Zoological Studies **37**(1): 63-73 (1998)

Zoological Studies

Seasonal and Hydrographic Variations of Ichthyoplankton Density and Composition in the Kuroshio Edge Exchange Area off Northeastern Taiwan

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(Accepted December 12, 1997)

Jiunn-Bin Huang and Tai-Sheng Chiu (1998) Seasonal and hydrographic variations of ichthyoplankton density and composition in the Kuroshio edge exchange area off northeastern Taiwan. *Zoological Studies* **37**(1): 63-73. A total of 327 ichthyoplankton samples were taken during 14 cruises from June 1989 to September 1992 in the waters off northeastern Taiwan. The density of ichthyoplankton was lowest in winter, increased in spring, reached the maximum in summer, and declined in autumn. Average densities in the 3 hydrographic ecotopes indicate that the ichthyoplankton density was highest in the East China Sea Shelf (ECS), moderate in the Kuroshio Current (KUR), and lowest in the mixing zone (MIX). In total, 59 789 individuals of ichthyoplankton assigned to at least 124 families and 547 species were collected. The major ichthyoplankton species, comprising about 60% of the total catch, were distinctive in different seasons and waters. *Decapterus* spp. (14.01%) and *Auxis* spp. (6.23%) were abundant in spring; *Auxis* spp. (6.91%) and *Benthosema pterotum* (5.80%) in summer; *B. pterotum* (55.23%), gobiids (4.14%), and *Synagrops* sp. (3.17%) in autumn; and *B. pterotum* (15.35%) and *Gonostoma gracile* (7.48%) in winter. The abundant ichthyoplankton species in the 3 hydrographic ecotopes were *B. pterotum* (22.98%) and *Auxis* spp. (5.11%) in ECS; *Decapterus* spp. (28.60%) and *Auxis* spp. (7.10%) in MIX; and *B. pterotum* (5.61%) and *Vinciguerria nimbaria* (4.43%) in KUR. The dendrogram based on major ichthyoplankton species exhibits 7 species-associated groups.

Key words: Larval fish, East China Sea Shelf, Kuroshio.

The Kuroshio is a warm current originating in the tropical North Pacific. It flows northward along the eastern coast of Taiwan and encounters the continental shelf of the East China Sea in the offshore area northeast of Taiwan. As the Kuroshio is forced to turn, primarily due to geomorphologic effects, a part of the water mass maintains its inertial momentum heading onto the shelf. The mixing between the waters of the East China Sea and the Kuroshio results in complicated marine processes (Liu 1983, Liu and Pai 1987).

Three hydrographic environments can be identified in the offshore area of northeast Taiwan (Fig. 1). The 2 major end-members are the East China Sea (shelf water) and the Kuroshio (oceanic water). A cold dome exists at the shelf break between the 2 end-members (Chern and Wang 1990, Liu et al. 1992a,b). This cold dome is formed by a plume of subsurface water upwelling to the surface (Chern and Wang 1989, Wong et al. 1991, Liu et al. 1992a) and serves as a significant nutrient source to the East China Sea (Wong et al. 1991). This area is a part of the southern East China Sea, an important fishing ground for fishermen of the northeastern coast of Taiwan (Anony. 1970-1993). Some of the ichthyoplankton are larvae of commercially important species. Knowledge of the distribution and abundance of these fishes is therefore key to understanding the seasonal occurrence of their parent stocks and possibly the fishing grounds.

In the Kuroshio edge exchange area off northeastern Taiwan, previous ichthyoplankton studies were based on materials collected from specific cruises for density distribution (Chiu 1991a,b

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1992), species composition (Chiu and Lee 1991, Yeh 1992), diurnal changes (Chiu 1991b), and representative species (Chiu and Lee 1991). Data integration was treated by Chen and Chiu (1992) for area comparison and Chiu and Hsyu (1994) for inter-annual variation. This study attempts to describe the seasonal abundance of ichthyoplankton in the waters northeast of Taiwan and to summarize the species compositions in the 3 hydrographic ecotopes: East China Sea, Kuroshio Current, and their mixing zone.

MATERIALS AND METHODS

Survey area

The study area is located in the western North Pacific in the offshore area of northeast Taiwan at approximately 24.5° to 27°N and 121° to 124°E (Fig. 1). This area consists of at least 3 physiographic units -- the East China Sea shelf (100-200 m), the East China Sea slope (200-1000 m) and the Southern Okinawa Trough (> 1000 m) (Yu and Hong 1992). The Kuroshio flows from the south into this area and exits to the northeast towards Japan. There are 3 hydrographic environments: the East China Sea shelf water (ECS), the Kuroshio Current (KUR, or oceanic water), and mixing water (MIX) (Chern and Wang 1990, Chern et al. 1990).

