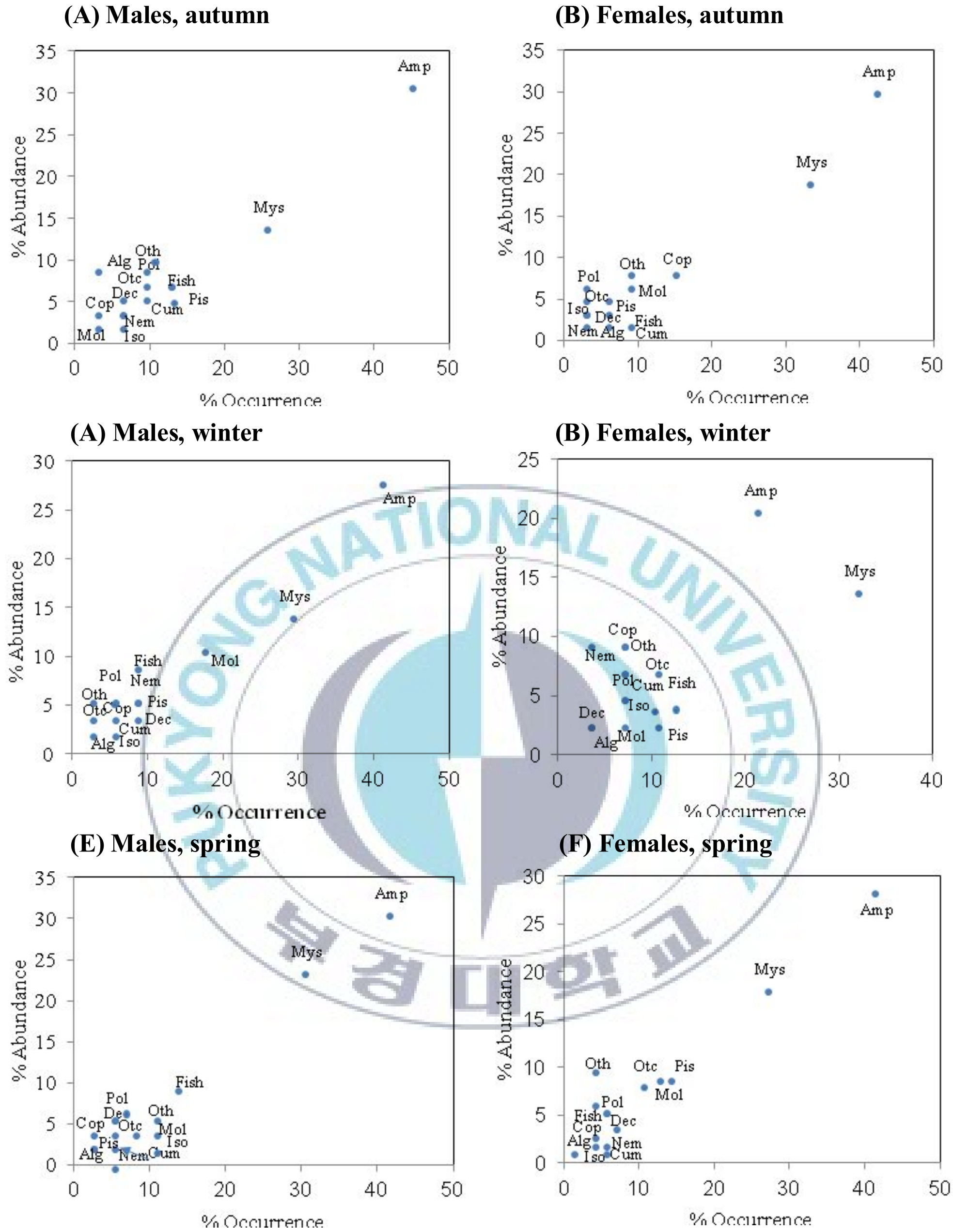


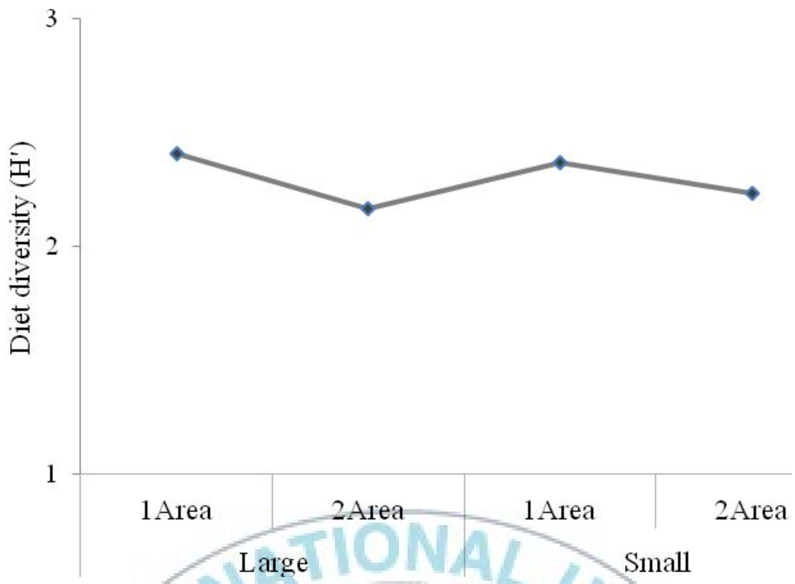
Fig. 27. *C. hakodatei*. Relative importance of major stomach content items for seasons samples pooled by sex.

3.7. Trophic diversity and equality

The trophic diversity and evenness for each size class for both areas are presented in (Fig. 28A). Trophic diversity varied slightly among the size in both areas and no statistically significant differences were established between the size classes. Diversity for small shrimps was the highest in area 1. Both index values were higher in small size at area 1 than in the area 2, it means the shrimp in area 2 were more dependent on a few prey items with a lesser contribution from others (Fig. 28B).

Seasonally trophic diversity was generally low (Fig. 29A). For both size classes diversity was highest in summer. No appreciable differences were observable between size classes in any season. Trends were similar for diet evenness (Fig. 29B). The higher index values in summer indicated that the prey items consumed were more evenly distributed, as demonstrated by the relative importance of seasonal diet composition. In other seasons, shrimp were more dependent on a few prey items with a lesser contribution from others.

(A)



(B)

Fig. 28. Trophic diversity (A) and equality (B) of prey items found in small and large size classes of *C. hakodatei* at each area.

