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Seasonal Variation and Production of Zooplankton in Chŏnsu Bay, Korea

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천수만 동물플랑크톤의 계절변화와 생산량

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The zooplankton of Chŏnsu Bay was collected and analyzed to study the seasonal variation in species composition and abundance, and to estimate the total annual production of Copepoda. With a pronounced seasonal fluctuations in species composition and abundance, *Paracalanus indicus and Corycaeus affinis* predominated during summer and fall, while larger species such as *Centropages abdominalis* and *Acartia omorii* dominated in spring. Zooplankton abundance showed the minimum in March, then increased and reached the maximum in August. It is suggested that seasonal variation of zooplankton in the study area is largely affected by variation in size fraction and quantity of phytoplankton as well as temperature. Being productive compared with other areas, the estimated total production of Copepoda was 134 g/100 m^3/yr (dry weight).

천수만의 동물플랑크톤을 채집, 분석하여 그 종조성과 수도(數度)에 있어서의 계절변화와 Copepoda의 연간 생산량이 규명되었다. 종조성과 수도의 현저한 계절 변동과 함께 *Paracalanus indicus* 및 *Corycaeus affinis*가 여름에서 가을에 걸쳐 우점하는 반면, *Centropages abdominalis*와 *Acartia omorii*가 봄에 우점함을 보인다. 동물플랑크톤의 수도는 3월에 최소치를 나타내고 이어서 점점 증가하여 8월에 최대치에 도달한다. 연구해역에서 동물플랑크톤의 계절변화는 식물플랑크톤의 크기 및 양의 변화와 수온에 의해 주로 영향을 받음이 알려졌다. Copepoda의 연간 총 생산량은 건조 중량으로 134g/100 m^3로 추정되었으며 타 해역에 비해 높은 생산성을 나타낸다.

INTRODUCTION

Marine zooplankton, at least those from temperate estuarine and coastal habitats, are subject to extensive temporal variation in their environment. Some investigations in Korean waters indicate a marked seasonality of zooplankton assemblages in species composition and abundance (Kim & Huh, 1983; Kim, 1984; Shim & Lee, 1986). But factors influencing the distribution and seasonal succession of marine zooplankton are poorly understood. Recent studies (Dodson, 1979; Lunsdale, 1981) have shown that distribution and abundance patterns cannot be explained solely by physical tolerances. In literature it is generally understood that there are significant interactions among various components of planktonic communities, and that biological factors such as predation and interspecific competition play important roles (Parsons *et al.*, 1984).

Meanwhile, coastal regions of temperate waters are highly productive (Russell-Hunter, 1970). In Chŏnsu Bay known as a good fishery

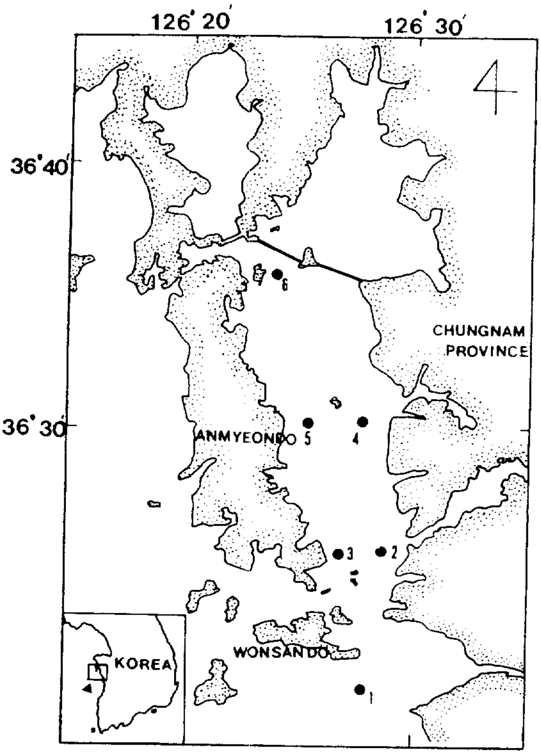

Fig. 1. A map of the study area showing 6 sampling stations.

groud, the total biomass and production of zooplankters, as food sources for fishes, is clearly important. However, existing data on the seasonal variation of zooplankton in this study area are quite limited.

