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# A Preliminary Analysis of Ichthyoplankton on the Kuroshio Edge Exchange Area

TAI-SHENG CHIU

*Department of Zoology*
*National Taiwan University*
*#1 Roosevelt Road, Sec. 4*
*Taipei 10764, Taiwan*

## Abstract

Ichthyoplankton in the water column off northeastern Taiwan in the Kuroshio edge exchange area was sampled by round-mouthed ichthyoplankton net in June 1989 to understand the ichthyoplankton community structure and its linkage with the Kuroshio edge exchange process.

The distribution of ichthyoplankton exhibited a pattern of: a) high density in the northwest near the East China Sea; b) low density in the southern area of the Kuroshio Current proper; and c) moderate density in the intermediate area. Canonical correlation analysis indicated a significant correlation between hydrological and biological factors.

## Introduction

The offshore waters of northeastern Taiwan generally come from two origins: the East China Sea (midshelf origin) and the Kuroshio (oceanic origin) (Chern and Wang 1989). The area is one of the most productive neritic fishing grounds in Taiwan (Anon. 1988). However, basic biological and environmental information of this area is rare (Tan and Chen 1975; Huang 1985; Huang et al. 1985).

Ichthyoplankton surveys in the northwestern Pacific for fishery development and management have been routinely made in Japan for many years, but in Taiwan similar surveys were not launched until very recently except for cruises by Hu (1974a, 1974b). Since knowledge of the life history of pelagic fish, both at early and adult stages, and their habitats is vital to the reasonable utilization of the resources, such surveys are becoming necessary.

The present survey is part of a large integrated project, the Kuroshio Edge Exchange Process (KEEP). The KEEP study area covers the area between 122°E-123°30'E and 25°N-26°30'N. This presentation is primarily concerned with the distribution of fish eggs and ichthyoplankton and wet weight of total zooplankton.

## Materials and Methods

The study area was demarcated by the latitudes between 121°30'E and 123°15'E and the longitudes between 25°30'N and 26°N, and consisted of two types of marine topography: the continental shelf and the continental slope. The ichthyoplankton survey was conducted in 5-6 June 1989, as part of Cruise 212 of R/V Ocean Research I, Institute of Oceanography, National Taiwan University. The sampling stations were designed to represent a 15-minute square each (Fig. 1). This area roughly met with the predetermined KEEP area with a minor adjustment on specific sampling sites. Ichthyoplankton were sampled 24 hours a day. Information on the location of each sampling station is presented in Table 1.

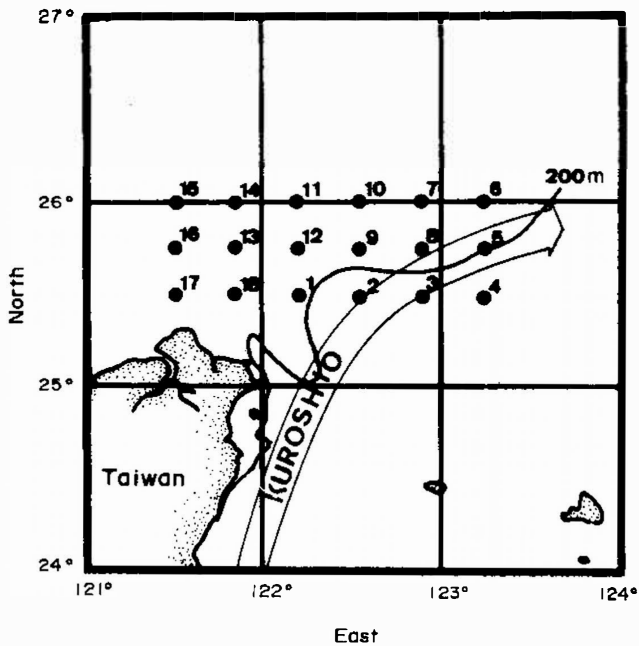


Fig. 1. Sampling stations in the ichthyoplankton survey in waters off northeastern Taiwan, 5-6 June 1989.

