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A study on zooplankton distribution patterns and indicator species in Kuroshio upstream area and adjacent East China Sea

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Abstract—— On the basis of the data of zooplankton biomass and three major taxa—— Copepoda, Chaetognatha and Siphonophora of May~June 1986, July~August and December 1987, the distributional patterns and the indicator species of zooplankton in the Kuroshio and adjacent waters of the East China Sea are preliminarily studied. The results are as follows:

The horizontal distribution of zooplankton biomass and the abundance of copepods, chaetognaths and siphonophores are higher in the continental shelf mixed water area than in the Kuroshio and oceanic water area. The maximum abundant area occurred in the continent area northwest of Taiwan and the south-centre section of the East China Sea continent, which are the mix front of different waters. Zooplankton in the water area inside of Ryukyu Islands presented low abundance and high diversity. There are clear seasonal variations in zooplankton biomass and abundance in the study area. The strength or weakness of different water masses and fronts is the basic reason for the variations of zooplankton biomass and abundance.

The species composition of zooplankton in the study area is complex and varies, however, the tropic oceanic species predominates overwhelmingly. The distribution of different ecotype species evidences the distribution of different water masses and the state of mixture. The indicator species of each water mass are listed in the paper so as to provide grounds for the variation of currents in the Kuroshio area.

The temperature and salinity of sea water are important factors affecting zooplankton distribution, composition and diversity, however the role of salinity is major. With the replacement of one season by another, the correlative levels of temperature and salinity to various zooplankton taxa are more or less significant.

INTRODUCTION

A great deal of study work on zooplankton in the East China Sea has been done by Chinese and foreign scholars (e. g. CSK). However, there are still many shortcomings in the research on the areas such as the offshore of the East China Sea, the northeast of Taiwan and the both sides of the Ryukyu Islands. The Chinese and Japanese researchers have recently developed cooperative study in this respect. According to the data from the Sino-Japan Joint Research Programme on the Kuroshio in the spring of 1986, the summer and the winter of 1987, the horizontal distribution characteristics and indicator species of zooplankton in the Kuroshio upstream area and adjacent waters have been analysed in this paper so as to provide basic information for thoroughly studying the biological oceanography of Kuroshio.

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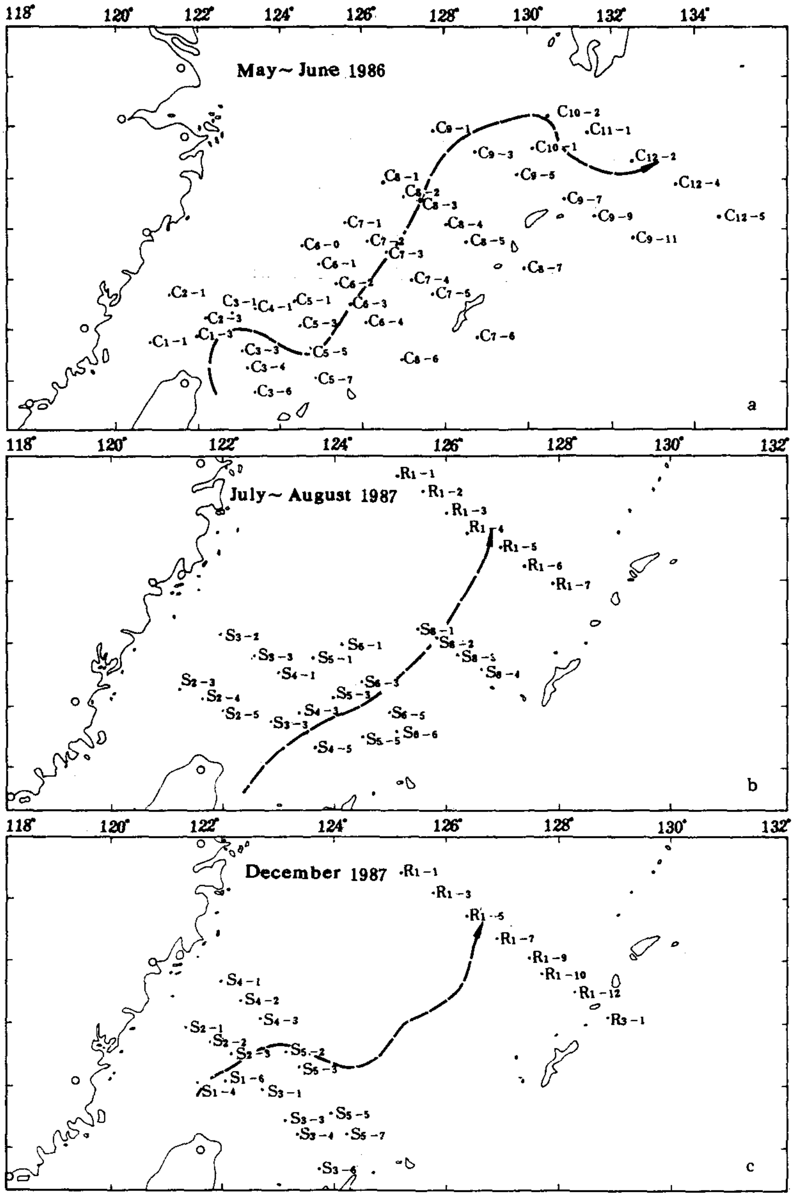

Fig. 1. The sampling stations and the current axes of the Kuroshio. The position of current axes of the Kuroshio: a. In spring, it is determined with the temperature gradient (from Pu Yongxiu); b. c. in summer and winter, it is determined with the 22℃ isotherm of 30 meter layer (from Pan Yuqiu).

The latitude of the study area is from 24°30′ to 30°30′N and the longitude is from 120°45′07″ to 133°20′08″ E. The current maximum zone of Kuroshio longitudinally flows over the study area and the sections across it (Fig. 1). Samples were collected by the standard plankton net (80 cm diameter opening, 569um mesh size and 270 cm length) towed vertically from 200 meter depth to the surface. Zooplankton biomass (excluding Coelenterata and Tunicata) is wet weight, which was measured by the electronic scales .

The species diversity (H') and homogeneity (J) were calculated by Shannon-Weaver's and Pielou's formulas respectively, i. e. ,

$$H' = \sum_{i=1}^{S} P_i \log_2 P_i, \qquad J = H'/\log_2 S.$$

The mean temperature ($\bar{t}$) and salinity ($\bar{S}$) in this paper were weighted average of 200～0 m.

THE HORIZONTAL DISTRIBUTION AND SEASONAL VARIATION OF ZOOPLANKTON BIOMASS AND ABUNDANCE OF SEVERAL MAJOR GROUPS

Zooplankton biomass

The materials of three cruises have been analysed. It has been found that the average zooplankton biomass in the study area is the highest in summer (57. 49 mg/m^3) but lower in spring (42. 80 mg/m^3) and the lowest in winter (20. 06 mg/m^3). The order of the ratio between the highest and the lowest biomass is summer (21. 6 : 1) > spring (14. 5 : 1) > winter (8. 8 : 1) (Table 1).