This study is devoted preliminary to the presence of species composition and abundance of zooplankton and an overview of seasonal variation of zooplankton assemblages in Chŏnsu Bay during September, 1985-August, 1986. The possible mechanisms contributing to the observed patterns are suggested. In addition, annual production of Copepoda is estimated for the understanding of the characteristics of the interactions between primary producers and secondary ones in terms of energy transfer.

STUDY AREA

Chŏnsu Bay is located at 36° 23′-37° 37′N latitude and 126° 20′-126° 30′E longitude in western part of Korea (Fig. 1). The general description of the bay should be referred to Shim and Yeo (1988).

MATERIALS AND METHODS

Sampling Zooplankton and Some Field Works

Zooplankton smples were obtained monthly from 6 stations from September, 1985 to August, 1986 except November, February and July. Zooplankters were collected by a NORPAC net (WP-2 type) with 0.6 m mouth diameter. The mesh aperture of the net used was 250 μm. The sampler equipped with flowmeter was hauled horizontally for 10-15 minutes at a speed of about 2 knots at 1-2 m depth. The volumes of water filtered through the net were usually 100-200 m^3. The filtering efficiency was assumed to be 100%. The net was carefully washed at the end of each towing to obtain organisms that tend to aggregate. Since the towing distance is more important than the size of the net in determing the accuracy of samples (Wiebe, 1972), each towing was intended to keep almost same distance. Water temperature was measured by YSI Dissolved Oxygen Meter (Model 57) on board and salinity was determined by Autosal Guildine Model 8400 in laboratory. Chlorophyll concentrations were measured by Turner Designs III Fluorometer.

Laboratory Works

Sampled zooplankters were observed with Olympus Zoom Stereomicroscope up to maximum 160 magnifications. Zooplankters were identified into species level, but planktonic larvae were classified into appropriate toxonomic groups due to the difficulty in identification. The adults of Copepoda were identified into species, but copepodites and nauplii of Copepoda were simply grouped into copepodites and nauplii. The larger zooplankters such as hydromedusae, ctenophores, chaethognaths and megalopa stage of decapods were first sorted out and counted. The numerical abundance measurements of the remaining smaller forms were made by counting the individual numbers in a Bogorov counting tray. The numbers counted were converted into individual numbers per unit volume (inds/m^3).

Dry Weight Measurement of Copepoda

The dry weight of each copopod species was measured to 10^{-5} g using Mettler 51 balance and was corrected for preservation by assuming a 25% loss (Omori, 1978). Since the samples collected were contaminated considerably by phytoplankton and detritus, it was considered that measurements of entire zooplankton samples as a whole were inadequate. The selected specimens were sorted with micropipette from the mixed plankton into homogeneous groups as to species. The sample (200-300 individuals for *Paracalanus*, 100-200 individuals for *Centropages* and *Labidocera*, 200-300 individuals for *Acartia* and *Tortanus*, 300-400 individuals for *Corycaeus*) was placed by pipette on a nylon netting base of about 200 μm mesh-opening and 40 mm in diameter resting on a sintered glass filter funnel. The sample is sucked dry at about 250 mm Hg (Omori, 1978). Time for the rinse was shorter than 15 seconds and mostly less than 3 seconds. The base had been previously washed with distilled water, dried in an oven and then weighed. After removing the filter funnel the sample was placed in an plastic box with the base and was dried in an oven at 60 °C for 24 hours to a constant weight (Richman, 1971). Subsequently, the sample was stored in the dessicator for 24 hours, then weighed. For the rarer species which comprise less than 1% of total number of Copepoda, dry weights were estimated from length using the equation in Hirota (1981). The measurement was made with an ocular micrometer mounted in a dissecting microscope up to 10^{-2} mm. Body length has been taken in the median line, from the anterior point of the fore-head to the distal end of caudal rami with the copepod in dorsal view, so the caudal bristles were included to body length. The population biomass of each species was then computed for each species, then was calculated in each station.

