Spatio-temporal Distribution of the Genus *Acartia* (Copepoda: Calanoida) in the Southwestern Waters of Korea

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Abstract - The spatio-temporal distribution of four coexisting acartiid species in two subgenera *Acartiura* (*Acartia hongi* and *A. omorii*) and *Odontacartia* (*A. erythraea* and *A. pacifica*) was examined at seven stations in the southwestern waters of Korea, between January to December 1998. *A. hongi* occurred dominantly in the northern regions from winter to spring while *A. omorii* predominated in the southern regions in spring and early summer when the more saline (>33.0 psu) and high chlorophyll-*a* concentration water mass appeared. With the increase of temperature (>20°C), however, both species disappeared and then replaced with *A. erythraea* and *A. pacifica*. *A. erythraea* (rare species), appeared in the middle regions where the high chlorophyll-*a* concentration (3 μg l^{-1}) in the summer, while *A. pacifica* was abundant in all regions through summer and fall. It is suggested that the seasonal succession of the genus *Acartia* was subgenus-specifically affected by environmental factors such as temperature, salinity and chlorophyll-*a* concentration.

Key words : acartiid species, spatio-temporal distribution, environmental factors

INTRODUCTION

Copepods, usually comprising at least 70% of the plankton fauna, play an important role as prey for many small carnivores and/or as grazers on phytoplankton in the marine food web (Raymont 1983). Many copepods co-occur in the same regions. To avoid or reduce an inter-specific competition, these species with similar ecological requirements have different occurrence periods, distribution patterns and feeding habits connected with environmental factors such as salinity, temperature and food (Jeffries 1962; Alcaraz 1983; Ueda 1987).

The acartiid species (Copepoda, Calanoida) are very important plankton components in estuaries, lagoonal and neritic waters (Ara 2001). The co-occurrence of sibling species of the genus *Acartia* very varies from two species in temperate estuaries (Conover 1956; Jeffries 1962; Greenwood 1981) to nine ones in monsoonal areas (Tranter and Abrams 1971). In the southwestern waters of Korea four acartiid species (*Acartia erythraea, A. hongi, A. omorii* and *A. pacifica*) occur to be different spatio-temporally. In particular, The southwestern waters of Korea surrounded into many small islands are characterized as shallow water depth (<30 m) and strong tidal currents (5 m sec^{-1}). In winter the Yellow Sea Warm Current originated from the Tsushima Warm Current, which has the physical characteristics of the high-thermal · high-saline water, extends directly to the northern parts of the Yellow Sea. In summer, when stratification is well established, the tidal front is formed between well-mixed and stratified regions. The western region

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of Jindo is particularly known to be the strongest tidal currents along the Korean coast. In addition freshwater discharges into the coastal area from rivers make hydrographic conditions much more complex (Lie 1989; Seung 1992; Cho *et al.* 1995; Feng 1998).

In this study co-occurring patterns of acartiid species from the southwestern sea of Korea are presented and discussed in relation to the abiotic and biotic environmental factors such as temperature, salinity and food conditions, which can affect their distribution.

MATERIALS AND METHODS

Field investigations were monthly carried out at seven stations in the southwestern waters of Korea through January to December 1998 (Fig. 1). Zooplankton were collected by oblique towing from the bottom to the surface using a standard net (60 cm in mouth diameter, 0.33 mm in mesh size) equipped with a flowmeter (Rigosa co.) for 5 minutes. The samples were immediately preserved in 5% neutralized formalin/sea water solution on board. Temperature and salinity were measured from the surface to the bottom at each station using a CTD (Hydroburd-Electronics, model 19). Chlorophyll-*a* concentration was measured according to the protocol of Parsons *et al.* (1984). In the laboratory zooplankton samples were split from 1/2 to 1/16 using a Motoda splitter. From the subsamples, *Acartia* species are sorted out and counted under a dissecting microscope. The individual numbers were converted to individuals per cubic meters of seawater (indiv.m^{-3}).

Gut contents of adult females of four acartiid species were examined with scanning electron microscope (HITACHI S-3000N). Individuals with contents in the gut were picked up from the original samples and rinsed in the 3rd distilled water. Guts were removed from the copepod prosome under a stereo microscope. Extracted guts were dehydrated through a graded ethanol series and t-butyl alcohol, and then dried using critical point dryer (Hitachi HCP-2). The dried samples were mounted on stubs and removed gut tissues by double sided adhesive tape and then coated with gold using the Ion sputter (Hitachi E-1010).