Table 1. The zooplankton biomass and ratio between the highest and the lowest biomass in spring, summer and winter

Season	Date of sampling	Surveyed area	Number of stations	Biomass (mg/m^3)	Ratio
Spring	May 23～ June 14, 1986	24°40′00″～30°30′00″N 127°45′07″～133°20′08″E	43	42. 80	14. 5 : 1
Summer	July 19～ August 7, 1987	25°22′00″～29°40′48″N 121°07′36″～127°45′00″E	27	57. 49	21. 6 : 1
Winter	December 8～25, 1987	24°24′00″～29°27′54″N 121°13′38″～128°48′09″E	24	20. 06	8. 8 : 1

The distribution of biomass is uneven. In spring and summer, there are two higher concentration centres in the continental shelf area northwest of Taiwan and the south-center section of the East China Sea continental shelf, which are an up-flow region of the Kuroshio subsurface water and a front of different waters (the Taiwan Warm Current, the continental shelf mixed water and the Huanghai Sea cold water) respectively. The lower value region lies in the waters between the 200 metre isobath and the Ryukyu Islands. In winter , there is only one higher value area, that is, in the south-center section of the East China Sea continent which is influenced by the Huanghai Sea cold water. The distribution trend of zooplankton biomass is higher in the continental shelf mixed water than in the current maximum zone of Kuroshio and its outside area (Fig. 2).

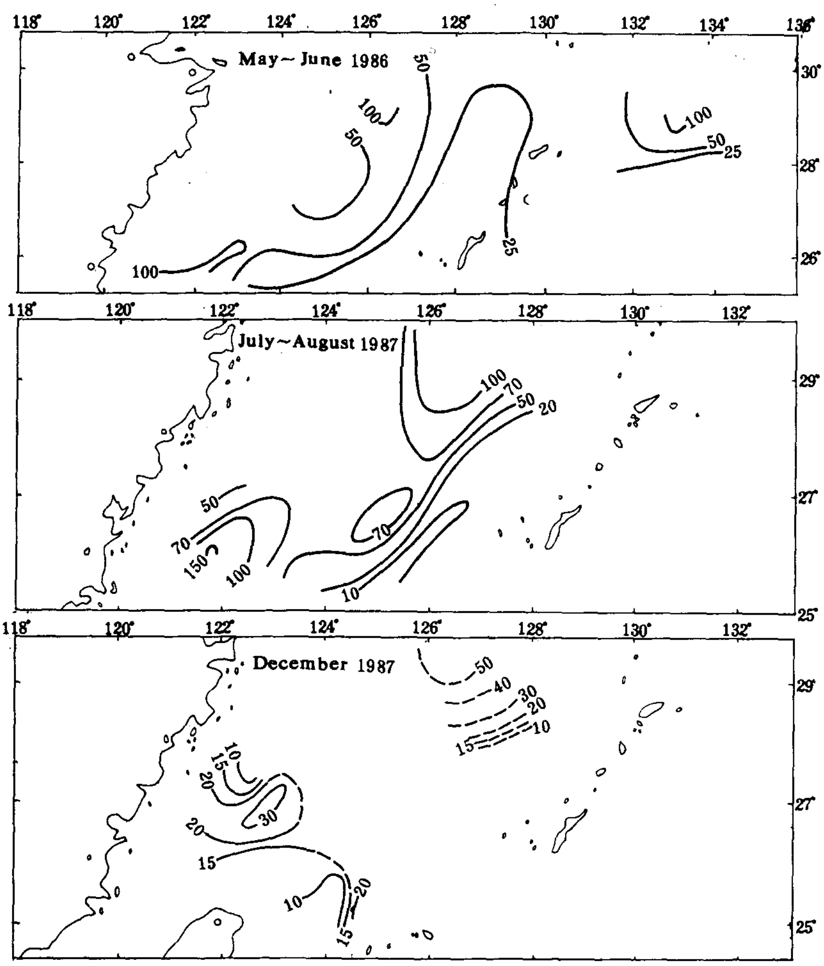

Fig. 2. The horizontal distribution of zooplankton biomass (mg/m^3).

Abundance of several major groups

i. Copepoda

In spring: The average abundance of individuals (ind.) is 46.58 ind./m^3 with a greater variation (from 5.53 to 417.14 ind./m^3). The distribution pattern of the abundance is higher in the west but lower in the east of 200 metre isobath. The isopleth of 25 ind./m^3 almost consists with the Kuroshio front. There are two noticeable higher concentration centers in southwest and northwest of the study area, in which the abundance is 179.50 ind./m^3 and 419.14 ind./m^3 respectively. The former one at Station (St.) C8-1 mainly consists of *Calanus sinicus*, which makes up above 88.00% of the total Copepoda. The latter one (at St. C3-1) is mainly composed of *Eucalanus subtenuis*, *E. subcrassus* and *E. macronatus*, which make up above 75.90%.