Ichthyoplankton samples

A total of 327 samples (226 in ECS, 26 in MIX, and 75 in KUR) were collected during 14 cruises from June 1989 to September 1992 (Fig. 1; Table 1). Ichthyoplankton surveys were conducted on

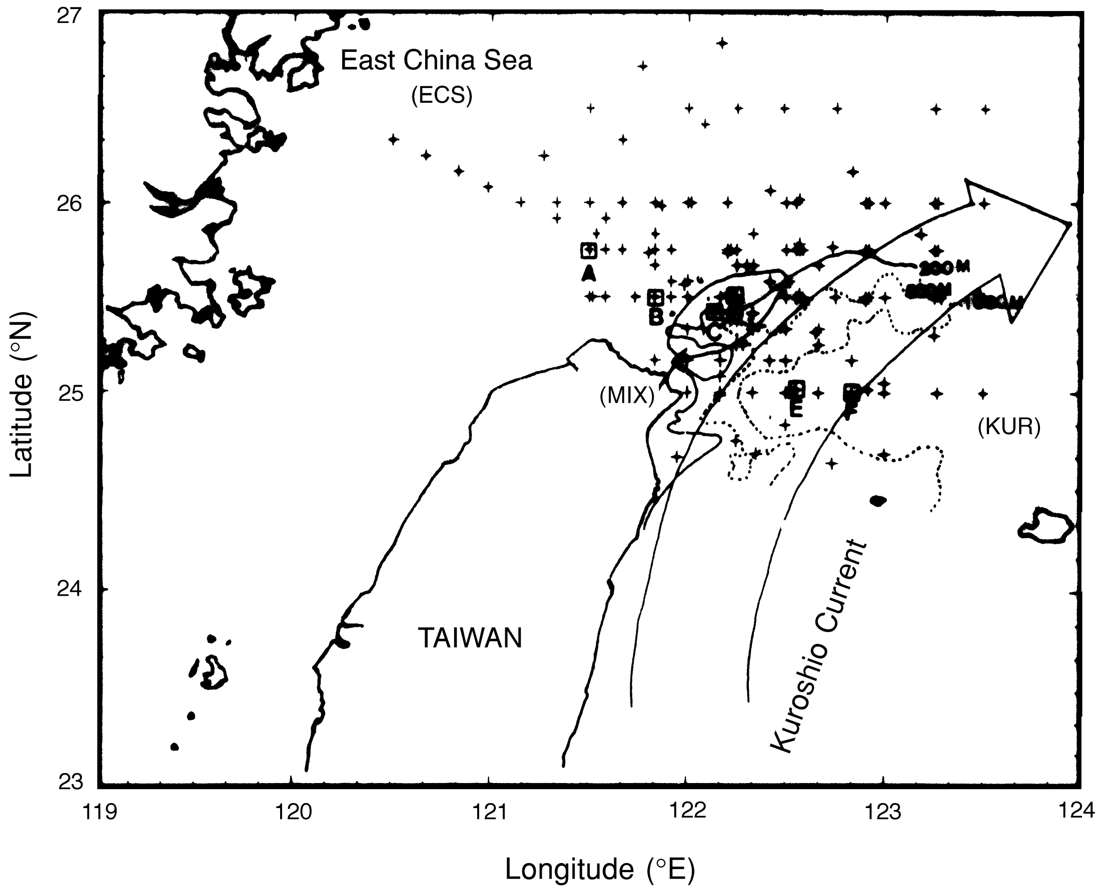

Fig. 1. Three hydrographic environments: the East China Sea (ECS), mixing waters (MIX; the stations encircled indicate where possible water mixing occurred), and the Kuroshio (KUR). (+, Sampling stations; Cross-squares A-F stations: selected stations for the determination of 3 hydrographic environments, see Figure 2).

board the R.V. "Ocean Research 1" (OR1, 900 T; cruise numbers 212, 222, 223, 304, 309, 321, 327, and 330B) and the R.V. "Hai-fu" (HF, 350 T; cruise numbers 248F, 249F, 252F, 260F, 269F, and 272F). Hydrographic data were obtained by a conductivity-temperature-depth (CTD) profiler (SBE 9/11, Sea-Bird Electronics) on OR1 and by a mini-CTD profiler (SBE 19 Seacat, Sea-Bird Electronics) on HF. Ichthyoplankton samples were collected by a round-mouth ichthyoplankton net with a diameter of 130 cm and mesh size of 1 mm. The net was towed obliquely along as close as possible to the bottom at the shelf stations, and from a depth of 200 m to the surface at the slope and oceanic stations. The net was raised at a speed of 0.3 m s^{-1} at a vessel cruise speed of 2-3 knots. The volume of water filtered was measured by a flowmeter (HydroBios) attached at the mouth of the net. The samples were preserved in a 10% formalin sea water solution and taken to the laboratory.

Among those 327 samples, 197 were collected in summer, 33 in spring, 76 in autumn, and 21 in winter (Table 1). The number of stations surveyed on each cruise was dependent on weather conditions and other factors. The average water volume sampled in each ichthyoplankton tow was 609.8 m^3, with a minimum of 239.3 m^3 and a maximum of 1017.5 m^3. The number of species contained in each sample ranged between 1 and 169 with an average of 34 species.

Data analysis

For each sample, fish eggs, larvae, and early juveniles were sorted to species; their numbers were counted under a microscope, and they were weighed on an electronic balance. The remainder of each sample, consisting mainly of zooplankton, was also weighed. The density was standardized to the number of individual specimens or to grams of weight in 1000 m^3 of filtered sea water.