Table 1. Physical data on the ichthyoplankton survey.

| Station | Position Lat.;Long. | Date M/D/YY | Time HHMM | Depth (m) | Temperature (°C) |
|---|---|---|---|---|---|
| 1 | 25°30'N;122°12'E | 6/5/89 | 0407 | 127 | 22.1 |
| 2 | 25°30'N;122°33'E | 6/5/89 | 0605 | 298 | 25.3 |
| 3 | 25°30'N;122°54'E | 6/5/89 | 0900 | 1,091 | 27.1 |
| 4 | 25°30'N;123°15'E | 6/5/89 | 1040 | 847 | 27.7 |
| 5 | 25°45'N;123°15'E | 6/5/89 | 1228 | 133 | 27.3 |
| 6 | 26°00'N;123°15'E | 6/5/89 | 1418 | 126 | 27.1 |
| 7 | 26°00'N;122°54'E | 6/5/89 | 1624 | 105 | 26.3 |
| 8 | 25°45'N;122°54'E | 6/5/89 | 1755 | 131 | 27.3 |
| 9 | 25°45'N;122°33'E | 6/5/89 | 2010 | 111 | 23.9 |
| 10 | 26°00'N;122°33'E | 6/5/89 | 2112 | 108 | 24.2 |
| 11 | 26°00'N;122°12'E | 6/5/89 | 2315 | 110 | 24.3 |
| 12 | 25°45'N;122°12'E | 6/5/89 | 0048 | 127 | 23.5 |
| 13 | 25°45'N;121°50'E | 6/6/89 | 0242 | 132 | 25.1 |
| 14 | 26°00'N;121°50'E | 6/6/89 | 0424 | 110 | 25.5 |
| 15 | 26°00'N;121°30'E | 6/6/89 | 0620 | 72 | 25.4 |
| 16 | 25°45'N;121°30'E | 6/6/89 | 0748 | 76 | 25.0 |
| 17 | 25°30'N;121°30'E | 6/6/89 | 0938 | 118 | 25.4 |
| 18 | 25°30'N;121°50'E | 6/6/89 | 1140 | 131 | 26.1 |

Sampling gear was a round-mouthed ichthyoplankton net (Chiu and Liu 1989) with a mouth opening of 1.3 m diameter, a conical net 4 m long, and mesh size of 1.0 mm. A rubber bucket was fitted at the end of the net for collecting organisms. The net was weighted with a 25 kg depressor and the wire released at a rate of 0.5 m·sec$^{-1}$. The net was towed approximately at a ship speed of 2.0 knots and retrieved at a rate of 0.3 m·sec$^{-1}$. Sampling depth range was about 200 m or within 10 m from the bottom at shallower depths to the surface. Bottom depth was determined by an echosounder (Simrad EK500). The depth reached by the net was estimated approximately by the length of wire released and the angle of wire. A hydrological flowmeter (Hydro-Bios Kiel) was mounted in the center of the mouth of the net to estimate water volume filtered. Hydrological profiles of the water column were drawn based on data collected by electronic sensors attached to a Conductivity Temperature Depth Profiler (CTD) (SBE 9/11, Sea-Bird Electronic).

Samples were fixed *in situ* with 10% formalin in seawater and sorted upon return. The ichthyoplankton catches were eggs or larval or juvenile fish plus incidental zooplankton. Before detailed identification and body measurement, they were counted under a binocular microscope and weighed with an electric balance. The counts and weights were converted to density according to flowmeter readings following the method described by Kendall and Dunn (1985).

There were 10 standardized hydrological factors (variables): 1) bottom depth; 2), 3), 4) water temperature at surface, -50 m and -100 m (or bottom when depth < 100), respectively; 5), 6) water salinity at surface and -50 m; 7), 8) water fluorescence at surface and -50 m; 9), 10) dissolved oxygen at -20 m and -100 m; and five density factors (log(x+1) transformed); 11) numerical density of fish eggs; 12) numerical density of ichthyoplankton; 13) density of fish eggs in weight; 14) density of ichthyoplankton in weight; 15) density of zooplankton in weight. All factors were subjected to canonical correlation analysis.