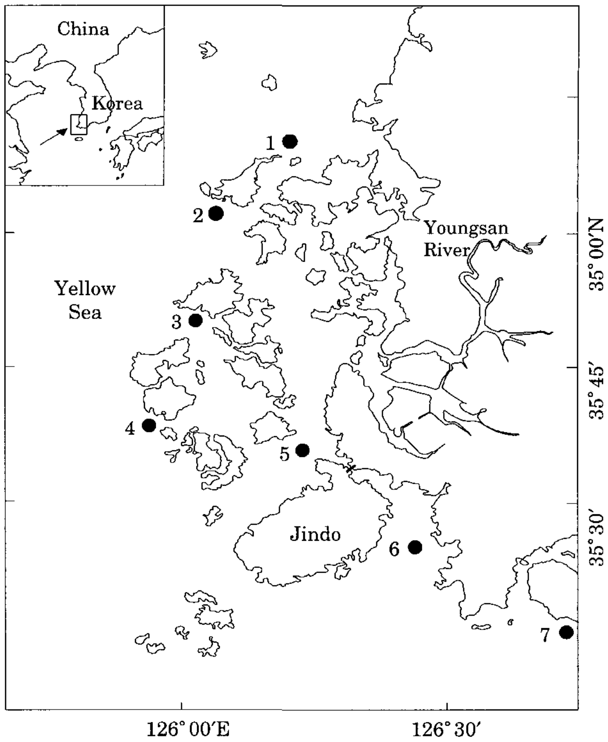

Fig. 1. Map of the sampling sites in the southwestern waters of Korea.

RESULTS

1. Hydrography

The mean water temperatures follow regular annual cycles, varying between a minimum of 5°C in February, and a maximum of 24°C in August (Fig. 2). Temperature between stations differs from 0.4°C on January to 6.1°C on August. In contrary to the temperature, salinity was relatively constant between stations. But there was seasonal differences between 30.1 psu on November and 34.2 psu on July. Also, salinity was always higher in southern region than in the northern one, indicating that the Yellow Sea Warm Current affect the southern portion of the system. Chlorophyll-*a* concentration ranged from 0.8 in November to 4.2 μg l^{-1} in July and recorded high values more than 3 μg l^{-1} in the vicinity of the southern area in summer.

2. Seasonal changes

There was a distinct seasonal variations in species

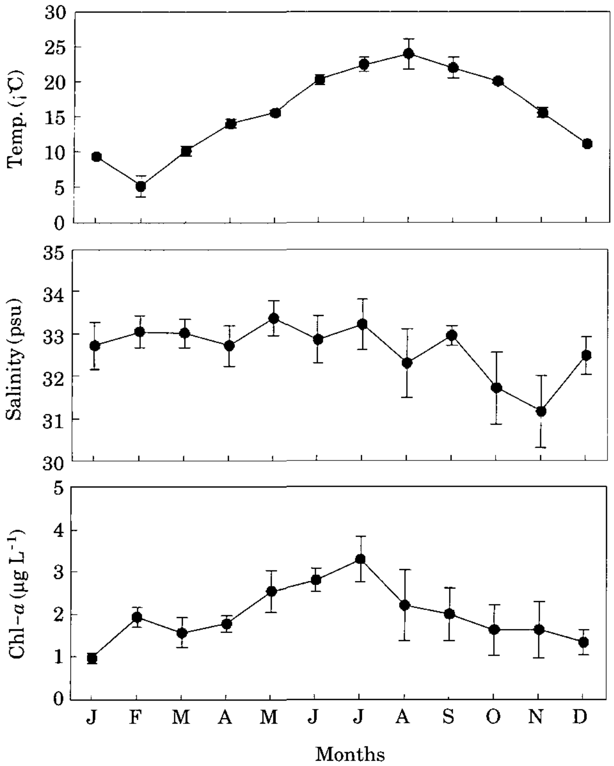

Fig. 2. Monthly variation (mean±SE) of temperature, salinity and Chlorophyll-*a* concentration.