Three hydrographic environments (ECS, MIX, and KUR) were separated based on the properties of water masses, according to the criteria established by Chern and Wang (1989), and Chiu and Hsyu (1994). The criteria were water temperature and dissolved oxygen at the surface and at 50 m depth (cold and low value, respectively for MIX), the bottom depth (deeper than 200 m for KUR), and apparent total fluorescence value at 50 m depth (high value for ECS) (Chiu 1991a). Along a transect, different water masses were distinguished by temperature-salinity diagrams (Fig. 2); the mixing water mass was situated between ECS and KUR. This method was cross-referenced to satellite images of sea surface temperature (to reveal a cold dome for mixing water) (Lin et al. 1992).

Ichthyoplankton samples were grouped into 12 (4 x 3) categories; 4 seasons -- spring (March-May), summer (June-August), autumn (September-November), and winter (December-February), and 3 hydrographic ecotopes -- ECS, MIX, and KUR.

Table 1. Cruise information of the ichthyoplankton study in the waters off northeastern Taiwan

Cruise	Sampling date			Samples[a] taken	Water volume (m^3) average	No. of species sorted	
						average	range
212	5 - 6	Jun.	1989	18 (15, 1, 2)	273.2	48	30 - 74
222	21 - 22	Aug.	1989	10 (6, 2, 2)	239.3	40	16 - 67
223	26 - 29	Aug.	1989	25 (20, 1, 4)	304.1	29	9 - 53
248F	1 - 3	May	1990	16 (11, 0, 5)	609.3	35	16 - 60
249F	18 - 20	July	1990	14 (11, 1, 2)	487.1	22	6 - 37
252F	20 - 22	Sep.	1990	32 (30, 0, 2)	472.0	57	3 - 169
260F	21 - 23	May.	1991	17 (8, 3, 6)	339.2	38	7 - 95
269F	15 - 17	Jul.	1991	36 (33, 0, 3)	509.7	56	3 - 121
272F	26 - 28	Aug.	1991	15 (9, 1, 5)	961.6	27	1 - 53
304	9 - 11	Dec.	1991	18 (9, 4, 5)	1017.5	31	7 - 56
309	21 - 22	Jan.	1992	3 (1, 1, 1)	559.9	10	3 - 16
321	25 - 27	Jun.	1992	11 (1, 3, 7)	682.3	43	30 - 81
327	10 - 13	Aug.	1992	68 (40, 9, 19)	659.7	25	7 - 57
330B	13 - 17	Sep.	1992	44 (32, 0, 12)	953.1	16	3 - 35
Total / average				327 (226, 26, 75)	609.8	34	1 - 169

[a] Total samples (samples taken from the East China Sea, Mixing zone, and Kuroshio, respectively).

For each category, percentage of a species in a sample was used to represent the relative abundance. For simplicity, species occurring as rarely as < 1% in each sample were excluded from further analysis. A concise species composition table was made to illustrate seasonal and hydrographic variations. Our summary procedure involved keeping a species on the list as long as it occurred at least once at > 1% in any sample, but lumping other species together within their respective families. Major ichthyoplankton species were defined as species (or groups of unknown species identified to generic level) making up > 1% at least once in any category (4 seasons and 3 hydrographic ecotopes). Major species (39) and season-hydrographic categories (11, no datum for autumn-MIX category) were grouped into dendrograms depicting their correlations. Clustering analysis was conducted using Spearman's rank correlation coefficients into a UPGMA (unweighted pair-group method using arithmetic averages) method.

RESULTS

Density

Seasonal variations

Average densities of organisms in the 4 seasons are presented in Table 2. Densities by number of fish eggs and ichthyoplankton generally followed the pattern of being lowest in winter, increasing in spring, reaching a maximum in summer, and diminishing in autumn. Results of analysis of variance indicate that significant seasonal differences occurred in the densities of fish eggs and ichthyoplankton.