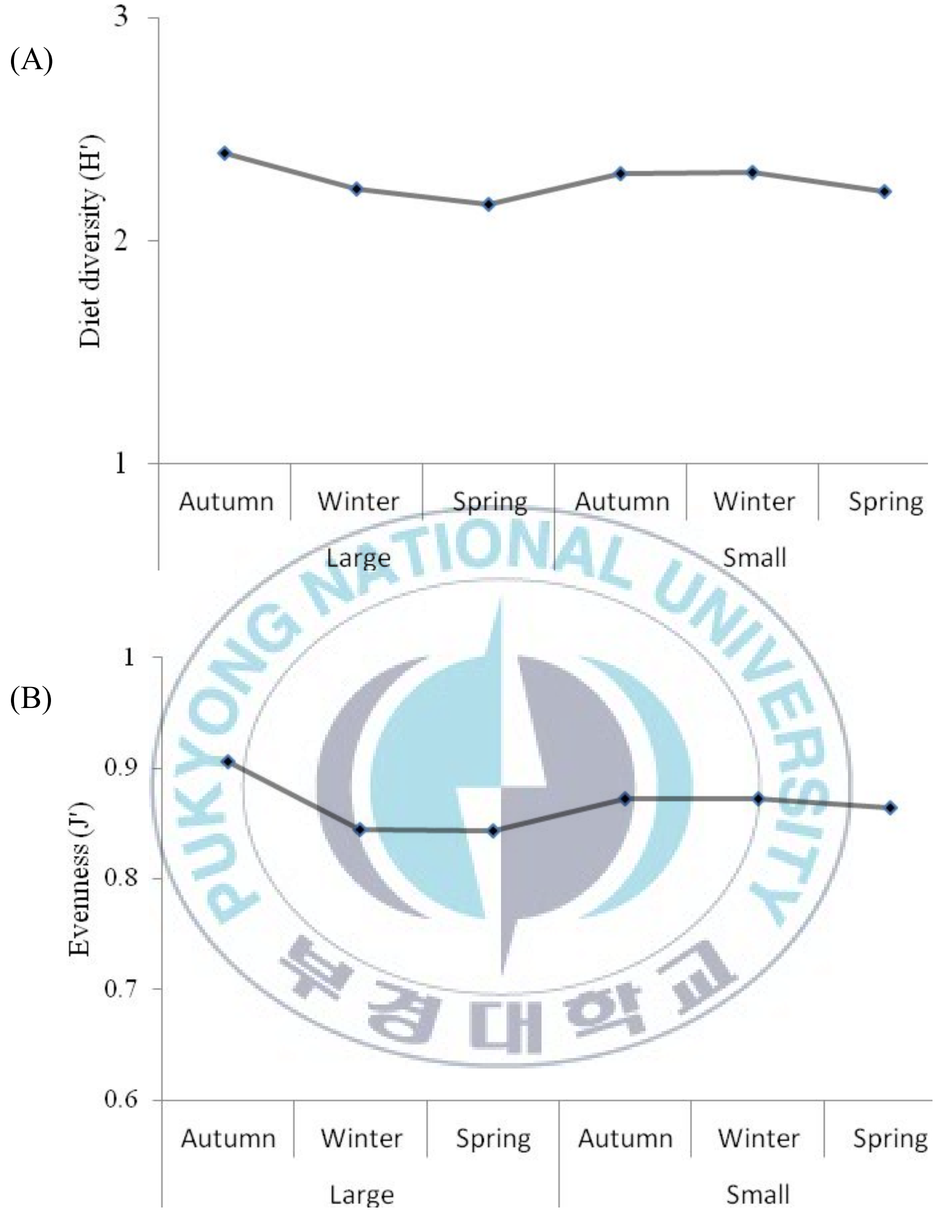


Fig. 29. Trophic diversity (A) and equality (B) of prey items found in small and large size classes of *C. hakodatei* at each season.