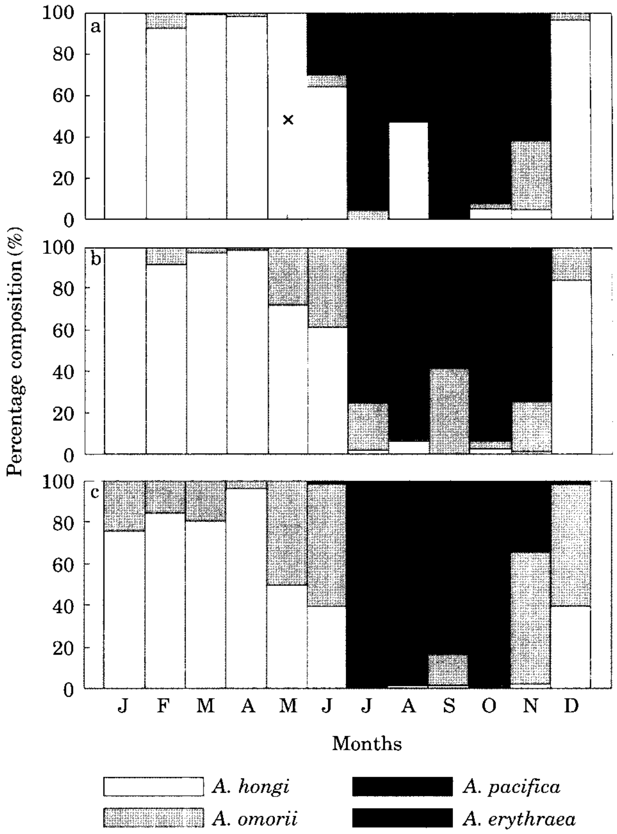

Fig. 3. Seasonal changes in the relative percentage of four species of *Acartia* at the northern (a), intermediate (b) and southern (c) regions. ×: missing data.

composition over the season at the three regions; northern (sts. 1-2), intermediate (sts. 3-5) and southern region (sts. 6-7). *A. hongi* dominated in winter and spring, while *A. pacifica* did in summer and fall (Fig. 3). *A. omorii* usually occurring together with *A. hongi*, was dominant in May and June in the southern region. *A. erythraea* made up only about <19% from July to November.

3. Spatio-temporal distribution

The four acartiid species classified into two subgenera *Acartiura* (*A. hongi, A. omorii*) and *Odontacartia* (*A. erythraea, A. pacifica*) showed different distribution patterns between intra-subgenus and/or inter-subgenus. *A. hongi* appeared dominantly in the northern areas in winter and spring when the water temperature and salinity were relatively low (Fig. 4). Its abundance indicated the peak numbers of 35,754 indiv.m^{-3} in March and after then it was sharply disappeared from the water mass in summer. On the other hand, *A. omorii* relatively predominated in the southern areas during spring and its maximum abundance was in the vicinity of high chlorophyll-*a* concentration (>3 μg l^{-1}). With the temperature increase (>20°C), *A. hongi* and *A. omorii* (subgenus *Acartiura*) were replaced by *A. pacifica* and/or *A. erythraea* (subgenus *Odontacartia*) progressively from northern to southern areas. *A. erythraea*, was appeared to the some regions with temperature above 24°C and high chlorophyll-*a* concentration during summer, while *A. pacifica* was abundant in most regions in summer and fall (Fig. 5).

Temperature-salinity-abundance diagram showed differences in ecological requirements of the congeners (Fig. 6). Although both species of *Acartiura* occurred throughout a wide range of temperature and salinity, *A. hongi* was dominant at the colder (<10°C) and less saline (<33 psu) waters, compared with *A. omorii*, *A. pacifica* was dominant in a range of 20 to 24°C and 30.5 to 34.0 psu., respectively while *A. erythraea* was dominant where temperature and salinity exceed 24°C and