Different patterns were found in densities by

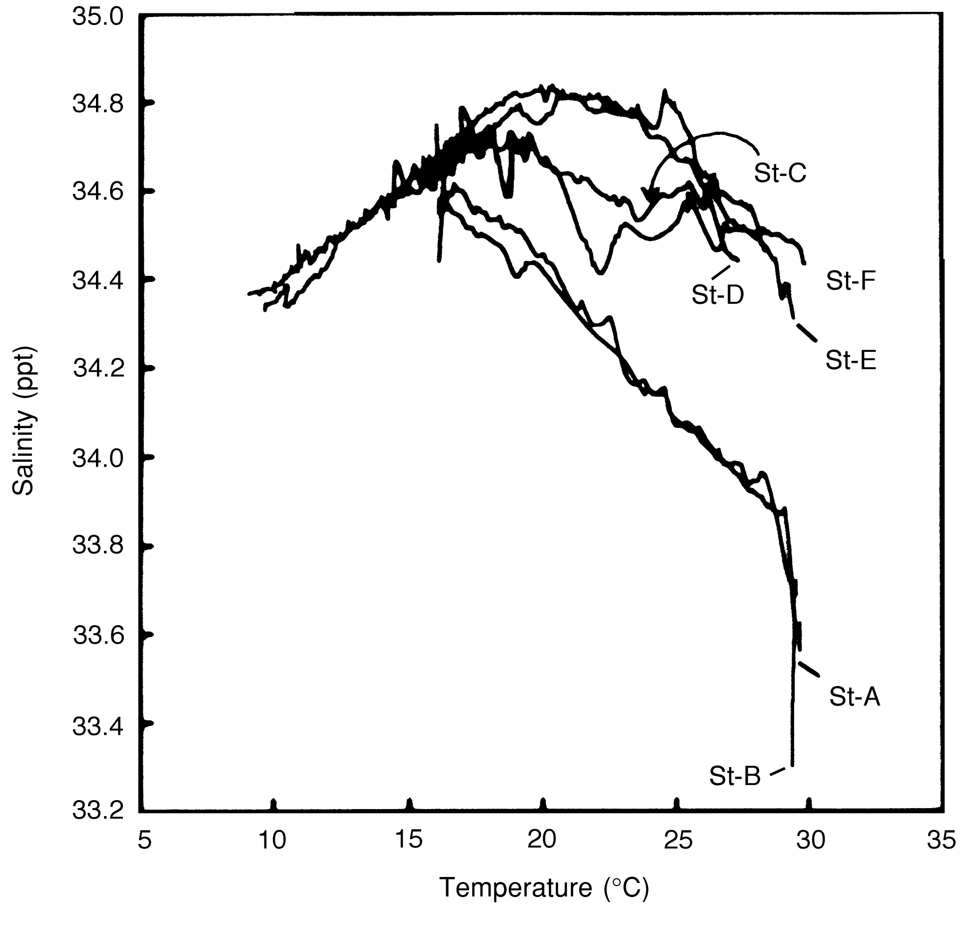

Fig. 2. Temperature and salinity profiles (T-S diagram) of water mass showing 3 different hydrographic environments (East China Sea (ECS): A -25°45'N 121°30'E, B -25°30'N 121°50'E; Mixing zone (MIX): C -25°25'N 122°08'E, D -25°30'N 122°12'E; Kuroshio (KUR) - E -25°01'N 122°33'E, F -25°01'N 122°55'E).

weight for fish eggs, ichthyoplankton, and zooplankton (Table 2). The density of fish eggs was lowest in winter, reached a maximum in spring, and diminished from summer to autumn. The patterns for ichthyoplankton and zooplankton were similar, but they differed from that of fish eggs; being lowest in winter, increasing from spring to summer, and reaching a maximum in autumn. Significant differences among seasonal categories of density by weight were detected in fish eggs and in zooplankton, but not in ichthyoplankton.

Hydrographic variations

Average densities of organisms in the 3 hydrographic ecotopes are shown in Table 2. Densities of fish eggs and ichthyoplankton by number were highest in ECS, moderate in KUR, and lowest in MIX. The ratio of the densities of ichthyoplankton between the ecotopes was approximately 2 for KUR/MIX and ECS/KUR. Results of the analysis of variance indicate that the differences among hydrographic ecotopes were significant for fish eggs and for ichthyoplankton. The above pattern was also found in densities by weight for fish eggs, ichthyoplankton, and zooplankton.

Results from analysis of variance on the densities also indicate that there was no statistical significance in specific hydrographic ecotopes during a specific season, except in the density of zooplankton by weight; density of zooplankton was relatively high in ECS during autumn. Cross correlations among the 5 density measurements of fish eggs, ichthyoplankton, and zooplankton are shown in Table 3. Densities of fish eggs and ichthyoplankton by number were statistically correlated at the 5% significance level, while the densities by weight were significantly correlated among fish eggs, ichthyoplanktons and zooplankton at the 1% level.

Species composition

A total of 59 789 individuals belonging to at least 124 families and 547 species or species groups were collected in the 4-yr study. The major ichthyoplankton comprised 60.05% by weight of the collections. *Benthosema pterotum* was most abun-

Table 2. Seasonal and hydrographic variations of densities of fish eggs, ichthyoplankton, and zooplankton in the waters off northeastern Taiwan, 1989-1992

		Sample	Density (no./1000 m^3)		Density (g/1000 m^3)		.
		size	Fish eggs	Ichthy.	Fish eggs	Ichthy.	Zoopl.
Season							
Spring	(Mean)	33	627	394	0.854	1.302	81.645
	(Std)		115	70	0.150	0.196	18.483
Summer	(Mean)	197	849	522	0.486	1.431	145.660
	(Std)		178	42	0.065	0.116	10.190
Autumn	(Mean)	76	240	452	0.343	1.583	241.067
	(Std)		30	54	0.051	0.262	34.775
Winter	(Mean)	21	12	78	0.029	0.374	33.511
	(Std)		3	11	0.006	0.078	3.376
Seasonal difference							
	(F-ratio)		2.669	2.718	5.736	1.111	6.559
	(p-value)		0.048	0.045	0.001	0.344	< 0.001
Hydrographic ecotope							
ECS	(Mean)	226	839	563	0.576	1.617	187.905
	(Std)		156	39	0.060	0.116	13.879
MIX	(Mean)	26	86	150	0.188	0.520	48.863
	(Std)		32	33	0.085	0.116	8.780
KUR	(Mean)	75	194	274	0.207	0.987	89.030
	(Std)		40	41	0.054	0.206	17.119
Ecotopic difference							
	(F-ratio)		4.363	10.706	8.240	4.835	6.752
	(p-value)		0.014	< 0.001	< 0.001	0.009	0.001