4. Discussion and Conclusion

The most important prey items are crustaceans, and other does not play an important role in *Crangon hakodatei* diet. Crustaceans dominance in food components has been reported for several species of *Crangon*. For example, *Crangon crangon* (Pihl and Rosenberg, 1984, Oh, 2001), *Crangon franclscorum* (Stimpson, 1856; Sitts and Knight,1979) and *Crangon uritai* (Hanamura, 2003).The diet of *C. hakodatei* consists of benthic organisms and they can be divided into three main categories: (1) organisms that, as a result of vertical migrations, may dwell close to the bottom during part of the day (mysids, shrimps, fishes, etc.); (2) organisms that, dwell on or just beneath the surface of the substratum (amphipods, gastropods, etc.); (3)organisms that live completely or partially buried, digging out small galleries in the substratum (bivalves, cumaceans, polychaetes, etc.). This diet, although including a diversity of prey, was amphipods and mysids as the dominant food item in all areas, seasons, size groups and sexes. Amphipods are usually dominant species in diverse habitats and play an important role in the food chain of marine ecosystems as the main food sources to other predatory animals (Crawford, 1937; Zhang, 1974). Mysids are a ubiquitous component of the zooplankton assemblages in a variety of aquatic environments, and may, at times, comprise a significant proportion (up to 20%) of the total zooplankton biomass (Mauchline, 1980; Price, 1982; Webb et al., 1987; Grange, 1992; Jerling and Wooldridge, 1995; Froneman, 2001). The occurrence in the stomachs of major crustaceans items was noted to be not related to size, sex and areas. Mysids and amphipods were frequently found in both size of shrimps, Some food items were so tiny and the percentage of their volume to the volume of total diets was so small, as algae were only occasionally observed in low quantities in the gut contents of Crangon hakodatei. They may be accidentally ingested with other food, or released from the guts of ingested prey. In area 2 algae were completely absent from food items that were found in the stomach of *C. hakodatei*. Adsorbed material, sand and mud grains were reported in the stomach content. It was suggested that they might assist in trituration and supplement the grinding process of the gastric mill (Tiews, 1968 ; Capelli, 1980). In the present study, mysids were one of the dominant food items. In areas with silt and clay, important components were meiofauna and macrofauna (Phile and Rosenberg 1984). On sand, calanoid copepods dominated (Boddeke et al. 1986). The results of our investigation are similar to those reported in other studies of *Crangonidae* shrimps. This family is almost exclusively carnivorous, as seen in *Crangon affinis* De Haan (Kosaka, 1970; Hong and Oh 1989), *Crangon. allmani* (Allen, 1960), *C. crangon* (Lloyd and Yonge, 1947; Tiews, 1968) *C. franciscorum* and *Crangon Nigricauda* (Wahle, 1985), *Crangon septemspinosa* (Price, 1962) and *Crangon uritai* (Nakaya et al., 2004) .The most important factor affecting the diet of Crangon spp. is spatial and temporal availability of prey(Wilcox and Jeffries, 1974; Wahle, 1985; Oh, 2001), as seen which amphipods are the most productive benthopelagic animals (Venables, 1981; Moller and Rosenbreg, 1982). Also spatial differences in the diet of *C. hakodatei* are related to differences in habitats, particularly in substrate type, which would determine the abundance and structure of the different community of potential prey. Based on many food investigations, species of *Crangon* in general are suggested to adopt an opportunistic strategy, so the major food items of *C hakodatei* may also shift, depending on the habitat and on prey availability. According to the results of this study, the diet of *C. hakodatei* is diverse, consisting of different macrobenthic organisms. However, six prey categories (amphipods, mysids, other species, molluscs, copepods and nematodes) showed high values of abundance and frequency of occurrence in area 1, and prey items (amphipods, mysids, other crustaceans, nematodes, molluscs, isopods) in area 2. Three prey categories in area 1 (cumaceans, isopods, other crustaceans) showed lowest values of abundance and frequency of occurrence, while in area 2 (algae, decapods, cumaceans) showed lowest values of abundance and frequency of occurrence. Fishes remains were found in the stomach contents of *C. hakodatei* of all sizes. These were probably dead or injured fishes because sand shrimp is not likely to chase fast moving animals.

In this study, significant differences in stomach fullness of sand shrimp among areas could not be related to availability of food items because the dominant and preferred trophic groups of macrobenthic organisms did not change drastically in any season at either site. Stomach fullness was affected by both extrinsic (season) and intrinsic (sex) factors, and was relatively low in spring with highest value recorded for Vacuity index for females, the main reproductive period (Lloyd and Yonge, 1947; Meredith, 1952; Henderson and Holmes, 1987). Males exhibited lower values of stomach fullness, food quality indices and evenness than females. Both sexes consumed the same prey items, but in different abundance and frequency of occurrence. From the above results, a slightly higher predatory ability of females is shown. These differences could also be attributed to sexual dimorphism and to size difference between the sexes. Shrimp body size and consumption of small prey size is not observed. Trophic diversity indices varied little among areas, but were higher in large size than in small size, The highest values were observed in spring, a likely consequence of the substantial increase in the availability of prey items, while the lowest values in autumn were observed as a result of reduction in the range of prey items. Another possible explanation might be attributed to the changes of prey abundance associated with seasonal variations of primary production.