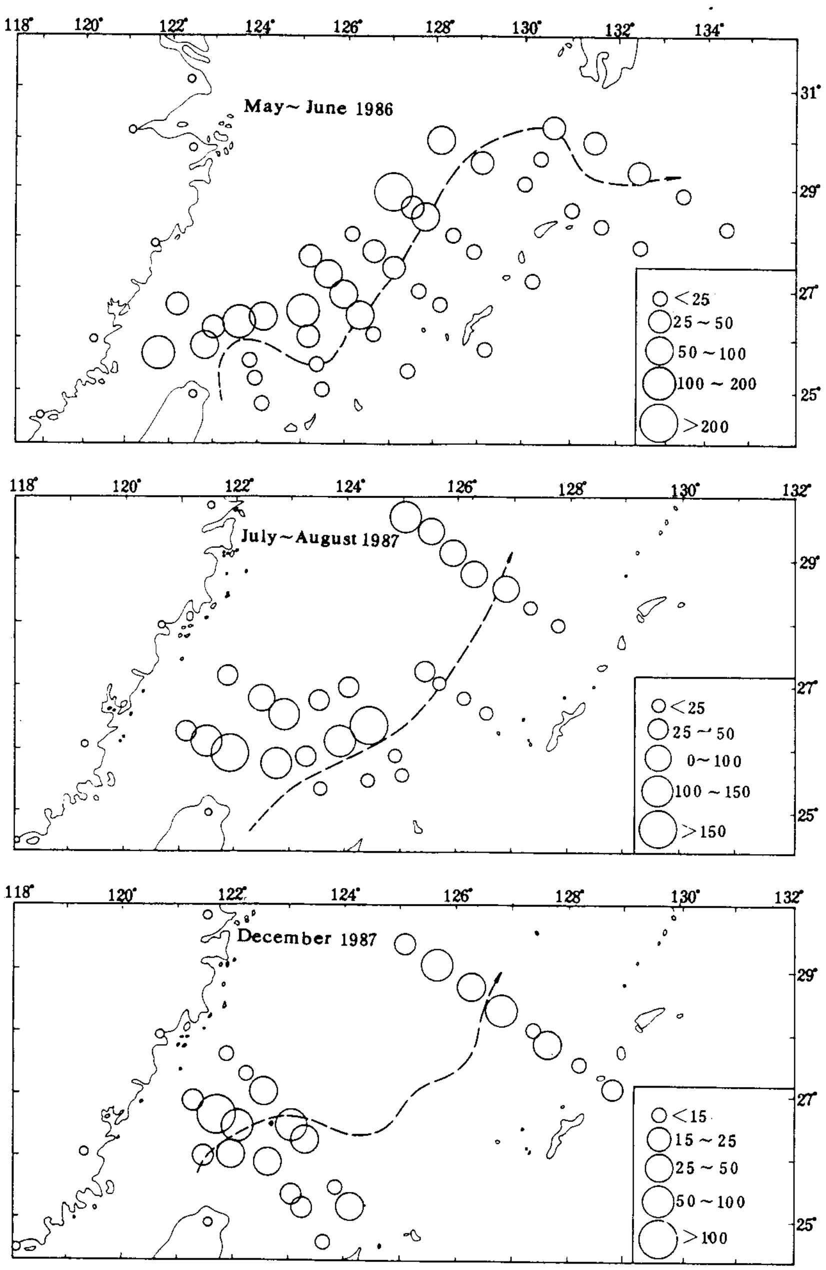

Fig. 3. The horizontal distribution of the abundance of Copepoda (0. 01 ind. /m³).

In summer: The average abundance is 61. 09 ind. $/m^3$, and the variation range is from 11. 20 to 162. 60 ind . $/m^3$. The higher concentration centers are in the Kuroshio front and the continental shelf mixed water north of Taiwan, in which *Undinula vulgaris* makes up above 50%. According to the temperature data of 50 meter from Pan Yuqiu (1987), there are two up-flow regions of the Kuroshio subsurface water in these areas, their positions close to the higher concentration centers of Copepoda.

In winter: The average abundance is 34.80 ind./m^3, and the variation range is from 5.80 to 116.60 ind./m^3. The higher concentration center is in the continental shelf northwest of Taiwan. *Euchaeta marina*, *E. plana*, *E. concinna* and *Pareuchaeta russelli* account for about 70%, because of the effects of the Zhejiang-Fujian coastal water, the Taiwan Strait water and the Kuroshio water. In the south-center section of the East China Sea continental shelf, the species composition is the same as above, but abundance is only half of the former abundance (Fig. 3).

ii. Chaetognatha

The abundance of Chaetognatha decreases towards oceanic waters in spring and summer, and it is very low in the offshore area southeast of Wenzhou and the waters of the Kuroshio outside in winter. There are two higher value areas. One is in the continent area northwest of Taiwan, which is mainly composed of *Sagitta enflata* in all seasons. The other is in the south-center section of the East China Sea continental shelf, which mainly consists of *S. nagae* in spring at St. C8-1, *S. enflata* in summer at Sts R1-2 and R1-3 and *S. bedoti* in winter at St. R1-1. The lower value area is generally in the waters between the current maximum zone of Kuroshio and the Ryukyu Islands (Fig. 4).

As far as seasonal variation of the abundance of Chaetognatha, summer occupies the first (10.41 ind./m^3), and the variation range is from 1.15 to 39.64 ind./m^3. Spring comes second (6.29 ind./m^3), with the variation range of 1.31 to 21.27 ind./m^3, while winter is minimum (3.02 ind./m^3), with the variation range of 0.76 to 16.76 ind./m^3.

iii. Siphonophora

In spring: The average abundance is 2.12 ind./m^3, and the variation range of the abundance is from 0.33 to 20.19 ind./m^3. There are two higher concentration centers in the continental shelf area northwest of Taiwan (at St. C2-1 and Sts. C1-3, C2-3) and the south-center section of the East China Sea continent (at St. C8-1). The abundance of St. C2-1 is 20.13 ind./m^3, in which *Muggiaea atlantica* and *Lensia subtiloides* account for 49.7% and 41.2% respectively. Sts C1-3 and C2-3 lying in the outside of St. C2-1 have the same abundance of 4.98ind./m^3, however, the dominant species are *L. subtiloides* (43.8%) and *Bassia bassensis* (19.3%). *M. atlantica* makes up 75.5% at St. C8-1. Rare individuals with an even distribution are found in the current maximum zone of Kuroshio and its outside area.

In summer: The average abundance is 1.535 ind./m^3 and the variation range is from 0.04 to 9.16ind./m^3. The distribution pattern is similar to that of spring. There are two higher concentration centers in the south-center section of the East China Sea continental shelf (at St. R1-1) and continent area northwest of Taiwan (at Sts S2-3 and S2-4). The abundance of the former is higher than that of the latter. Dominated by *L. subtiloides* (52.6%) and *Diphyes chamissonis* (45.4%), the abundance of the former is 9.16 ind./m^3. The abundance of the latter is 4.27 ind./m^3. Besides *L. subtiloides* (42.3%) and *D. chamissonis* (22.8%), the dominant species also *contains Sulculeolaria chuni* (17.6%) which is a tropic oceanic eurytopic species. The number of Siphonophora is rare at Sts S3-3, S5-1, S6-1, S8-1 and R1-4 (below 0.25 ind./m^3), especially at St. R1-4 where it has only