Estimation of Annual Production of Zooplankton

At present there is no single method that provides the best estimate of zooplankton production. The methods which have been used by various workers on different zooplankton species or populations vary considerably in terms of the kind of data collected and their analyses (Omori and Ikeda, 1984).

The equation used here was derived from the data set which Copepoda comprise the largest proportion. This equation is as follows:

$$\log P/B = -0.16-0.34 \quad (\log M)$$

where M is adult body mass in dry weight and P/B is production to biomass ratio. Ranges for P/B estimates were obtained by taking 50 and 200% of the predicted value, as suggested by Banse and Mosher (1980).

RESULTS AND DISCUSSION

Hydrological Conditions

Water temperature of study area ranged from 1.7 °C (January, st. 4) to 27.7 °C (August, st. 6), and the average temperature of each cruise ranged from 2.5 °C to 25.7 °C. Table 1 shows monthly variations of the surface water temperature and salinity at each station of the study area. Meanwhile annual variation of salinity is less variable as the range from 28.74‰ in August to 31.68‰ in April. Vertical profiles of temperature and salinity show that surface and bottom values were essentially identical for most of study area. It is, however, evident from the T-S

Table 1. Results of measurement of water temperature (T °C) and salinity (S ‰)

Month		Station Number					
		1	2	3	4	5	6
SEP.	T	24.3	23.2	24.9	25.0	25.2	24.9
	S	30.2-30.3	29.7-29.9	29.8-30.0	29.8	30.0	27.5-29.5
OCT.	T	17.5-17.8	17.5-18.1	16.0-16.5	15.8-17.0	17.5-18.0	15.8-17.1
	S	30.7-30.9	30.2-30.4	30.5-30.6	29.3-29.9	29.2-29.7	22.8-29.3
DEC.	T	6.2-7.0	6.8-7.1	8.1-8.2	7.5-8.2	—	—
	S	31.6-31.7	31.6	31.5-31.6	34.1	—	—
JAN.	T	2.5	2.1-2.8	3.5-3.8	1.7-1.8	3.1-3.5	2.0-2.5
	S	31.7	31.5-31.7	31.7	31.5	31.6	31.4-31.5
MAR.	T	4.1	5.2	4.8	5.1	4.9	5.2
	S	31.6-31.7	31.7-32.0	31.6-31.7	31.8-31.9	31.6-32.3	31.3-31.4
APR.	T	9.1	11.2	9.2	10.1	11.9	11.3
	S	31.6	31.5-31.9	31.6-31.8	31.8-32.1	31.5-31.7	31.6-31.8
MAY	T	12.6	14.1	13.6	14.2	14.9	16.0
	S	31.3-31.5	31.2-31.5	31.3-31.4	31.2-31.3	31.2-31.3	31.3-31.6
JUN.	T	23.0	18.7	19.9	19.7	—	23.6
	S	31.4-31.5	31.3-31.4	31.3	31.3	31.3	31.1-31.3
AUG.	T	24.5	25.5	25.8	26.3	26.5	27.7
	S	29.2	28.9-29.0	28.8-29.0	28.6	28.6-28.8	27.7

Table 2. List of zooplankton observed in the study area.

Noctiluca scintillans

unidentified Hydromedusa sp.

Muggiaea atlantica

unidentified Ctenophora sp.

Evadne tergestina
Penilia avirostris

Calanus sinicus
Paracalanus indicus
Pseudodiaptomus marinus
Centropages abdominalis
C. tenuiremis
Sinocalanus tenellus
Calanopia thomsoni
Labidocera bipinnata
L. euchaeta
L. minuta
Acartia omorii
A. pacifica
Tortanus forcipatus

Oithona atlantica
O. similis
unidentified *Oncaea* sp.
Corycaeus affinis
unidentified *Corycaeus* sp.

unidentified *Clytemnestra* sp.
Euterpina acutifrons
unidentified *Microsetella* sp.

unidentified Amphipoda sp.