dant species, accounting for 19.12% of the total catch. It occurred in 78.3% of the tows and all year round. The 2nd most abundant species group was *Auxis* spp. (2 species) which accounted for 4.95% of the total catch. This species group occurred in 70.0% of the total tows. The 3rd most abundant species group was *Decapterus* spp. (7 species) which accounted for 3.54% of the total catch and occurred in 69.4% of the total tows. The 4th most abundant species was *Priacanthus macracanthus* (2.22%), which is common in the coastal area north of Taiwan, and was found in 46.2% of the total tows. The last mentioned 3 species or species groups are important for fisheries and occurred mainly in May-September. The 5th most abundant species was *Vinciguerria nimbaria* comprising 1.84% of the total catch and found in 52.9% of the total tows. These 5 major species or species groups account for 31.67% of the total catch.

Seasonal variations

In spring, 274 species and species groups were identified and the most abundant were *Decapterus* spp. (14.01%), *Auxis* spp. (6.23%), *Benthosema pterotum* (5.90%), *Priacanthus macracanthus* (3.97%), and *Scomber australasicus* (3.57%). In summer, 375 species and species groups were found and were dominated by *Auxis* spp. (6.91%), *B. pterotum* (5.80%), *P. macracanthus* (2.79%), *Mene maculata* (2.75%), and *Thunnus obesus* (2.62%). Gobiids (4.58%) were also abundant in this season but most of them are difficult to identify to the generic level. In autumn, among the 239 species and species groups recorded, the most dominant ones were *B. pterotum* (55.23%), *Synagrops* sp. (3.17%), *Encrasicholina punctifer* (2.55%), *Nibea albiflora* (2.09%), and *Champsodon snyderi* (1.97%). Gobiids (4.14%) were also abundant in this season. In winter 131 species and species groups (much fewer than in other seasons) were identified with the dominant species being *B. pterotum* (15.35%), *Gonostoma gracile* (7.48%), *Diaphus* spp. (7.31%), *V. nimbaria* (4.39%), and *Myctophum orientale* (2.85%).

Hydrographic variations

In ECS, 332 species and species groups were identified, with an abundance of *B. pterotum* (22.98%), *Auxis* spp. (5.11%), *P. macracanthus* (2.49%), *M. maculata* (2.03%), and *Decapterus* spp. (1.78%). Gobiids (4.20%) were also abundant. In MIX, 203 species or species groups were identified, which is considerably fewer than in ECS or KUR. The dominant species or species groups were *Decapterus* spp. (28.60%), *Auxis* spp. (7.10%), *B. pterotum* (6.18%), *Scomber australasicus* (5.27%) and *Diaphus* spp. (4.43%). In KUR, 338 species and species groups were identified with the dominant species being *B. pterotum* (5.61%), *V. nimbaria* (4.43%), *Diaphus* spp. (3.94%), *Auxis* spp. (3.20%), and *Cyclothone* spp. (3.07%).

Species associations

Seven clusters of ichthyoplankton species and species groups were identified by the UPGMA method (Fig. 3), although naming of these clusters is semi-arbitrary. Cluster 1, represented by *Trachinocephalus myops*, is characterized by less season-hydrographic variation. Cluster 2 is identified as a summer-offshore (MIX+KUR) species group represented by *Diaphus* spp. Cluster 3 is formed by winter species, such as *Gonostoma gracile* and *Vinciguerria nimbaria*. Cluster 4 consists of autumn-winter species dominated by *Benthosema pterotum*. Clusters 5 and 6 are principally composed of spring-summer species, of which the former contains mainly spring species, while the latter contains the summer species.

Table 3. Correlation among densities of fish eggs, ichthyoplankton, and zooplankton in the waters off northeastern Taiwan 1989-1992 (above the diagonal, correlation coefficient (*r*); below the diagonal, *p*-value)

	Density (no./1000 m^3)		Density (g/1000 m^3)		.
Density measurement	Fish eggs (1)	Ichthy. (2)	Fish eggs (3)	Ichthy. (4)	Zoopl. (5)
(1)		0.119	0.798	0.084	0.070
(2)	0.032		0.204	0.753	0.393
(3)	< 0.001	< 0.001		0.181	0.212
(4)	0.131	< 0.001	0.001		0.463
(5)	0.207	< 0.001	< 0.001	< 0.001	