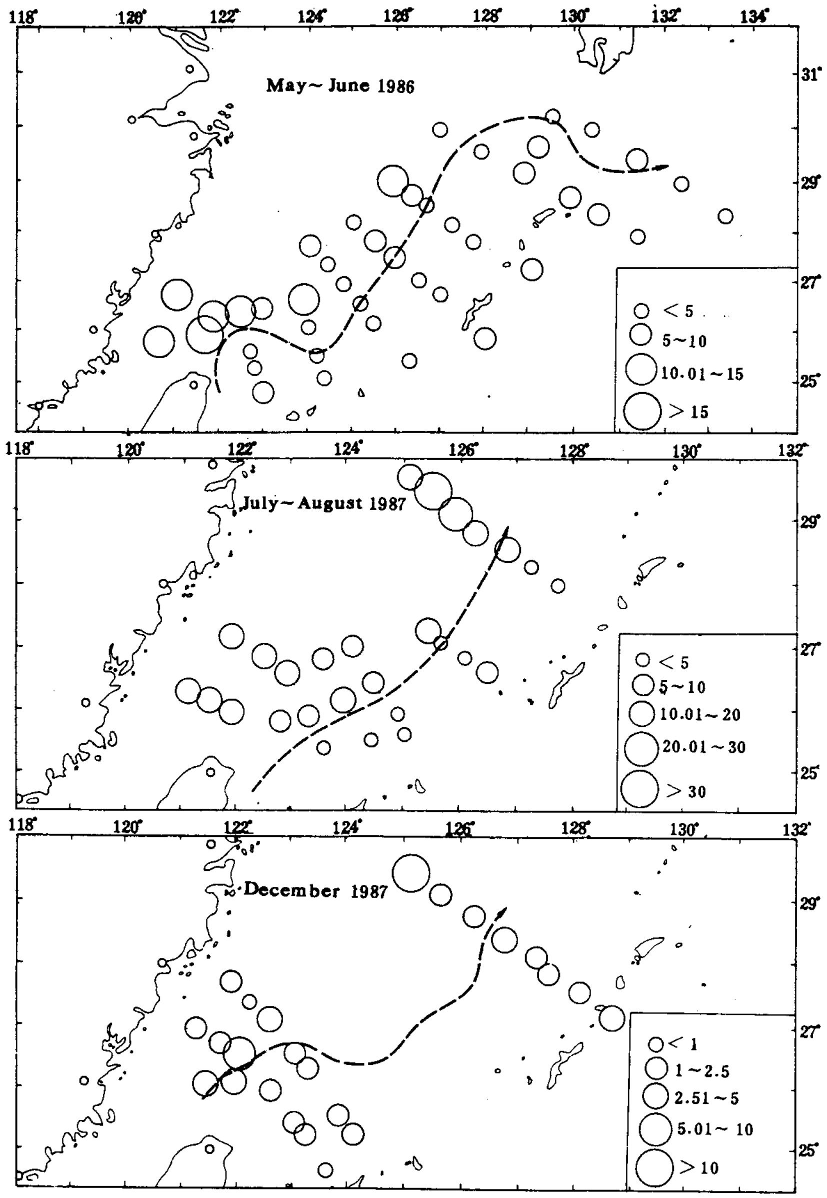

Fig. 4. The horizontal distribution of the abundance of Chaetognatha (ind. /m^3).

0. 04 ind. /m^3 of *D. chamissonis* which is a neritic species.

In winter ; The individual number is generally lower with the average abundance of 0. 85 ind. /m^3 and the variation range of 0. 05 to 2. 02 ind. /m^3. The higher concentration centers in the offshore waters have moved to the waters near Kuroshio front. The abundance of north one (at St. R1-7) is 2. 02 ind. /m^3, in which the dominant species is not obvious, however, some oceanic eurytopic species, for example, *B. bassensis*, *Chelophyes concorta*, *Abylopsis tetragona*, *A. eschscholtzi* and so on constitute the majority (65. 4%). Another one is in the continental shelf area northwest of Taiwan (at Sts. S1-6 and S2-3) with the abundance of 1. 76 and 1. 70.ind. /m^3 respectively. The dominant species of there is similar to that of the former one (Fig. 5).

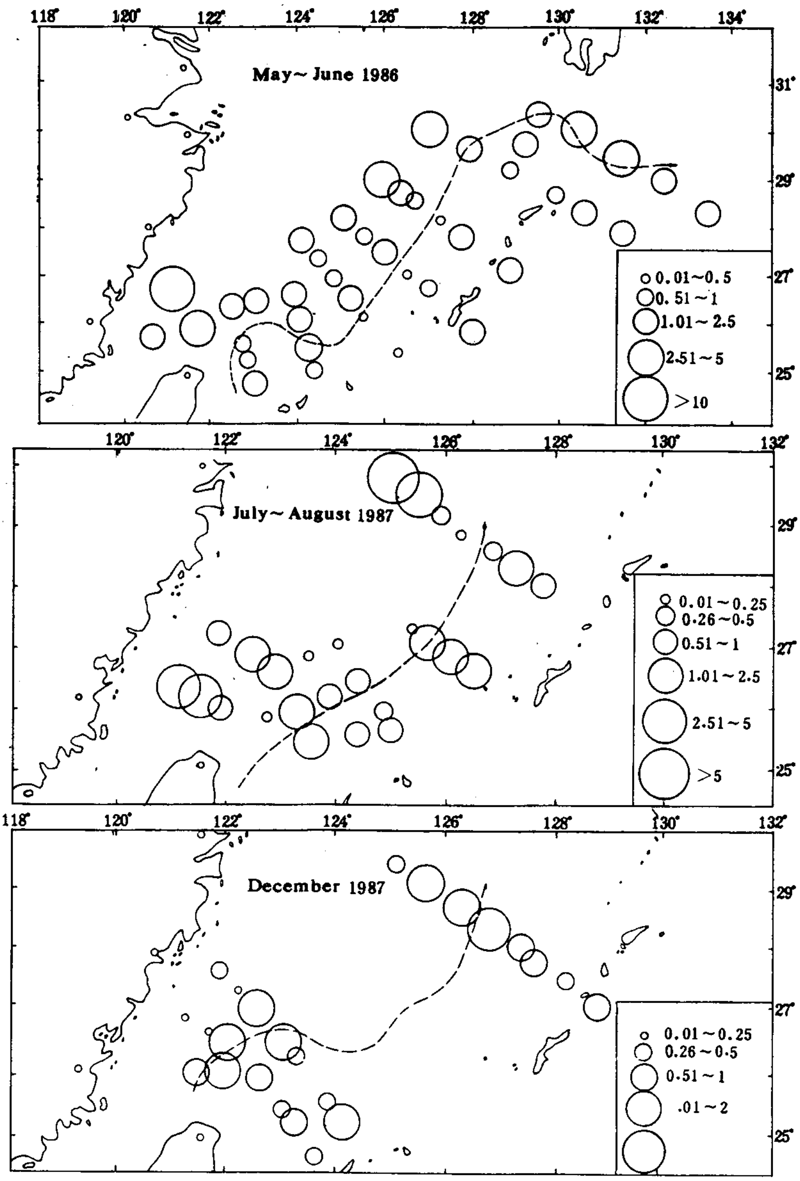

Fig. 5. The horizontal distribution of the abundance of Siphonophora (ind. /m^3).

To sum up, the seasonal variation and horizontal distribution of Copepoda, Chaetognatha and Siphonophora are very similar. The higher concentration centers are in the fronts of different water masses, while the abundance in the current maximum zone of Kuroshio and its outside waters is lower. The main species of the higher concentration centers are shown in Table 2.

Table 2. The main composition of three categories of zooplankton in higher concentration centres

Season	Spring		Summer		Winter	
High concentration	I	II	I	II	I	II
Copepoda	*Calanus sinicus*	*Eucalanus subcrassus* *E. subtenuis* *E. mucronatus*	*Undinula vulgaris*	*Undinula vulgaris*	*Clanus sinicus* *Eurchaeta marina* *E. plana* *E. concinna* *Pareuchaeta russelli* *Paracalanus aculeatus*	*Euchaeta marina* *Calanus sinicus*
Chaetognatha	*Sagitta nagae*	*Sagitta enflata*	*Sagitta enflata*	*Sagitta enflata*	*Sagitta bedoti* *S. enflata*	*Sagitta enflata*
Siphonophora	*Muggiaea atlantica*	*Lensia subtiloides* *Muggiaea atlantica*	*Lensia subtiloides* *Diphyes chamissonis*	*Diphyes chamissonis* *Lensia subtiloides* *Sulculeolaria chuni*	*Bassia bassensis* *Diphyes chamissonis* *Chelophyes contorta*	*Bassia bassensis* *Chelophyes contorta*

I. South-center section of the East China Sea continental shelf; II. continental shelf area northwest of Taiwan.

THE COMPOSITION, DISTRIBUTION AND INDICATOR SPECIES OF ZOOPLANKTON

The zooplankton species in the study area is plentiful. Two hundred and twenty-three species of Copepoda were indentified in the samples of spring. Total 54 species of Siphonophora and 20 species of Chaetognatha were indentified in spring, summer and winter. The number of species is fewer in the continental shelf area than in the current maximum zone of Kurashio and its outside waters. This means the zooplankton in the continental shelf area has higher dominance and lower diversity, but that in the Kuroshio and outside oceanic waters has lower dominance and higher diversity.