In conclusion Stomach contents of *C. hakodatei* suggest that this species feed mainly on a variety of benthic organisms. The shrimp are trophic links between the benthos and the fishes which prey upon the shrimp. In the Korean east coast, the shrimp also, presumably, have an important trophic role in the transport of energy to higher consumer levels. Diet composition is also useful for assessing the trophic competition among species provided that prey resources are limited, differences in food consumption of the investigated species of shrimps clearly appear from this study.

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I dedicate this thesis to my son Ali, and I thank him for his love and support during my odyssey in Korea.

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Reference

Akbulut, M., M. R. Ustaoğlu, E. Ş. Çelik1, 2009. Fresh water and brackish water Malacostraca (Crustacea-Arthropoda) fauna of Sinop and Samsun and their ecology. J. Black Sea/Mediterranean Environment, 15: 47- 60.

Allen, J. A., 1960. On the biology of *Crangon allmani* Kinahan in Northumberland waters. J. Mar. Biol. Assoc. UK, 39: 481–508.

Bird, F. L., 1997. Burrowing and Feeding Ecology of the Ghost Shrimp Biffarius Arenosus (Decapoda: Callianassidae). Ph.D. Thesis, Victoria University of Technology. USA., 221 pp.

Boddeke, R., G. Drissen, W. Doesburg, G. Ramaekers, 1986. Food availability and predator presence in a coastal nursery area of the brown shrimp (*Crangon crangon*). Ophelia, 26: 77–90.

Boddeke, R., 1989. Management of the brown shrimp (*Crangon crangon*) stock in Dutch coastal waters. In: Marine invertebrate fisheries: Their assessment and management (ed. by J.F. Caddy), WileyInterscience Pub., pp. 3, 35-62.

Boo, S. M., I. K. Lee, 1986. Studies on Benthic Algal Community in the East Coast of Korea. 1. Florsitic composition and periodicity of a Sokcho rocky shore. Ko. J. Phyco., 1(1): 107-116.

Bracken, H. D., A. Toon, D. L. Felder, J. W. Martin ,M. Finley, J. Rasmussen, F. Palero, K. A. Crandall, 2009. The Decapod Tree of Life: Compiling the Data and Moving towarda Consensus of Decapod Evolution. Arthropod Systematics Phylogeny, 67(1): 99-116.

Capelli, G. M., 1980. Seasonal Variation in the Food Habits of the Crayfish Orconectes propinquus (Girard) in Trout Lake, Vilas County, Wisconsin, U.S.A. (Decapoda, Astacidea, Cambaridae). Crustaceana, 38: 82–86.

Cha, H.K., J.U. Lee, C.S. Park, C.I. Baik, S.Y. Hong, J.H. Park, D.W. Lee, Y.M. Choi, K. Hwang, Z.G. Kim, K.H. Choi, H. Sohn, M.H. Sohn, D.H. Kim and J.H. Choi, 2006. Shrimps of Korean Waters. National Fisheries Research and Development Institute., pp. 170-172 (In Korean).

Chen, S., Q. Wang, Y. Peng, J. Liu, 2006. Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem, Third Meeting of the Regional Working Group for the Biodiversity Component. China UNDP/GEF/YS/RWG-B2/3.

Choi, J. H., J. N. KIM, S. T. Kim, H. K. Cha, 2002. Population Dynamics of *Crangon hakodatei* from Coastal Area of Geoje Island, Korea. J. Kor. Fish. Soc. 35(4): 380-385.

Chough, SK. 1983. Marine Geology of Korean Seas. International Human Resources Development. Boston. 157 pp.

Christoffersen, M. L., 1988. Genealogy and phylogenetic classification of the world Crangonidae (Crustacea, Caridea), with a new species and new records for the south western Atlantic. Revista Nordestina de Biologia., 6: 43-59.

Chuhukalo, V. I., M. A. Shebanova, 2008. Feeding Habits of Several Mass Shrimp Species in the Sea of Okhotsk. J. Mar. Biol. Rus., 34(7): 468–471

Cody, M. L., J. M. Diamond, 1975. Ecology and evolution of communities. The Belknap Harvard University Press, Cambridge.