Sagitta crassa
S. crassa f. *naikaiensis*

Oikopleura dioica
O. longicauda

Lamellibranchia veliger
Prosobranchia veliger
Polychaeta larva
Cirripede nauplii and cyprii
Copepoda nauplii and cyprii
Decapoda zoea and megalopa
Pluteus
Fish larva

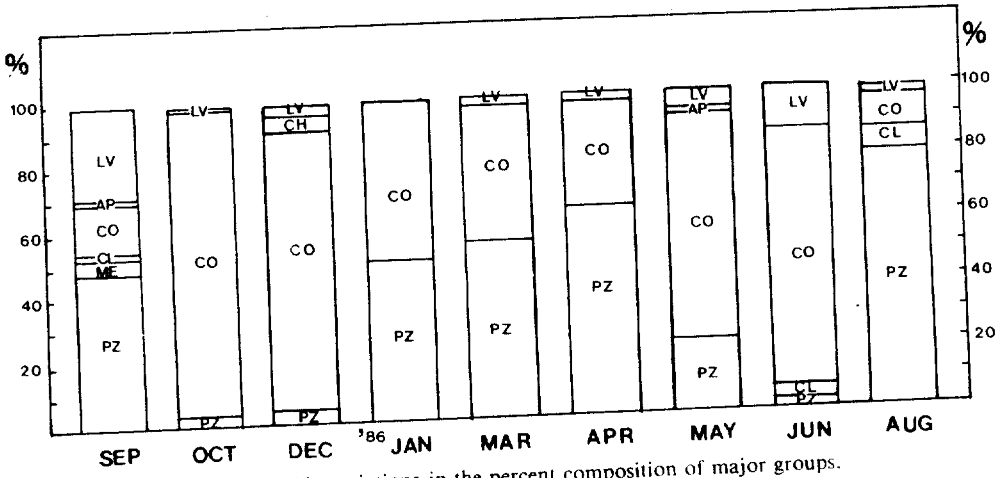

Fig. 2. Monthly variations in the percent composition of major groups.

data that offshore water which is characterized by relatively low temperature and high salinity affect the water mass up to the half way from the bay enterance.

Species Composition

Forty-one taxa of zooplankton were identified from the total of 54 samples, which consisted of 1 protozoan, 1 hydromedusa, 1 siphonophore, 1 ctenophore, 2 cladocerans, 21 copepods, 2 chaethognaths, 2 appendicularians and 8 kinds of planktonic forms of various benthic invertebrates and fishes with copepodite and nauplius stages of copepods (Table 2). Changes in the percent composition of the major groups are shown in Fig. 2.

Copepods are the most abundant constituents (ca. 60%) of all zooplankters in this study are except short period when a protozoan, Noctiluca scintillans, marked outstanding numbers (Table 3). Shim & Park (1983), Shim & Ro (1982) and Shim & Lee (1986) had already reported the similar results from the neighboring waters of Korea.

In fall, *Noctiluca scintillans* (37%, in September), *Paracalanus indicus* (41%, in October) and *Corycaeus affinis* (40%, in October) were dominent species. Winter samples were dominated by *Noctiluca scintillans* (50%, in January) and *Paracalanus indicus* (64%, in December). In spring, *Noctiluca scintillans* (64%, in April), *Acartia omorii* (47%, in May) and *Centropages abdominalis* (17%, in May) were dominant. In Summer, *A. omorii* were predominant (62%, in June) first, and then *P. indicus* and *C. affinis* had the large percentages (Table 3).

Standing Stocks

There were marked seasonal variations in numerical abundance of zooplankton per unit volume which ranged from minimum 475 inds/m^3 at station 2 in Janauary, 1986 to maximum 131,281 inds/m^3 at station 6 in August, 1986 (Fig. 3). Average individual numbers were 4,479 inds/m^3 in September, 8,231 inds/m^3 in October, 5,482 inds/m^3 in December, 7,073 inds/m^3 in January, 1,773 inds/m^3 in March, 2,205 inds/m^3 in April, 2,482 inds/m^2 in May, 1,991 in June, and 35,331 inds/m^3 in August (Fig. 4). These values were greater than those reported previously in the coastal areas (Shim & Lee, 1986; Shim & Park, 1983), and similar to those in the neighboring Garolim Bay (Kim & Huh, 1983). This indicates that this bay is relatively high productive area compared with other coastal waters.