## Results

### *Hydrological Factors*

Depth of the sampling sites ranged from 72 to 1,091 m. Stations 2, 3 and 4 were located beyond the continental shelf. (Fig. 1).

Surface temperature of the sampling sites ranged from 22.1 to 27.3°C (Fig. 2). The fluctuation of surface temperature was parallel to solar radiation with a higher magnitude around noon (about 27°C) and a lower magnitude from midnight to dawn (<24°C). The temperature at depths of 50 and 100 m in the sampling sites ranged from 19.6 to 26.4°C and from 15.5 to 24.7°C, respectively. Water temperatures at greater depth were generally shown to have a parallel trend with the magnitude of surface temperature except for minor variations at Stations 6, 7, 10 and 11 (Fig. 2). In Stations 1-4 and 12-18, thermal radiation from the surface to the deeper zone was homogenous, but a thermocline was present at a depth range of 50-100 m at Stations 6-7. A shallower thermocline was found at a depth range of 0-50 m at Stations 10-11.

Salinities at the surface and at 50 m depth were 33.8-34.5 ppt and 34.1-34.7 ppt, respectively (Fig. 2). Surface waters generally had lower salinity than subsurface waters, except at Station 4 at the outer edge of the sampling area.

The dissolved oxygen contents at 20 and 100 m depths were 4.93-5.28 $ml \cdot l^{-1}$ and 4.27-5.00 $ml \cdot l^{-1}$, respectively (Fig. 2).

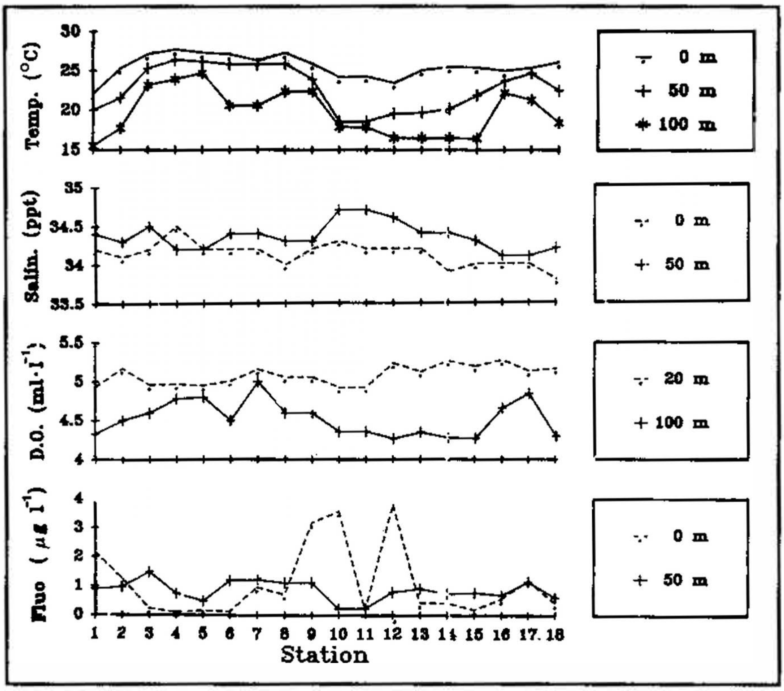


Fig. 2. Station specified line graph indicating water temperature (0, -50, -100 m); salinity (0, -50 m); dissolved oxygen (-20, -100 m); and fluorescence (0, -50 m).

Fluorescence indices showed an irregular trend (Fig. 2). The index at the surface layer and at 50 m depth was 0.1-3.8 $\mu g \cdot l^{-1}$ and 0.22-1.47 $\mu g \cdot l^{-1}$, respectively. A high index of surface fluorescence was recorded at Stations 9, 10 and 12.

### *Density Distribution Patterns* (Table 2)

The density of fish eggs for each sampling station ranged between 0 and 31,765 eggs/1,000 $m^3$. Two patches were found with their centers located at Stations 2 (24,113 eggs/1,000 $m^3$) and 15 (31,765 eggs/1,000 $m^3$), respectively.