Conkright, M. E., W. M. Sackett, 1986. A stable carbon isotope evaluation of the contribution of terrigkious carbon to the markie food web in Bayboro harbor, Tampa Bay, Florida. Mar. Sci., 29: 131-139.

Conover W. J., 1971. Practical nonparametric statistics. John Willey and Sons Inc. New York.

Costello, M. J., 1990. Predator feeding strategy and prey importance: a new graphical analysis. J. Fish Biol., 36: 261–263.

Crawford, G. I., 1937. A review of the amphipod genus *Corophium*, with notes on the British species. J. Mar. Biol. Assoc. U.K., 21: 589-630.

Crisp, D. T., 1963. A preliminary survey of brown trout (*Salmo trutta* L.) and bullheads (*Cottus gobio* L.) in high altitude becks. Salm. Trout Mag., 167: 45-59. Chough, SK. 1983. Marine Geology of Korean Seas. International Human Resources Development. Boston, 157 pp.

Daniel W. W., 1974. Biostatistics: A foundation for analysis in the health sciences. John Willey and Sons Inc. New York.

Deegan, L. A., B. J. Peterson, R. Porther, 1990. Stable Isotopes and Cellulase Activity as Evidence for Detritus as a Food Source for Juvenile Gulf Menhaden. Estuaries, 13(1): 14-19.

Espinoza, M., I. S. Wehrtmann, 2008. Stomach content analyses of the threadfin anglerfish *Lophiodes spilurus* (Lophiiformes: Lophiidae) associated with deepwater shrimp fisheries from the central Pacific of Costa Rica. J. Trop. Biol. 56(4): 1959-1970.

Fagade, S. O., C. I. O. Olaniyan, 1972. The biology of the West African shad *Ethmalosa fimbriata* (Bowditch) in the Lagos lagoon, Nigeria. J. Fish Biol., 4: 519-533.

Foale, S., R. Day, 1992. RecognizabiUty of algae mgested by abalone. Aust. J. of Mar. Freshw. Res., 43: 1331-1338.

Froneman, P. W., E. A. Pakhomov, A. Treasure, 2000. Trophodynamics of the hyperid amphipod, *Themisto gaudichaudi*, in the waters surrounding the Prince Edward Islands. Polar Biol., 23: 429–436.

Grange, N., B. R. Allanson, 1995. The influence of freshwater inflow on the nature, amount and distribution of seston in estuaries of the Eastern Cape, South Africa. Estuarine Coastal Shelf Sci., 40: 403–420.

Hanamura, Y., M. Matsuoka, 2003. Feeding Habits of the Sand Shrimp, *Crangon uritai* Hayashi and Kim, 1999, In the Central Seto Inland Sea, Japan. Crustaceana., 76(8): 1017-1024.

Hayashi, K. I., J.N. Kim 1998. Neotype designation of *Crangon affinis* (Decapoda, Caridea, Crangonidae). Fish. Sci. Jap., 64: 711-714.

Hayashi, K. I., J. N. Kim, 1999. Revision of the East Asian species of *Crangon* (Decapoda: Caridea: Crangonidae). Crus. Res., 28: 62-103.

Henderson, P.A., R. H. A. Holmes, 1987, On the population biology of the common shrimp *Crangon crangon* (L.) (Crustacea: Caridea) in the Severn Estuary and Bristol Channel. J. Mar. Biol. Assoc. UK., 67: 825–847.

Holthuis, L. B., 1993. The recent genera of the caridean and stenopodidean shrimps (Crustacea, Decapoda) with an appendix on the order Amphionidacea. Nationaal Natuurhistorisch Museum, Leiden

Hong, S. Y., C. W. Oh, 1989. Ecology of the sand shrimp, *Crangon affinis*, in the Nakdong River estuary, Korea. Bull Korean Fish. Soc., 22: 351–362.