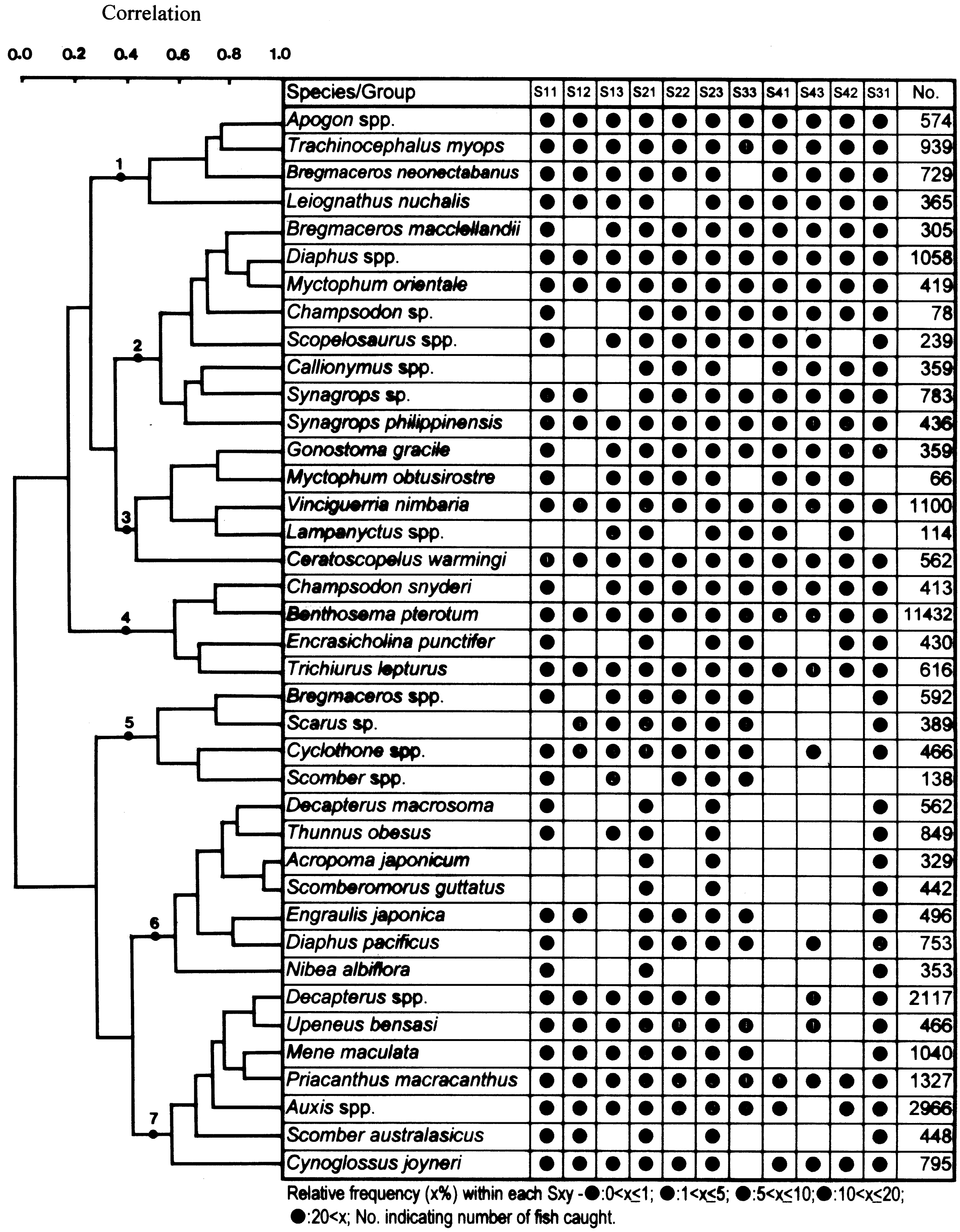

Fig. 3. Dendrograms depicting the correlations of ichthyoplankton species in the waters off northeastern Taiwan, 1989-1992. Sxy denotes category in x season and y hydrographic ecotope; x: 1 - spring, 2 - summer, 3 - autumn, 4 - winter; y: 1 - East China Sea (ECS), 2 - mixing water (MIX), 3 - Kuroshio (KUR), for example S11 represents spring in ECS.

Cluster 7 is composed of species which occurred primarily in spring and summer but extended into autumn and winter. The components of this group are species of commercial fishery importance including *Decapterus* spp., *Auxis* spp, *Priacanthus macracanthus*, and *Scomber australasicus*.

DISCUSSION

Density

The data obtained in this study are from a 4-yr (1989-1992) oceanographic investigation of the northeastern waters of Taiwan. Due to constraints of weather conditions, year-round data were not available. But, seasonal and hydrographic variations in densities of fish eggs, ichthyoplankton, and zooplankton were detectable (Table 2).