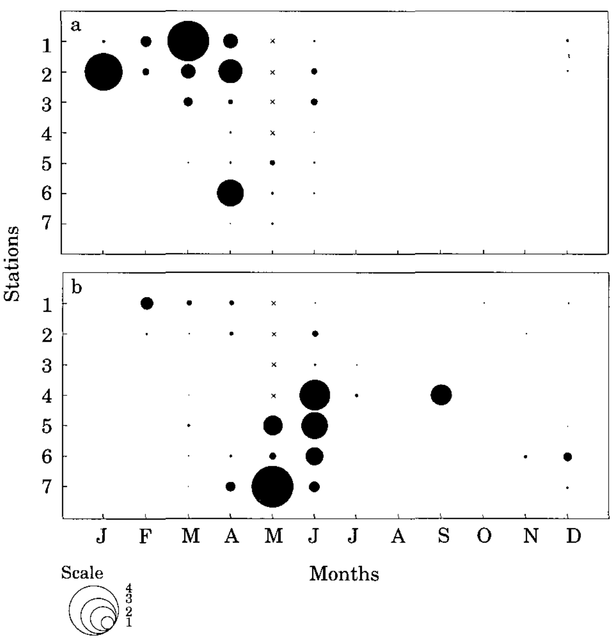

Fig. 4. Spatio-temporal distribution of *Acartia hongi* (a) and *A. omorii* (b) belonging to the subgenus *Acartiura*. ×: missing data. Abundance of each species is estimated by multiplying numbers on scale by 10^4 for *A. hongi* and by 10^3 for *A. omorii*.

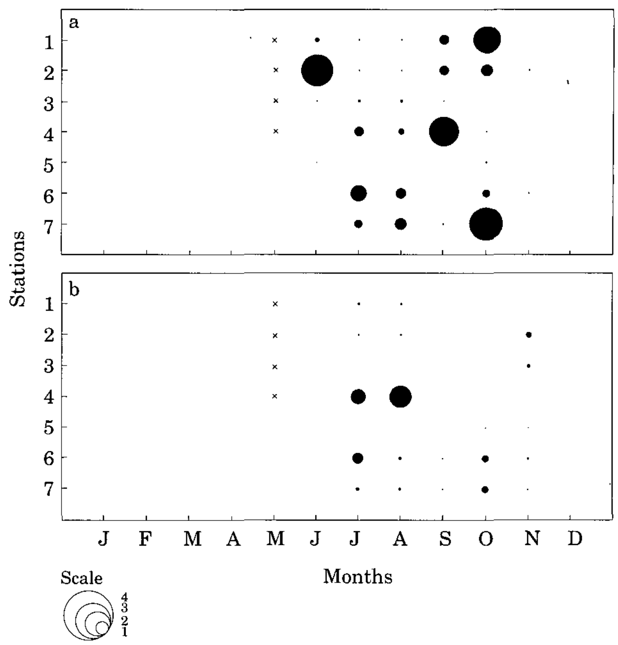

Fig. 5. Spatio-temporal distribution of *Acartia pacifica* (a) and *A. erythraea* (b) belonging to the subgenus *Odontacartia*. ×: missing data, Abundance of each species is estimated by multiplying numbers on scale by 10^3 for *A. pacifica* and by 10^2 for *A. erythraea*.

32.5 psu., respectively.

DISCUSSION

Four acartiid species differ from their distribution patterns according to the environmental factors such as temperature, salinity, and chlorophyll-*a* concentration. Thermal effects on the distribution of acartiid copepods appeared to be differences over intra-subgenera. *Acartiura* (*A. hongi* and *A. omorii*) and *Odontacartia* (*A. erythraea* and *A. pacifica*) species were present in low- and high-temperature periods, respectively and it might be due to keep the reproduction in alternately occurred periods by adapted for the temperature variation. The seasonal succession between the different subgenera is seen in previous studies (Lee and McAlice 1979; Wooldridge and Melville-Smith 1979; Greenwood 1981). Moreton bay of Australia showed that *A.* (*Acartiura*) *tranteri* occurred in winter which temperature range between 14-21°C and *A.* (*Odontacartia*) *pacifica* was being dominant at high temperatures (>22°C). Thus, temporal segregation between the different subgenera were affected by temperature. On the other hand, *Acartia* species of the same subgenus were spatially segregated by salinity and chlorophyll-*a* concentration. In present study, although *A. hongi* and *A. omorii* emerged simultaneously in the winter and spring seasons, *A. hongi* was dominant in the vicinity of northern region where was affected by strongly freshened waters whereas *A. omorii* have the center of distribution in the southern regions at high salinity (>33.0 psu.). In the estuarine system of Mankyung and Dong-jin rivers of Korea, *A. hudsonica* (= *A. hongi*) was dominant in the mixohaline zone (5.0-28.0 psu.) and *A. omorii* was found in the mixoeuhaline zone (>28.0 psu.) (Suh *et al.* 1991). In the Japanese neritic waters, *A. omorii* and *A. hudsonica* are also spatially segregated by salinity, in which the latter prefers less saline water than *A. omorii* (33.0-34.5 psu.) (Ueda 1987). These facts indicate that the salinity is critical for the recruitment of these species. In spite of these facts, in the open coasts the effect of salinity for segregation between sibling species is parti-