Hong, S.Y., K.Y. Park, C.W. Park, C.H. Han, H.L. Suh, S.G. Yun, C.B. Song, S.G. Jo, H.S. Lim, Y.S. Kang, D.J. Kim, C.W. Ma, M.H. Son, H.K. Cha, K.B. Kim, S.D. Choi, K.Y. Park, C.W. Oh, D.N. Kim, H.S. Shon, J.N. Kim and J.H. Choi, 2006 Marine invertebrates in Korean coasts. Republic of Korea, Academy Publishing Company, Inc. 479 p.

Hynes, H. B. N., 1950. The food of fresh-water sticklebacks (*Gasterosteus aculeatus and Pygosteus pungitus*), with a review of methods used in studies of the food of fishes. J. Anim. Ecol., 19: 36–58.

Hyslop, E. J. 1980. Stomach content analysis: a review of methods and their application. J. Fish. Biol., 17: 411-429.

Jerling, H. L., T. H. Wooldridge, 1995. Feeding of two mysid species on plankton in a temperate estuary. J. Exp. Mar. Biol. Ecol.,188: 243-259.

Kim, H. S., 1976. A checklist of the Macrura (Crustacea, Decapoda) of Korea. College of Natural Science, Seoul National University, 1: 131-152.

Kim, H. S., K. B. Park, 1972. Faunal studies on the Macrurans in Korea, in Floral Studies on some Taxa of Plants and Faunal Studies on some Taxa of Animals in Korea. Ministry of Science and Technology, Seoul: 185–222 (In Korean with English summary).

Kim, J. N., K. I. Hayashi, 2003. *Syncrangon*, a New Crangonid Genus, with Redescriptions of *S. angusticauda* (De Haan) and *S. dentate* (Balss) (Crustacea, Decapoda, Caridea) from East Asian Waters. Zool. Sci. 20: 669–682.

Kim, J. N., J. H. Choi, 2006. Two caridean shrimps (Crustacea: Decapoda) from the Korean continental slope of the East Sea. Korean J. Syst. Zool. 22(1): 51-55.

Konishi, K., J. N. Kim, 2000. The first zoeal stage of sand shrimp *Crangon amurensis* Brashnikov, 1907, with a discussion of the larval characters of the Crangonidae (Crustacea, Decapod a, Caridea). Bull. Nat1. Res. Inst. Aquacult. , 30: 1-12.

Krebs, C. J., 1989. Ecological Methodology. Harper and Row, New York.

Kitting, C.L., B. Fry, M. D. Morgan, 1984. Detection of inconspicuous epiphytic algae supporting food webs in seagrass meadows. Oecologia 62: 145-149.

Kosaka M., 1970. On the ecology of the sand shrimp, Crangon affinis De Haan, as a prey of the demersal fishes in Sendai Bay. J. Facul. Mar. Sci. and Tec. Tokai. Univ.m 42: 59-80.

Lee, D.S. (ed)., 1987. Geology of Korea. Kyohaksa Pub. Co. Seoul. 514 pp.

Li, H. Y., S. Y. Hong, 2006. The effect of temperature and salinity on survival and growth of *Crangon uritai* (Decapoda: Crangonidae) larvae reared in the laboratory. Mar. Ecol., 28: 288-295.

Lloyd A., C. M. Yonge, 1947. The biology of *Crangon crangon* L. in the Bristol Channel and Severn Estuary. J. Mar. Biol. Assoc. UK., 26: 626–661.

Lorman, J.G., J. J. Magnuson, 1978. The role of crayfishes in aquatic ecosystems. Fisheries, 3: 8–10.

Mauchline, 1980. The biology of mysids and euphausiids. Adv. mar. Biol., 18:1-680.

Meredith, S. S., 1952. A study of *Crangon vulgaris* in the Liverpool Bay area. Proc Trans Liverpool. Biol. Soc., 58:75–109 Moller, P., R. Rosenberg, 1982. Production and abundance of the amphipod Corophium volutator on the west coast Sweden.-Netherlands J. of Sea Research 16: 127-140.

Mistakidis, M. N. (Ed.), 1970. Proceedings of the World Scientific Conference on the Biology and Culture of Shrimps and Prawns. FAO Fish. Rep.,(57) 4: 1167-627.