The seasonality of fish eggs and ichthyoplankton indicate that the density by number followed the pattern of being lowest in winter, increasing in spring, being highest in summer, and declining in autumn (Table 2). This seasonal pattern corresponds with that of the weather conditions and the process of water exchange in the northeast of Taiwan. Seasonal changes in the physical environment indicate that in ECS the water becomes stratified in summer and vertically well mixed in winter due to the stirring of the strong northeasterly monsoon (Chern and Wang 1989). The stirring of ECS water is also linked to the seasonal surface intrusion of the Kuroshio onto the ECS shelf, which begins in mid-October, 1 mo after the wind pattern changes from southerly to northeasterly (Tang and Yang 1993, Chuang and Liang 1994). After the onset of the winter monsoon, several hydrographic events occurred: in MIX the nitrate concentration of surface water increased from 11 to 13 μM; in the vicinity of the MIX area the surface water cooled to 19 °C; and in the ECS the water column became destratified (Liu et al. 1993). During the same period the loading of nitrate in the ECS shelf water also increased due to vertical mixing and horizontal diffusion from MIX. However, the elevated nitrate level does not benefit the growth of phytoplankton in winter (Chen 1994); probably the water temperature is still too low. In mid-April, the northeast wind reverses due to warm air from the south, the Kuroshio intrusion stops, the ECS water warms up (Chuang and Liang 1994), and accordingly the chlorophyll-a concentration increases (Chen 1994). The ECS water is still well mixed in May and the stratification of ECS water is not re-established until summer (Chern and Wang 1989). The seasonality of ichthyoplankton obtained in this study showed a parallel trend of establishing stratified water in the ECS area; summer stratified water corresponds to maximal densities in number of fish eggs and ichthyoplankton (Table 2). The stratification of ECS water maintaining a stable environment is especially important for the recruitment of shelf species, such as *Priacanthus macracanthus*, *Mene maculata*, and *Engraulis japonica*.

The densities by weight of fish eggs, ichthyoplankton, and zooplankton from the waters off northeastern Taiwan are generally correlated (Table 3); however seasonal variations were found in fish eggs and zooplankton, but not in ichthyoplankton (Table 2). Fish eggs had the highest density by weight in spring, while they were highest by number in summer, suggesting a difference in species composition (Fig. 3). Seasonality of ichthyoplankton density by weight was not detected as compared to seasonal variations in the density by number. The explanation for these different patterns is complex, because the species composition shifted from spring (*Decapterus* spp., *Auxis* spp., *Priacanthus macracanthus*, and *Scomber australasicus*) to autumn (*Benthosema pterotum*, gobiids and *Synagrops* sp.) (Fig. 3). Seasonal changes in zooplankton biomass were significant, doubling each season from winter to autumn (Table 2). In this study, although seasonality was detected in densities of fish eggs, ichthyoplankton, and zooplankton, the magnitude of variation is apparently lower than that estimated in middle latitudes (Tait 1981).

The densities of fish eggs and ichthyoplankton measured by number reveal a pattern with the highest in ECS, a moderate value in KUR, and lowest in MIX (Table 2). The density ratio of ichthyoplankton almost doubled from MIX to KUR, and from KUR to ECS. This spatial variation is comparable to those observed by other studies, such as a low value in MIX of zooplankton (Tseng 1994) and ichthyoplankton abundance (Chiu 1992, Yeh 1992), ichthyoplankton density (Chiu 1991a), and hydroacoustic biomass (Chu et al. 1993). Different patterns were also observed by others, such as high values of nutrients (Wong et al. 1991, Chen 1992), chlorophyll-a (Chen 1992), and zooplankton concentration (Chen and Chen 1992), and better quality of zooplankton production (Chen and Chen 1992) in MIX. The MIX environment does not favor the growth of ichthyoplankton populations since the water is unstable (Chern et al. 1990) and low in dissolved oxygen (Wong et al. 1991). During the formation of an eddy in MIX, a large fraction of subsurface Kuroshio water flows into the area due to sharp bending of the Kuroshio north of Taiwan (Chern et al. 1990). The flow is supported by internal tidal motion and causes an unstable turbulent mixing (Chern and Wang 1990). Lobel and Robinson (1988) reported a similar cold-core eddy occurring on the coast of Hawaii where zooplankton were most concentrated at the eddy center while larval fishes were most abundant in the periphery. All these data show that ichthyoplankton abundance is generally relatively low at the center of water exchange (MIX).

Species composition

The water off northeast Taiwan is a major fishing ground for neritic fisheries (Anony. 1970-1992). The results of this study are consistent with the pattern of fishery catches. More than 40% of the species (16 in 39, at least) are economically important in Taiwan. These include *Decapterus* spp., *Engraulis japonica*, *Mene maculata*, *Priacanthus macracanthus*, *Scarus* sp., *Auxis* spp., *Scomberomorus guttatus*, *Thunnus obesus*, *Nibea albiflora, and Trichiurus lepturus*. The occurrence of an ichthyoplankton assemblage is linked to the reproductive ecology of the adults and subsequent survival of larvae. In the spring-summer period, since the ECS water has experienced a turbulent winter mixing, the enriched water is suitable for the growth of phytoplankton and zooplankton which are essential to feed economically important fish species. However, this water is not suitable for oceanic species because during this period the Kuroshio intrusion stops and the supply of oceanic fish larvae ceases. The spawning of most commercially important species, such as *Decapterus* spp., *Auxis* spp, *Priacanthus macracanthus*, and *Scomber australasicus* (group 7 of Fig. 3) should have evolved a seasonal timing mechanism by which the appearance of their larvae overlaps the seasonal plankton bloom. The ichthyoplankton seasonality found in this study supports the 'match-mismatch' hypothesis (Cushing 1990) which explains the size of fish recruitment. An annual production cycle of organisms is common in temperate areas, but subtle in tropical-subtropical areas (Tait 1981). Seasonal changes of ichthyoplankton occur not only in quantity (Table 2) but also in composition and diversity in the waters off northeastern Taiwan. Temperature is critical for the development of temperate marine phytoplankton and zooplankton populations or communities (Tait 1981). Since the water temperature in the study area is not as critical in restricting plankton development as stated by Tait (1981), a stable ocean and enriched water mass may play a more important role in the success of larval production and recruitment of important commercial species in the waters off northeastern Taiwan.