Table 3. Averaged relative abundance (%) of common zooplankton in Chŏnsu Bay.

Organism	Sep.	Oct.	Dec.	Jan.	Mar.	Apr.	May	Jun.	Aug.
Noctiluca scintillans	70.32	4.6	4.4	49.8	55.6	64.9	23	2.6	79.5
unidentified Ctenophores	5.78								
Evadne tergestina	1.72							4.1	4.6
Penilia avirostris	1.1								2.8
Paracalanus indius	2.19	41.3	64.5	24.9	16.1	1.1	3	11.4	7.4
Centropages abdominalis			4.1	10.4	2.8	9	17.5	3	
C. tenuiremis	3.39								
Labidocera euchaeta			1.2						
Acartia omorii		9	8.5	8.2	13.6	18.6	46.8	61.7	
A. pacifica	2.59								
Tortanus forcipatus	5.68	1.2							
Oithona similis			1.7	2.9	3.8		1.2	1.2	
Corycaeus affinis	1.99	40.1	5.1	1.9	4.3	3.2		1.4	1.6
Sagitta crassa			4.8						
Oikopleura dioica							2.1		1.1
O. longicauda	1.3								
Lamellibranchia yeliger			2.2						
Copepodite & nauplius					2.66	2			
Cirripedia nauplius & cypris	1.1						1.8	10.7	
Fish larva							1.9		

The zooplankton was most abundant in August and least abundant throughout the spring time (Fig. 4). As shown in Fig. 2, seasonal variation of zooplankton assemblages in Chŏnsu Bay was largely due to Copepoda community. But *Noctiluca scintillans* were considerably responsable in January, March, April, August and September. The determination of dry weight of copeopds shows similar tendancy of seasonal variation but spring biomass was not so small as shown in abundance data (Fig. 5).

Seasonal Variation of Abundant Species Groups

Copepods were the most abundant zooplankters throughout the year. From early summer through most of the fall in the inner bay (st. 5) and, in early winter, smaller zooplankton were dominant. These included *Paracalanus indicus*, *Corycaeus affinis* and *Oithona similis*. The abundance of smaller zooplankters (*P. indicus*, *C. affinis* and *O. similis*) had declined sharply, and *Acartia omorii* together with *Centropages abdominalis* had start to dominate the zooplankton assemblages. By August smaller zooplankters such as *P. indicus* and *C. affinis* were again numerically dominant.

Chlorophyll exhibited relatively high values during early spring when net plankton were bloom and low in the other seasons, and showed a pattern that was the inverse of abundance of zooplankton (Fig. 6). In general seasonal changes in the holoplankton of colder waters, especially of temperate waters, must be greatly influenced by the seasonal variation in temperature (Raymont, 1983). In Chŏnsu Bay, water temperature is lowest in winter-early spring (below 7 °C) and zooplankton abundance is lowered in these times, then increased, which indicates that temperature affected significantly the zooplankton abundance. When, however, temperature increased to above 10 °C, the dominant species of zooplankters are different (spring vs. fall). While *Centropages abdominalis* and *Acartia omorii* were dominent in late spring, *Paracalanus indicus* and *Corycaeus affinis* were domi-