Moller, P., R. Rosenberg, 1982. Production and abundance of the amphipod Corophium volutator on the west coast Sweden.-Netherlands. J. Sea Res. 16: 127-140.

Momot, W. T., H. Gowing, P. D. Jones, 1978. The dynamics of Crayfish and their role in Ecosystems. Am. Midl., Nat. 99: 10–35.

Nakaya, M., T. Takatsu, M. Nakagami, M. Joh, T. Takahashi, 2004. Spatial distribution and feeding habits of the shrimp Crangon uritai, as a predator on larval and juvenile marbled sole *Pleuronectes yokohamae*. Jap. Soc. Fish. Sci., 70(3): 445-455.

O'Brien, C. J., 1994. Ontogenetic change in the diet of juvenile brown tiger *Penaeus esculentus*. Mar. Ecol. Prog. Ser. 112: 195– 200.

Oh, C. W., R. G. Hartnoll, R. D. M. Nash, 2001. Feeding ecology of the common shrimp *Crangon crangon* in Port Erin Bay, Isle of Man, Irish Sea. Mar. Ecol. Progr. Ser., 214: 211-223.

Pechenik, J. A., 1996. Biology of the Invertebrates (Third Edition). Wm. C. Brown Publishers. 576 pp.

Pielou, E.C., 1975. Ecological diversity. Wiley, New York.

Plhl, L., R. Rosenberg, 1984. Food selection and consumption of the shrimp *Crangon crangon* in some shallow marine areas in western Sweden. Mar. Ecol. Progr. Ser., 15: 159-168.

Price, K. S., Jr., 1962. Biology of the sand shrimp, *Crangon septemspinosa*, in the shore zone of the Delaware Bay region. Chesapeake Sci., 3: 244-255.

Price, W. W., 1982. Key to adult shallow water Mysidacea of the Texas coast with notes on their ecology. Hydrobiologia., 93: 9–22

Shannon, C. E., W. Weaver, 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana.

Sitts, R. M., A. W. Knight, 1979. Predation by the estuarine shrimps *Crangon franciscoru* Stimpson and *Palaemon macrodactylus* Rathbun. Biol. Bull., Woods Hole, 156: 356-368.

Tiews, K., 1970. Synopsis of biological data on the common shrimp *Crangon crangon* (Linnaeus, 1758). FAO Fisheries Synopsis, 91: 1167-1224.

Venables, B. J., 1981. Aspects of the Population Biology of a Venezuelan Beach Amphipod, Talorchestia margaritae (Talitridae), including Estimates of Biomass and Daily Production, and Respiration Rates. Crustaceana, 41: 271-285.

Wahle, R. A., 1985. The feeding ecology of *Crangon franciscorum* and *Crangon nigricauda* in San Francisco Bay, California. J. Crustac. Biol. 5: 311–326.

Wear, R.G., M. Haddon, 1987. Natural diet of the crab *Ovalipes catharus* (Crustacea, Portunidae) around central and northern New Zealand. Mar. Ecol. Prog. Ser., 35: 39–49.

Webb, P., R. Perissinotto, T. Wooldridge, 1987. Feeding of *Mesopodopsis slabberi* (Crustacea, Mysidaceae) on naturally occurring phytoplankton. Mar. Ecol. Progr. Ser., 38: 115–123.

Wicksten, M. K., 1980. Range Extensions of Four Species of Crangonid Shrimps in the Eastern Pacific Ocean (Decapoda: Crangonidae). Bull. Southern California Acad. Sci. 79(1): 38-41.

Wilcox J. R., H. P. Jeffries, 1974. Feeding habitats of the sand shrimp, *Crangon septemspinosa*. Biol. Bull., 146: 424–434.

Zhang, W. Q., 1974. A new species of the genus *Corophium* (Crustacea, Amphipoda, Gammaridea) from the southern coast of Shantung Peninsula, North China. Stud. Mar. Sinica, 9: 139-146.