Hydrographic variation in the ichthyoplankton assemblage was observed in the waters off northeastern Taiwan. In total the ECS had almost an equal number of ichthyoplankton species to that of KUR (332 vs. 338), but significantly more than that of MIX (203). Three types of geographic distribution are discernible in the current data. Among the 547 species and species groups with season-hydrographic categorization, 36 species and species groups (6.6%) show the trend of ECS > MIX > KUR in abundance. These include primarily *Apogon notatus*, *Arnoglossus* spp., *Engyprosopon* spp., *Decapterus maruadsi*, *Selar crumenophthalmus*, gobiids, *L. affinis*, *Auxis* spp., *Euthynnus affinis*, *Saurida elongata*, *Synodus variegatus*, and *Trachioncephalus myops*. A much smaller fraction of species and species groups (1.3%) exhibits the trend of KUR > MIX > ECS, such as *Xyrichthys dea*, *Parophidion schmidti*, *Scopelarchus analis*, *Argyropelecus hemigymnus*, and *Sternoptyx diaphana*. Some species and species groups (3.8%) were most abundant in MIX: *Decapterus* spp., *Trachurus* sp., *Conger* sp., *Gnathophis nystromi*, *Hirundichthys oxycephalus*, *Margrethia obtusirostra*, *Valenciennellus tripunctulatus*, *Hygophum* sp., *Notoscopelus resplendens*, and *Polyipnus* sp.

The MIX water is formed by the subsurface Kuroshio water upwelling in the area approximately centered at 25.5°N and 122.5°E (Chern and Wang 1990, Chern et al. 1990, Lin et al. 1992). It evidently exists year round and is stable due to bottom topography (Liu et al. 1992b); an associated ecotope should therefore also exist. This ecotope is characterized by low temperature and high salinity (Chern and Wong 1990), being under-saturated in oxygen and enriched in nitrate (Liu et al. 1992b), with high chlorophyll-a (Chen 1992) and high zooplankton concentrations (Chen and Chen 1992). In our study, the highest densities of ichthyoplankton were found in the northwestern corner of the KEEP region (Fig. 1; Chiu 1991a, Yeh 1992), rather than in the core of MIX. A few scarce species were unique to MIX; i.e., ichthyoplankton species were either linked with ECS or KUR (Chen and Chiu 1992). In this work, we further demonstrate that ichthyoplankton found in the well-defined MIX water are more closely related to those in ECS than to those in KUR in the spring-early summer group and more closely related to those in the Kuroshio in the summer-early autumn group (Fig. 3).

Acknowledgments: We thank Ms. K.Z. Chang for discussion of ichthyoplankton identification and constructive help in specimen cataloging, and all crew members of the R.V. "Ocean Research 1" and R.V. "Hai-fu" for their assistance in sampling at sea. We extend our thanks to Dr. C.T. Shih of the Canadian Museum of Nature for kindly reviewing this manuscript. Comments from 2 anonymous referees are also appreciated. This study was partially funded by the National Science Council, Republic of China (grant No. NSC83-0209-M002-026-K) for research support.

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臺灣東北黑潮邊緣交換區浮游魚類密度及組成之季節及水文變異

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我們用取自臺灣東北海域的 14 次航海 327 個採樣（1989 年 6 月至 1992 年 9 月），來說明此區域浮游魚類的密度及組成受季節及水文因素所產生之變動。

一般而言，浮游魚類密度在此區域之變化循此形式變動：冬季密度最低，春季漸增，夏季達到最高，及秋季漸減。浮游魚類在三個水文生態區之平均密度顯示：東海陸棚水最高，黑潮水其次，及混合水最低。本試驗的四年中，共檢視了 59 789 尾魚，它們至少屬於 124 科的 547 物種。若以每個採樣多於 1% 的物種定為主要種，則主要種約佔 60%，且此主要種相對於季節及水文生態相均有差異。在春季主要種為 *Decapterus* spp. (14.01%) 及 *Auxis* spp. (6.23%)；在夏季為 *Auxis* spp. (6.91%)及 *Benthosema pterotum* (5.80%)；在秋季為 *B. pterotum* (55.23%)， gobiids (4.14%)及 *Synagrops* sp. (3.17%)；及在冬季為 *B. pterotum* (15.35%)及 *Gonostoma gracile* (7.48%)。在三個水文生態區之主要種分別為：在東海陸棚水 *B. pterotum* (22.98%)及 *Auxis* spp. (5.11%)，在混合水 *Decapterus* spp. (28.60%)及 *Auxis* spp. (7.10%)，及在黑潮水 *B. pterotum* (5.61%)及 *Vinciguerria nimbaria* (4.43%)。用聚類分析所得之樹狀圖顯示七個關聯物種群，此物種群可分別用季節－水文區為特性加以說明。

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