The density of ichthyoplankton was 242-19,649 individuals/1,000 $m^3$ with a patchy distribution peaking at Station 15 where dense fish eggs were also recorded. The concentric ichthyoplankton distribution around Station 15 might indicate a dispersion of fishes centrifugally.

Table 2. Densities of fish eggs, fishes and incidental zooplankton at each sampling site.

| Station | Water filtered ($m^3$) | Fish eggs (No.) | Fish eggs (wt.,g) | Ichthyoplankton (No.) | Ichthyoplankton (wt.,g) | Zooplankton (wt.,g) |
|---|---|---|---|---|---|---|
| | Density (/1,000 $m^3$) | | | | | |
| 1 | 406 | 246 | 0.17 | 242 | 0.72 | 113.15 |
| 2 | 323 | 24,113 | 7.05 | 632 | 0.69 | 80.58 |
| 3 | 353 | 51 | 0.06 | 263 | 0.35 | 68.50 |
| 4 | 390 | 778 | 0.50 | 1,047 | 1.34 | 108.18 |
| 5 | 223 | 117 | 0.13 | 686 | 0.73 | 110.04 |
| 6 | 427 | 2,088 | 1.13 | 267 | 0.41 | 171.64 |
| 7 | 790 | 65 | 0.08 | 332 | 0.43 | 0.62 |
| 8 | 207 | 0 | 0.00 | 1,497 | 1.62 | 2.63 |
| 9 | 289 | 470 | 0.33 | 550 | 1.55 | 67.85 |
| 10 | 291 | 0 | 0.00 | 1,395 | 2.92 | 198.44 |
| 11 | 240 | 309 | 0.17 | 521 | 1.06 | 144.69 |
| 12 | 395 | 0 | 0.00 | 1,059 | 1.30 | 330.49 |
| 13 | 235 | 111 | 0.10 | 1,876 | 2.62 | 269.44 |
| 14 | 202 | 1,001 | 0.60 | 10,202 | 11.69 | 503.10 |
| 15 | 129 | 31,765 | 22.68 | 19,649 | 25.04 | 2,126.92 |
| 16 | 136 | 530 | 1.16 | 13,812 | 18.98 | 1,591.16 |
| 17 | 199 | 476 | 0.68 | 8,202 | 6.34 | 658.45 |
| 18 | 181 | 491 | 0.42 | 2,241 | 2.61 | 267.95 |

Total biomass of fish eggs was 0-22.68 g/1,000 $m^3$, the highest centered around Stations 2 (7.05 g/1,000 $m^3$) and 15 (22.68 g/1,000 $m^3$). Eggs from Station 15 had highest average biomass.

Biomass of ichthyoplankton was 0.35-25.04 g/1,000 $m^3$ with the same pattern as measured by numbers of fish.

Biomass of total zooplankton taken was 0.62-2,127 g/1,000 $m^3$ with highest density at Station 15, where dense ichthyoplankton also occurred.

Density isopleth diagrams of fish eggs in Figs. 3-4 show a similar pattern. The steepest peak came from the northwestern corner and the relief axis bends in a northeasterly direction as the gradient drops due to the southern flushing. Another radiation axis pushes in a northerly direction. The dilution effect from the south resulted in low density of eggs in the area defined by 25.5°N-26°N and 122°E-123°E. The second and the third minor concentrations were found at 25.2°N, 122.5°E and 26.2°N, 123.2°e, respectively. The minor centers were influenced by minor water masses from the coastal zone of a nearby small island.