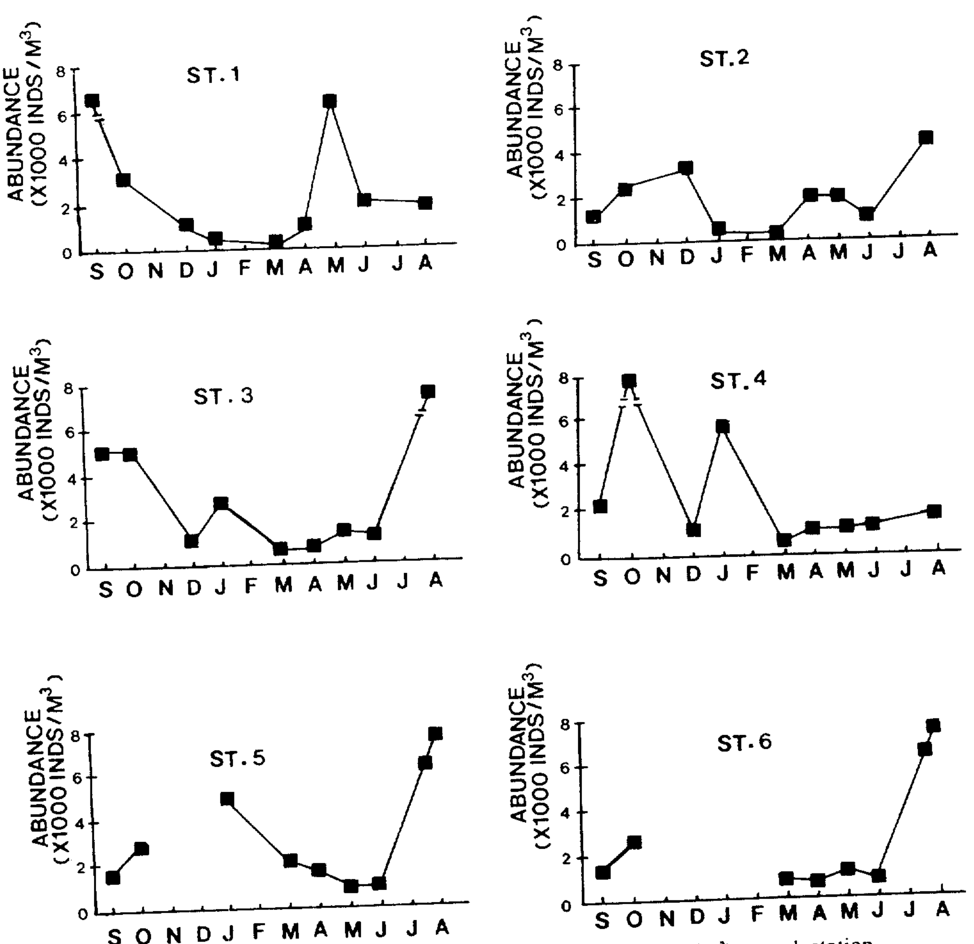

Fig. 3. Monthly variations of zooplankton abundance (inds./m³) at each station.

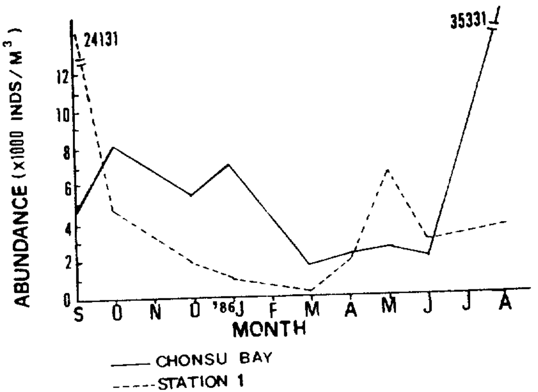

Fig. 4. Monthly variations of zooplankton abundance at Chŏnsu Bay and nearby waters (st. 1). The values of Chŏnsu Bay are calculated from averaging those of 5 stations (st. 2-st. 6).

Fig. 5. Monthly variations of copepod dry weight ($\times 10^{-6}$ g/m³) of Chŏnsu Bay. The values are obtained from averaging those of 5 stations (st. 2-st. 6).

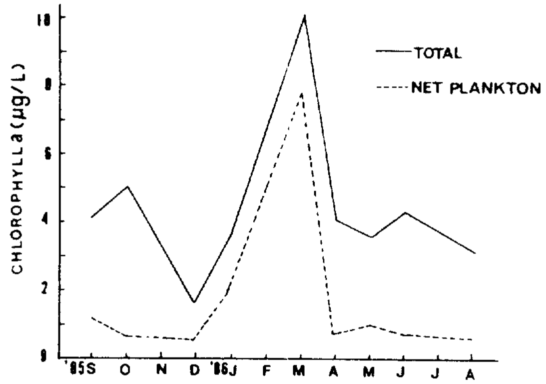

Fig. 6. Monthly variation of chlorophyll-a in Chŏnsu Bay. The values are obtained from averaging those of 5 stations (st. 2-st. 6).