On the basis of their ecological habits, the zooplankton in the study area can be divided into 4 types, which are named (1) warm-temperate neritic species, (2) tropic oceanic eurytopic species, (3) tropic oceanic stenotopic species and (4) tropic oceanic bathyal species respectively. The tropic species occupy a dominant position in the study area (Table 3).

Table 3. The seasonal variation of the individual percentages of tropic species in three categories of zooplankton

Season	Spring	Summer	Winter
Copepoda	67.80%	98.41%	95.86%
Chaetognatha	80.00%	91.95%	80.91%
Siphonophora	49.96%	48.46%	83.10%

Warm-temperate neritic species

The major representative species of this type are *Calanus sinicus*, *Muggiaea atlantica*, *Sagitta nagae*, *S. bedoti*, *Diphyes chamissonis* and so on. They fit the environment of lower temperature and higher salinity. The higher concentration centre is formed by mass individuals with a few species in the continental front affected by the coastal water. They are the major components of the two higher density centres in the south-centre section of the East China Sea continent affected by the Huanghai Sea cold water and Jiangsu-Zhejiang coastal water, and in the continental shelf area northwest of Taiwan influenced by Zhejiang-Fujian coastal water and the Taiwan Strait water. The distributional region expands or contracts with the strength or weakness of the coastal water in different seasons. However they are never be found in the current maximum zone of Kuroshio and its outside area (Fig. 6).

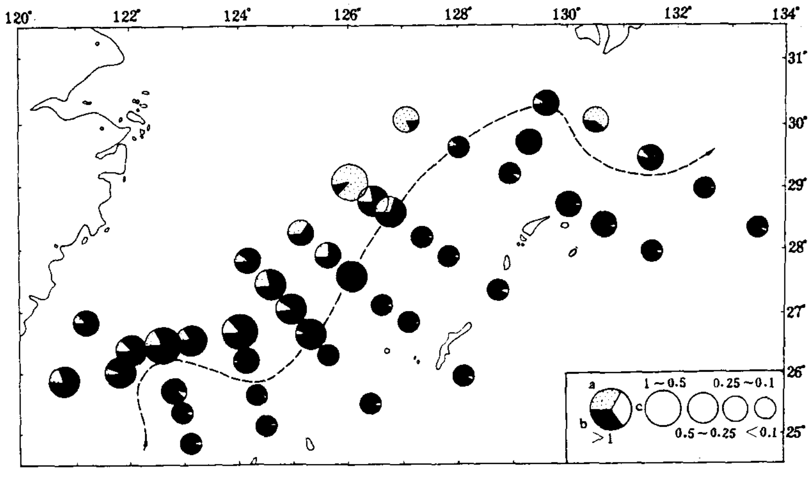

Fig. 6. The abundance (ind. /m^3) and percentage of each ecotype Copepoda in spring.
a. Warm-temperate neritic species; b. tropic oceanic eurytopic species; c. tropic oceanic stenotopic species.

Figure 7 gives the numerical distribution of *Calanus sinicus*. This species is widespread in the continent mix waters inside the Kuroshio front along the 200 m isobath. In spring, owing to the effect of the Yellow Sea cold water, the number of *Calanus sinicus* reaches the maximum of 370.84 ind. /m^3 at St. C8-1, which makes up 88.9% of total Copepoda. The proportion of immature to mature of it increases progressively to the front of Kuroshio with the increase of water temperature. The immature bodies make up 100 percent of the total in the Kuroshio front. In summer, the density centre shrinks back to the northwest and its abundance decreases. However, there is a higher concentration centre of 18.11 ind. /m^3 at St. S2-2 in the continent region northwest of Taiwan because of the influence of the Zhejiang-Fujian coastal water and Taiwan Strait water. In winter, the abundance of *Calanus sinicus* decreases to the minimum. The high concentration centres are found at Sts S2-1, S4-1 and S4-3 in the offshore area southeast of Wenzhou (have 5.75, 4.14 and 4.63 ind. /m^3 respectively) and at St.

R1-3 (4 ind. /m^3) in the south-centre section of the East China Sea continental shelf affected by the Huanghai Sea cold water.

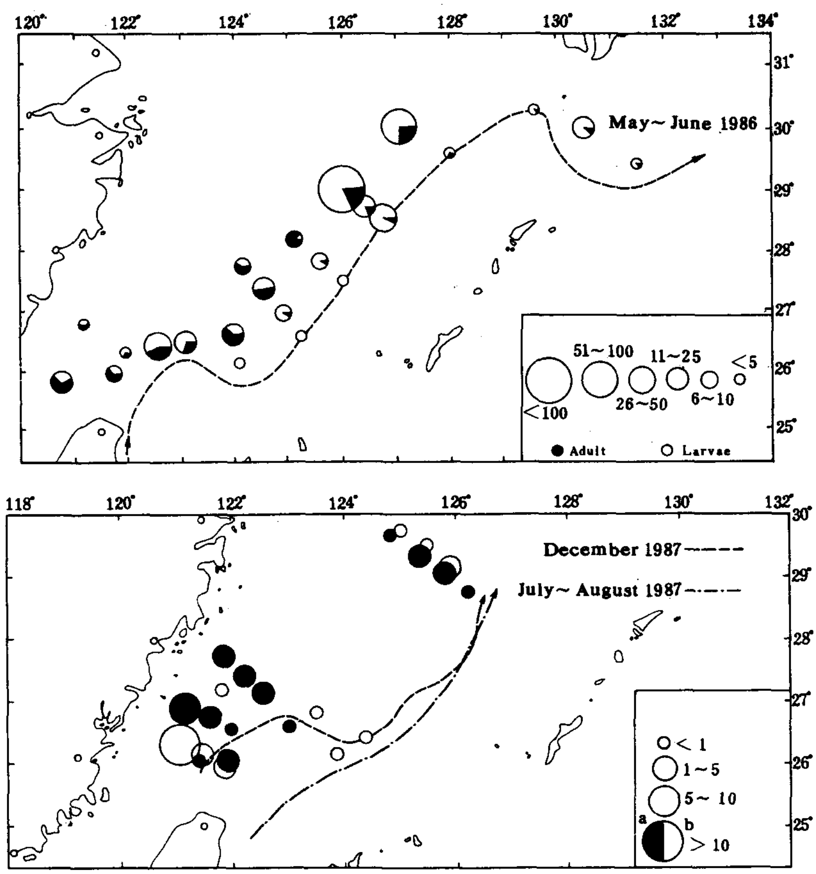

Fig. 7. The horizontal distribution of the abundance of *Calanus sinicus* (ind. /m^3). a. Winter; b. Summer.

Thus, it can be seen that the appearance and abundance of this ecotype zooplankton are controlled by the effect of the coastal water. They are the indicators of the coastal water in the surveyed area.