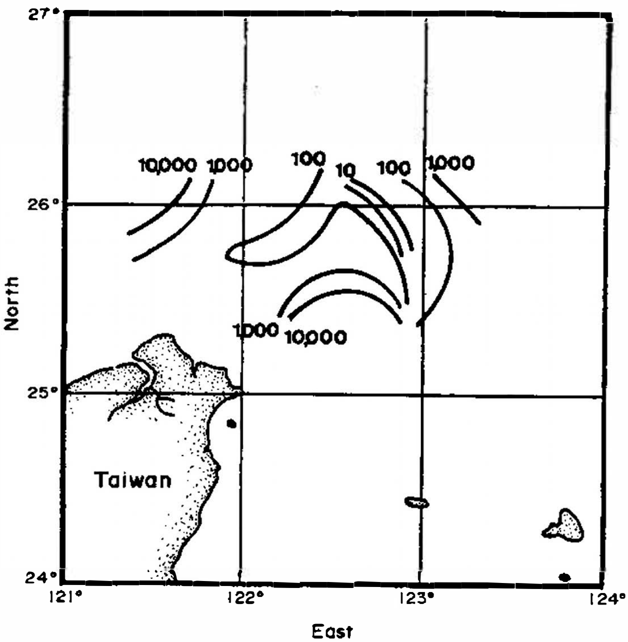


Fig. 3. Isopleth diagram of the counts of fish eggs (eggs/1,000 m$^3$).

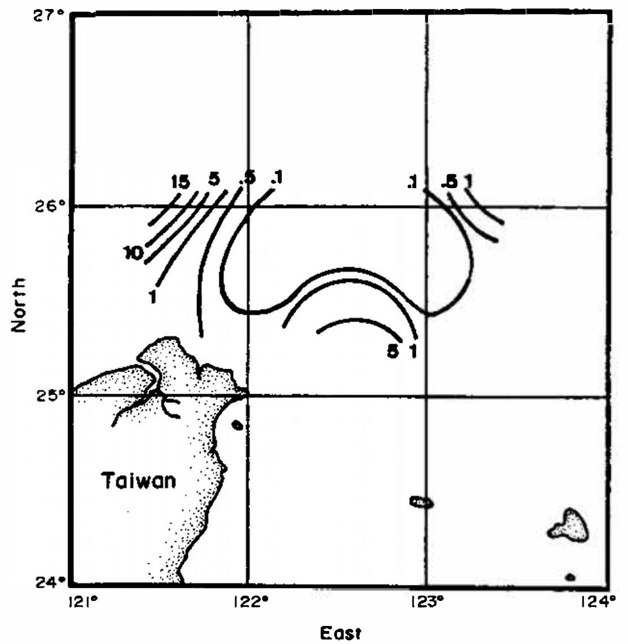


Fig. 4. Isopleth diagram of the biomass of fish eggs (g/1,000 m$^3$).

Isopleth diagrams of fishes are shown in Figs. 5 and 6 for counts and weights of ichthyoplankton, respectively. These two diagrams also have a similar pattern. The steepest peak came from the northwestern corner and the relief axis first pointed southeast, then around 25.5°N 122.5°E, the 500 contour line was intersected by the Kuroshio Current, which pushed the 1,000 contour line northeasterly and finally pulled the 500 contour line away from the study area toward the Japanese coastal zone.

The isopleth diagram of zooplankton as indicated by biomass (Fig. 7) shows a major concentration at the northwestern corner. The dilution effect of the Kuroshio Current is apparent in the area of 25.5°N-26°N and 122°E-123°E. A high density at the eastern side of the studied area suggests that the influence of the Kuroshio Current as indicated by density of invertebrates was marginal compared to its effect on the pattern of ichthyoplankton.

### *Canonical Correlation Analysis*

The 15 factors were subjected to canonical correlation analysis. The first canonical axis collected 31.7% of the total variance, the