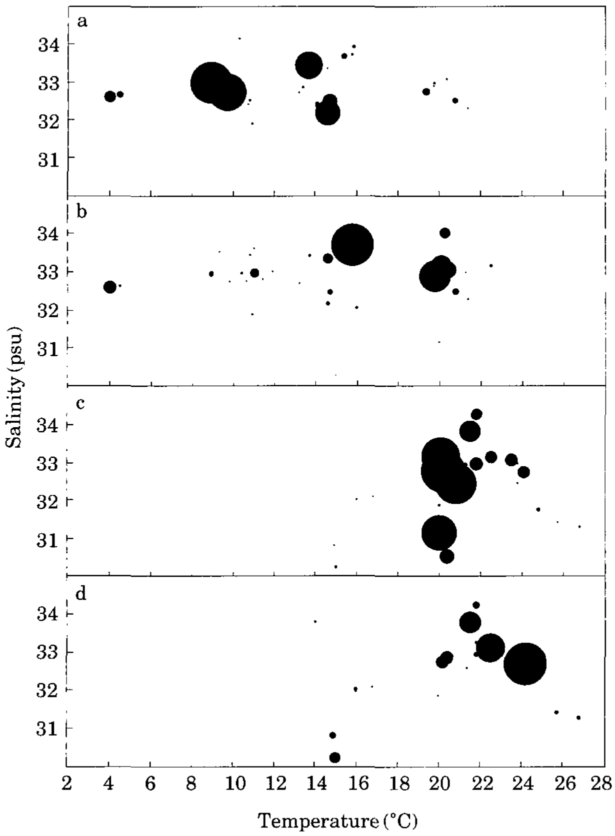

Fig. 6. Temperature-Salinity-Plankton diagram corresponding to *Acartia hongi* (a), *A. omorii* (b), *A. pacifica* (c) and *A. erythraea* (d) circle : population abundance (indiv.m^{-3}) at each station same as Figs. 4 and 5.

cular in the ocean ecosystem.

Copepods can coexist in the same regions by different food requirements. The gut contents analysis of the four acartiid species, however, indicate that their feeding habits is very similar between sibling species. Jeffries (1962) showed that *A. clausi* and *A. tonsa* are ominivorous with no major trophic differences. Tranter and Abraham (1971) also reported that the seven acartiid species from the Cochin Backwater have similar mouth parts and probably use the same sort of foods. Therefore, since coexisting species in the same regions may compete for foods, species adapted well in oligotrophic environments are dominated when the foods are rare except for rich-food periods. Different from *A. hongi* and *A. pacifica, A. omorii* and *A. erythraea* were relatively increased when the chlorophyll-*a* concentration was over 3 μg l^{-1}. It means that inter-specific competition may be declined under the rich-food conditions.

Acartiid species are disappeared from the plankton during a certain period. *A. hongi* dominates through winter to spring and after then disappears from water column at temperature above 20°C. It reappears in December when the water temperature was decreased and less saline water appeared. This situation can explain as resting eggs which is a recognized strategy that some copepod species, particularly in brackish and coastal waters, have evolved to overcome environmentally unfavourable conditions (Uye 1985; Marcus 1996).

In conclusion, occurrence of two subgenera in genus *Acartia* was mainly affected by temperature. *Acartia hongi* and *A. omorii* (the subgenus *Acartiura*) occurred below 20°C, while *A. erythraea* and *A. pacifica* (the subgenus *Odontacartia*) did over 20°C. However, the species included in the same subgenus differ from the spatio-temporal occurrence periods by salinity and food abundance. *A. hongi* and *A. pacifica* was predominant in the low salinity and chlorophyll-*a* concentration, comparing with *A. omorii* and *A. erythraea*. These facts shows that the spatio-temporal distribution between intra- and inter-subgenera may reflect their evolutionary trends for adapting different environments. To more complete understanding of the population dynamics at acartiid species, however, it is necessary to investigate not only the planktonic process but also the benthic process.

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