Tropic oceanic eurytopic species

The representative species of this ecotype group are *Sagitta enflata*, *Eucalanus subcrassus*, *E. subtenuis*, *Undinula vulgaris*, *Euchaeta marina*, *Bassia bassensis*, etc. They are common, abundant, various and widespread in the study area. The higher density centres are in the Kuroshio front and the front of different waters of the northwest of Taiwan, from which the abundance decreases to both directions which are the continent mix waters and Kuroshio area respectively. The individuals in both sides of Ryukyu Islands are less.

Most of the tropic oceanic eurytopic Chaetognatha shown in Fig. 8 are *Sagitta enflata*. The higher

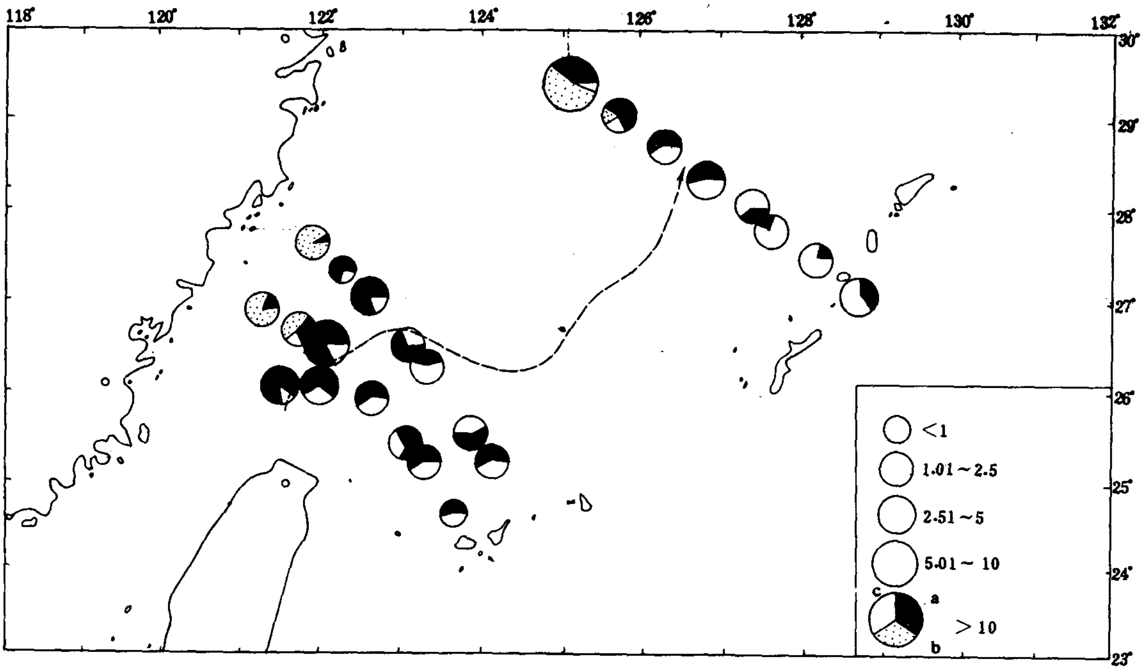

Fig. 8. The abundance (ind./m³) and proportion (%) of varied ecotype groups of Chaetognatha in winter.
a. Tropic oceanic eurytopic species; b. warm-temperate neritic species; c. tropic oceanic stenotopic species.

concentration area of it is in the front of various water masses, which is situated at St. C1-3 in spring, St. R1-2, R1-4, S2-5 and S2-4 in summer and St. S1-4, S2-3, S4-3 and R1-1 in winter. Taking a view from the distribution of *Sagitta enflata* in three seasons, the higher concentration area is in the front of Kuroshio, the number of which is far more than that in the Kuroshio. The analyses above show that the species of this ecotype zooplankton can be considered an indicator to indicate the limits of the effect of Kuroshio. The more or less of its number reflects the strength or weakness of the effect of Kuroshio to some extent.

Tropic oceanic stenotopic species

As the typical tropic oceanic species, they are mainly distributed in the low latitude ocean area around the equator. The mainly distributed area shown in Fig. 9 is in the Kuroshio waters of the east of the Kuroshio front and the outside ocean waters. They do not form dominance in individuals , but have high diversity. The appearance of these species can indicate the position of Kuroshio, so-called Kuroshio species. The major representative species are *Gaidius pungens*, *Euchirella galeata*, *Undeuchaeta incisa*, *Centropages elongatus*, *Sagitta lyra*, *S. hexaptera*, *Pterosagitta draco*, *Hippopodius hippopopus*, *Vogtia glabra*, *Rosacea plicata*, *Abyla bicarinata*, etc.