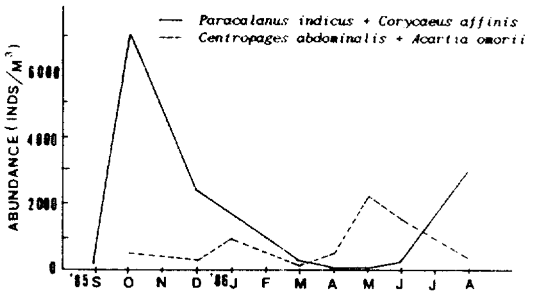

Fig. 7. Monthly variations of zooplankton abundance.

nant in fall (Fig. 7). Salinity changed so little through the year from 28.7‰ to 31.8‰ that it seems not to affect the seasonal change of zooplankton. Nevertheless, in Chŏnsu Bay the seasonality of zooplankton composition cannot solved by temperature alone. Many investigators believed that temperature had less marked effect on reproduction cycles compared with the seasonal variation in phytoplankton and possibly interspecific competition (Raymont, 1983). Chlorophyll *a* variation with time in Chŏnsu Bay attributed to the seasonal varition of net fraction (>20 μm) of phytoplankton which exhibited higher value in March, 1986 (Fig. 6). And the other periods except early spring, nanoplankton dominated the phytoplankton. In the connection with size fractionation patterns of phytoplankton through out the year, the patterns of seasonal change of dominant species of zooplankton can be largely explained. Greve and Parsons (1977) suggested that the size structure and type of phytoplankton at the base of planktonic food chain affected those of trophic components above it. They proposed that two generalized trophic pathyways exist in temperate waters:

> net phytoplankton (especially large diatoms) – zooplankton – young fish
> or
> nanophytoplankton (especially small flagellate) – small zooplankton – ctenophore and medusae

The proposed reasons for these patterns include observations that larger zooplankters appear to feed upon larger phytplankton, and gelationous zooplanktonic carnivorous such as ctenophores appear to be better able than young fish to feed upon small zooplankton. With certain modifications, the planktonic assemblages in Chŏnsu Bay corresonded to those predicted by Greve and Parsons (1977). In summer, fall and early winter, dominant plankters were: nanoplankton – small zooplankton (*P. indicus, C. affinis* and *O. similis*) – ctenophores. In spring and early summer dominant plankers: netplankton –large copepods (*A. omorii* and *C. abdominalis*).

The seasonally offset pulse of planktonic carnivores in Chŏnsu Bay clearly agreed with the pattern proposed by Greve and Parsons (1977). Ctenophores were only collected during the periods of which nanoplankton and small zooplankters were dominant. The inverse relationships in abundance of ctenophores and zooplankton (especially copepods) recorded between summer and fall (Fig. 7) are similar to the results of other field studies and consistent with observations that ctenophores can be voracious predators on cructacean zooplankton (Kremer, 1979).

Observations of planktonic assemblages In nearby coastal waters largely agree with the pat-

Table 4. Production estimates for major species of Chŏnsu Bay.

Species	Mean (and annual range) of population biomass (g/100m^3)	% of total biomass	Annual production (g/100m^3)	% of total production
Paracalnus indicus	1.129 (0-9.05)	39.59	62.04 (31.20-124.08)	46.08
Centropages abdominalis	0.731 (0-5.53)	25.63	25.75 (12.88- 51.50)	19.12
Corycaeus affinis	0.284 (0-2.14)	9.96	20.42 (10.21- 40.84)	15.17
Acartia omorii	0.463 (0-1.87)	16.23	17.70 (8.85- 35.40)	13.15
Tortanus forcipatus	0.093 (0-1.30)	3.26	3.81 (1.91- 7.62)	2.83
Acrtia pacifica	0.025 (0-0.38)	0.88	1.35 (0.68- 2.70)	1.00
Centropages tenuiremis	0.028 (0-0.87)	0.98	1.07 (0.54- 2.14)	0.79
Calanus sinicus	0.043 (0-0.64)	1.51	0.77 (0.39- 1.54)	0.57
Labidocera euchaeta	0.022 (0-0.65)	0.77	0.64 (0.32- 1.28)	0.48
Calanopia tomsoni	0.015 (0-0.67)	0.53	0.52 (0.26- 1.04)	0.39
Oithona similis	0.018 (0-0.22)	0.63	0.53 (0.27- 1.06)	0.39
Others	0.001 (0-0.13)	0.04	0.05 (0.03- 0.10)	0.04

terns of Chŏnsu Bay. But abundance of zooplankton was very low in fall, which was thought to be affected largely by low chl. *a* in this season (Fig. 6).