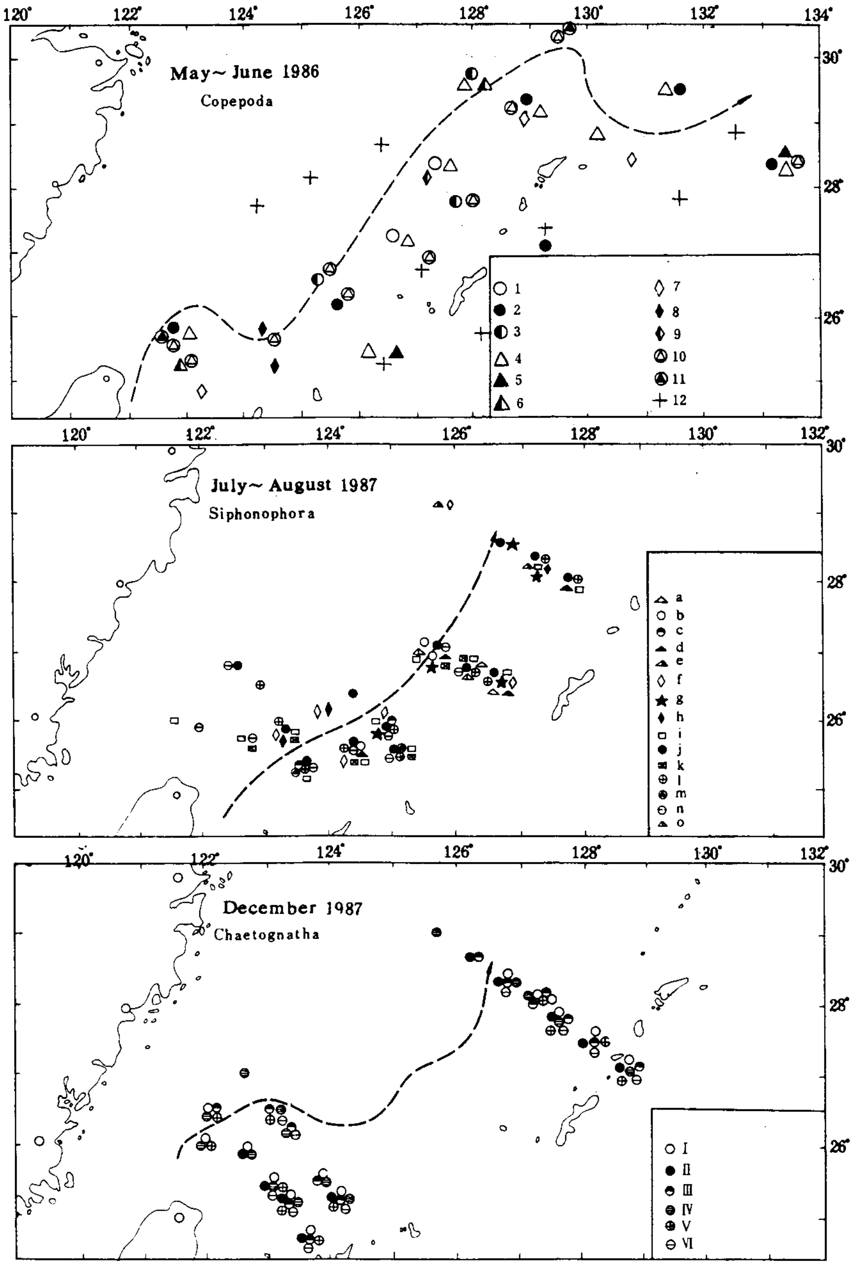

Fig. 9. A sketch map showing the appearance of tropic oceanic stenotopic species (including tropic oceanic bathyal species). 1. *Euchirella galeata*; 2. *Scottocalanus securifrons*; 3. *Undeuchaeta incisa*; 4. *Gaetanus minor*; 5. *Haloptilus austini*; 6. *Scolecithricella dentata*; 7. *Scaphocalanus brevicornis*; 8. *Centropages elongatus*; 9. *Euaugaptilus hecticus*; 10. *Haloptilus spiniceps*; 11. *Lubbockia squillimana*; 12. Deep-sea species. a. *Agalma elegans*; b. *Hippopodius hippopus*; c. *Vogtia glabra*; d. *Amphecaryon ernesti*; e. *A. acaule*; f. *A.* spp. (EP); g. *Rosacea* plicata; h. *Sulculeolaria turgida*; i. *Lensia hotspur*; j. *L. subtilis*; k. *L. meteori*; l. *L. campanella*; m. *L. cossack*; n. *Eudoxia macra*; o. *Abyla bicarinata*. I. *Sagitta hexaptera*; II. *S. lyra*; III. *S. pseudoserratodentata*; IV. *S. bipunctata*; V. *S. decipiens*; VI. *Krohnitta subtilis*.

Tropic oceanic bathyal species

The habitat of this group species is in deep sea under 1 000 meters. It is only seldom seen in the study area. The main representative species, *Calanoides carinatus*, is only found in spring cruise at Sts C6-0, C1-1 and C8-2. The depth there is only 100～125 m and the samples are taken in daytime. It is well worth further study whether it is caused by the up - flow of deep water.

The indicator study is an important respect in the ecological research of Kuroshio in the East China Sea. Apart from Chaetognatha, there is not well considered reference on this issue in the surveyed area. The major representative species of each ecotype and the ecological environment they indicate are listed as follows (Table 4).

Table 4. The typical representative of different ecotype zooplankton

	(Copepoda)	(Chaetognatha)	(Siphonophora)
Warm temperate neritic species	• *Calanus sinicus* *Paracalanus aculeatus*	• *Sagitta nagae* • *S. bedoti* *S. tokiokai*	• *Muggiaea atlantica* *Diphyes chamissonis* *Lensia subtiloides*
Tropic oceanic eurytopic species	• *Eucalanus subtenuis* • *Euchaeta marina* • *Undinula vulgaris* *U. darwini* *Neocalanus gracilis* *Scolecithrix danae* *Pleuromamma abdominalis* *Lucicutia flavicornis*	• *Sagitta enflata* *S. ferox* *S. robusta* *S. neglecta* *S. regularis* *S. pulchra*	• *Bassia bassensis* • *Abylopsis tetragona* *A. eschscholtzi* *Sulculeolaria chuni* *Chelophyes contorta* *Eudoxoides spiralis* *E. mitra*
Tropic oceanic stenotopic species	*Gaetanus pungens* *Euchirella galeata* *E. bella* *Undeuchaeta incisa* *U. major* *Scottocalanus securifrons* *S. australis* *Scolecithricella dentata* *Centropages elongatus* *Haloptilus austini* *H. spiniceps* *H. oxycephalus* *Lubbockia squillimana*	*Sagitta hexaptera* *S. lyra* *S. decipiens* *S. pacifica* *S. pseudoserratodentata* *S. bipunctata* • *Pterosagitta draco* *Krohnitta subtilis* *K. pacifica*	*Nanomia bijuga* *Hippopodius hippopus* *Vogtia glabra* *Rosacea plicata* *Lensia subtilis* *L. hotspur* *L. campanella* *L. cossack* *L. meteori* *Eudoxia macra* *Abyla* spp.
Tropic oceanic bathyal species	• *Calanoides carinatus* *Lophothrix frontalis* *Arietellus setosus*		

• Important species.

THE RELATIONSHIP BETWEEN THE DISTRIBUTION OF ZOOPLANKTON AND THE TEMPERATURE AND SALINITY

With the complex relationship between zooplankton and marine environment, the distribution of zooplankton is affected by various environmental factors. The results mentioned above have indicated that there is close relation between the currents, water masses and the distribution of zooplankton.

The correlations between the abundance (N), diversity (H') and homogeneity (J) of Chaetognatha and Siphonophora and the mean temperature ($\bar{t}$) and mean salinity ($\bar{S}$) of waters in the study area are calculated by the method of one factor linear regression. The results are given in Table 5.

Table 5. The correlations between the abundance (N), diversity (H') and homogeneity (J) of Chaetognatha and Siphonophora and the mean temperature ($\bar{t}$) and salinity $\bar{S}$ above 200 meters in the study area

	Season	Abundance (N) Chaet.	Abundance (N) Sipho.	Diversity (H') Chaet. (correlation)	Diversity (H') Sipho.	Homogeneity (J) Chaet. (coefficients)	Homogeneity (J) Sipho.
($\bar{t}$)	Spring ($n=43$)	—	—	** 0.508 6	** 0.624 8	** 0.484 2	** 0.577 8
	Summer ($n=27$)	—	* −0.383 1	—	—	—	** −0.610 4
	Winter ($n=24$)		—	** 0.644 5	** 0.641 1	—	—
($\bar{S}$)	Spring ($n=43$)	** −0.407 0	* −0.322 1	** 0.774 6	** 0.731 5	** 0.733 0	** 0.581 1
	Summer ($n=27$)	** −0.860 8	—	** 0.858 4	** 0.725 4	** 0.813 3	* 0.447 0
	Winter ($n=24$)	—		* 0.502 3	** 0.700 0	—	—

* Significant, $p<0.05$; * * very significant, $P<0.01$.

For Chaetognatha, there is close relationship between its distribution and the temperature and salinity in spring, in summer, the relationship with the salinity is close, however the relationship to the temperature is unidentified; and in winter, only the diversity has a significant correlation with the temperature and salinity.

The relationship between the abundance of Siphonophora and the temperature and salinity is not evident. Except the relationship with the temperature in summer, its diversity is positively correlated with the temperature and salinity in each season, however, the relationship with the salinity is closer. It is worthy of attention that the homogeneity of Siphonophora is negatively correlated with the temperature, but positively correlated with the salinity in summer.