As a result, it is suggested that the seasonal variation patterns of the abundance and size fraction of phytoplankton as well as temperature affect significantly the abundance and succession of dominant zooplankton species, and in turn the patterns of trophic pathway of Chŏnsu Bay ecosystem during September, 1985-August, 1986.

ZOOPLANKTON PRODUCTION

Empirically determined relationships for estimating P/B ratios, such as in Banse and Mosher (1980), appear to be useful for understanding of species importance and for estimating total production, especially when it can be applied to species whose life history patterns are presently unknown (Tremblay & Roff, 1983).

Production estimates by Banse and Mosher (1980) for the major copepod species and "others" are shown in Table 4. *Paracalanus indicus* is the most productive copepod comprising 46% of the total. *Centropages abdominalis, Corycaeus affinis* and *Acatia omorii* show high percentages. The first four speices make up approximately 94% of the annual production. *Tortanus forcipatus* (2.8%), *Calanus sinicus* (0.6%), *Centropages tenuiremis* (0.8%), *Labidocera euchaeta* (0.5%), *Calanopia thomsoni* (0.4%), *Acartia pacifica* (1%), *Oithona similis* (0.4%) come after the first four species. Other copepod species (*Pseudodiaptomus marinus, L. bipinnata, L. minuta, Corycaeus* sp., *Sinocalanus tenellus, O. atlantica, Microsetella* sp., *Clytemnestra* sp. *Euterpina acutifrons* and *Oncaea* sp. etc.) make up approximately only 0.04% of the total annual production.

Assessing species importance in terms of energy flow (production), rather than standing stock, yields different results to some extent. The importance of *Paracalanus indicus, Acartia omorii* and *Corycaeus affinis* in annual production in Chŏnsu Bay was expected from numerical abundances. These species comprise approximately 26, 21 and 16% of copepod abundance (Table 2). *Centropages abdominalis* which comprises 9% in abundance have 19% of the annual production. The importance of *C. abdominalis* in annual production in Chŏnsu Bay is above the expectation from numerical abundances.

The total annual production by copepods on Chŏnsu Bay amounts to approximately 140 g/100 m^3/yr, or 50 gC/100 m^3/yr having assumed log (dr weight) = 0.508 + 0.977 log (carbon) (Wiebe *et al.,* 1975). In approximation these values can be expressed as 23.4 g/m^2/yr (8.4 gC/m^2/yr) in Chŏnsu Bay. So the total annual production (Carbon) of copepods collected by a 250 m-mesh net in Chŏnsu Bay is estimated approximately 650 tons. This value is considered some underestimated one for total zooplankton production because other groups which have high percentages of total zooplankton counts (Table 4) at times are not involved in estimating the zooplankton production.

However, except short period (August-September) copepods dominated (approximately 80%) the zooplankton assemblages all through the year, and it is evident that the estimation of secondary production solely from copepods does not deviate meaningfully from the zooplankton production.

Ikeda and Motoda (1978) estimated annual secondary production on the Tsushima current as 3.65-21.9 gC/m^2/yr. The value (8.4 gC/m^2/yr) in Chŏnsu Bay is considered to be relatively high when the shallowness of this bay (<20 m) is taken into account. Meanwhile the transfer coefficient (secondary production/primary production) is 5.5% when the primary production on Chŏnsu Bay is 150 gC/m^2/yr (Jo, 1988).

To sum up, it is suggested that the secondary production estimated by equation of Banse and Mosher (1980) is relatively high one which reflect the high primary production, and well accords with the expect that this bay is good fishery ground.

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