The correlations between the biomass (W), abundance (N), species number (S), diversity (H') and homogeneity (J) of Copepoda and the mean temperature ($\bar{t}$) and mean salinity ($\bar{S}$) of waters in the study area in spring are analysed by the method of two factors linear regression. Analysis results are as follows:

$$W = 1\,341.23 - 0.47\bar{t} - 37.96\bar{S}, \quad (F_W = 8.630, \quad r_1 = -0.036, \quad r_2 = -0.459)$$

$N = 5\,255.29 - 2.70\bar{t} - 149.25\bar{S}$, ($F_N = 14.074$, $r_1 = -0.066$, $r_2 = -0.542$)
$S = -1\,208.26 + 1.08\bar{t} + 35.84\bar{S}$, ($F_S = 16.313$, $r_1 = 0.112$, $r_2 = 0.556$)
$H' = -80.23 + 0.09\bar{t} + 2.38\bar{S}$, ($F_{H'} = 33.231$, $r_1 = 0.202$, $r_2 = 0.678$)
$J = 10.20 + 0.01\bar{t} + 0.31\bar{S}$. ($F_J = 29.243$, $r_1 = 0.216$, $r_2 = 0.646$)

The correlations between each dependent variable and two independent variables ($\bar{t},\bar{S}$) are all significant (remarkable level detected by "F", $F_{0.01[2.40]} = 5.18$). There are negative correlations between the biomass, abundance and the mean temperature, mean salinity, and positive correlations between the species number, diversity, homogeneity and the mean temperature, mean salinity, of which the correlations between the diversity, homogeneity and the mean temperature, mean salinity are more significant. Moreover, "r" values of the two independent variables ($r_2 > r_1$) indicate that the contribution of salinity is greater than the temperature.

Dividing the study area into the Kuroshio waters (21 stations) and the mixed waters of continental shelf (22 stations) in the light of hydrological condition, and using the same method, we have found that there are insignificant correlations between each dependent variable of Copepoda and two independent variables in the Kuroshio waters. In the mixed waters of continental shelf, though there are the trend of negative correlations between the biomass, abundance and the mean temperature, mean salinity, the correlations between them are not very close. However, the correlations between the species number, diversity, homogeneity and the mean temperature, mean salinity are very significantly positive ($F_{0.01[2.19]} = 5.93$), their regression equations are as follow:

$S = -1\,407.91 + 0.82\bar{t} + 41.79\bar{S}$, ($F_S = 13.896$, $r_1 = 0.119$, $r_2 = 0.650$)
$H' = -106.45 + 0.09\bar{t} + 3.15\bar{S}$, ($F_{H'} = 44.022$, $r_1 = 0.291$, $r_2 = 0.830$)
$J = -14.73 + 0.01\bar{t} + 0.44\bar{S}$, ($F_J = 42.418$, $r_1 = 0.313$, $r_2 = 0.821$)

The "r" values of the two independent variables ($r_2 > r_1$) show that the salinity still plays a leading role in the mixed waters of continental shelf.

To sum up, the correlations between the diversity, homogeneity of zooplankton and the salinity are very significant. However, the effect of the temperature on them is less significant, especially in summer.

RESULTS AND DISCUSSION

(1) In the study area, the zooplankton biomass and the abundance of major groups are higher in the continental shelf area than in Kuroshio and its outside waters. The higher biomass and concentration centres are in the continental shelf area along the fronts of various water masses. With the evolution of the seasons and the mutual evolvement of water masses, the location and the abundance of high density centres would effect a relevant change. The higher density centre in the continental shelf area northwest of Taiwan is located in the front of the Zhejiang - Fujian coastal water, the Taiwan Strait water and the Kuroshio subsurface up - flow water. Since the hydrological feature is similar to the Kuroshio water, the zooplankton community here is dominated by tropic eurytopic species. The northern higher density centre, the south- centre section of the East China Sea continent, is located in the front of the continent mix water of the East China Sea and the Huanghai Sea cold water, therefore, it may still belong to the southern fringe of the sub-hyperthermal haline zooplankton community of middle Huanghai Sea. The dominant species of this higher density centre, *Calanus sinicus*, *Sagitta bedoti* and *Muggiaea atlantica*, which have the ecological habit of sub-hyperthermal haline, have sup-

ported the correctness of our inferences. The front caused by superposition of various water masses is the important reason for forming the high biomass of zooplankton. On the contrary, the lower abundance and higher diversity take place in the Kuroshio waters and its outside oceanic waters where the properties of water are relatively stable .

(2) The distribution of zooplankton of different ecotypes can be considered to be the proof for dividing the different property water masses in our study area. The distribution of tropic oceanic stenotopic species can indicate the location of Kuroshio exactly. The appearance of warm-temperate neritic species indicates the position at which the coastal water arrives. The wide distribution of the tropic oceanic eurytopic species shows that the Kuroshio warm water affects all study area. And the variation of their abundance represents the strength or weakness of the front of Kuroshio water mixing with other water masses.

It has some superiority to recognize the source and characteristics of water mass by using biological indicators in the study of Kuroshio ecosystem, particularily in the mix area of various water masses where, on the hydrology, we hardly trace the water movement, and estimate the mixture ratio and effect region, because the characteristics of temperature and salinity of origin water disappears immediately owing to the rapid mix between different water masses. We put forward the indicator species of various water masses on the basis of the analyses of their ecological habits.

Sagitta nagae, which is mainly distributed in the continental shelf area inside Kuroshio, is an indicator of the coastal water. That the species is found in the current maximum zone of Kuroshio has verified Pan's (1987) viewpoint which, in summer, the continent mix water expands to the outside of Kuroshio current maximum zone because of the strength of coastal water. The same phenomenon found in the north of Miyako Island in summer was reported by Inoue (1979). The selection of indicator species depends on different sea areas and seasons . That *Sagitta enflata* can be an indicator of the Kuroshio water in the waters of the south of Japan during winter and spring has been reported by Kuroda (1977). However, in the East China Sea, it usually concentrates in the up-flow area of the Kuroshio subsurface water and the front area of the Kuroshio water, the Taiwan warm water and the continental water. So it is probably more suitable to consider it as an indicator of the mix water instead of the Kuroshio water in the East China Sea. This is consistent with the views of Lin Y. (1982).

With the study of recent years, we think that the proposal of Zheng Zhong (1978) (i. e. the biological indicator should be a community instead of a species for improving the accuracy and avoiding the contingency) is quite right. It is a preliminary try to use a ecotype group as the indicator of water masses in this paper. It is particularly important for tropic oceanic stenotopic species to indicate the Kuroshio water because they have many species with a few individuals.

(3) Quantitative analysis indicates that the variation of temperature and salinity is an important restrictive factor to affect the distribution and composition of zooplankton. In them the contribution of salinity is much more than that of temperature. However, previous qualitative analyses thought the effect of temperature was still greater. This is because sea area conditions and used analyses methods are different from each other, the results would be not identical . We suggest that poly-factors comprehensive research, e. g. multi-dimentional model, can be used to promote the study o Kuroshio ecology, because the distribution of living beings in water is controlled by the synthetical effects of all factors.

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