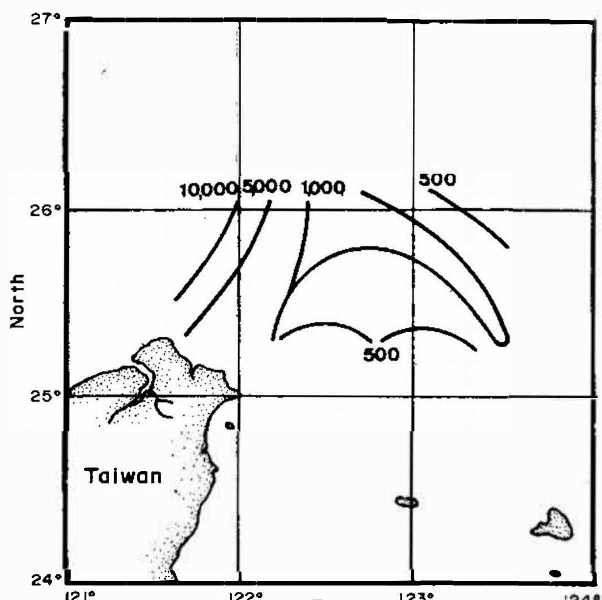


Fig. 5. Isopleth diagram of the counts of ichthyoplankton (inds/1,000 $m^3$).

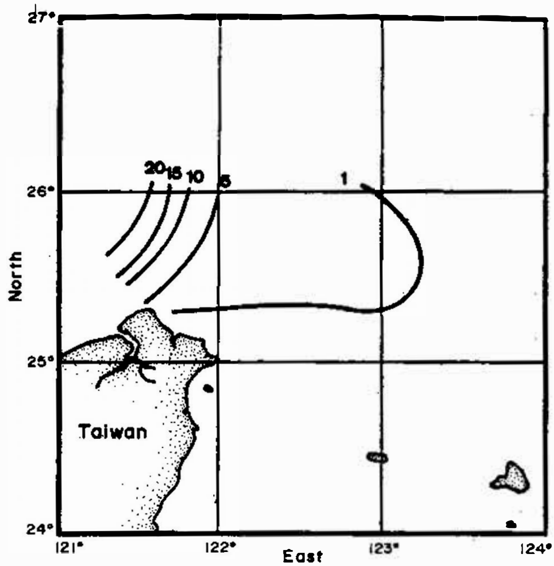


Fig. 6. Isopleth diagram of the biomass of ichthyoplankton (g/1,000 $m^3$).

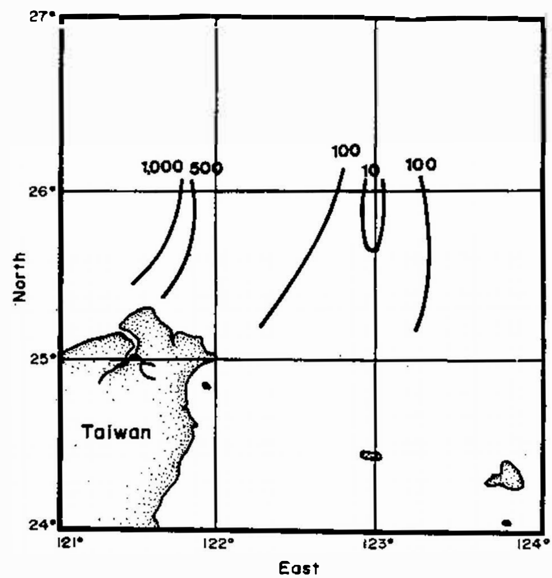


Fig. 7. Isopleth diagram of the biomass of zooplankton (g/1,000 $m^3$).

second; 26.1% and the third, 22.8%. The canonical correlations and their loadings are shown in Table 3. The first three canonical scores indicate a significant correlation between hydrographic factors and density measures (R=0.920, 0.835 and 0.781, respectively).

Table 3. Canonical correlations and loadings.

| Variables | Canonical variate 1 | 2 | 3 |
|---|---|---|---|
| Set 1 (hydrographic factors) | | | |
| depth | -0.013 | 0.362 | 0.043 |
| 0 m temp. | 0.690 | -1.619 | -1.043 |
| 50 m temp. | -0.879 | 2.468 | -0.427 |
| 100 m temp. | -0.046 | -1.334 | 1.208 |
| 0 m salinity | -0.147 | 0.019 | 0.374 |
| 50 m salinity | -0.756 | 0.415 | -0.347 |
| 0 m fluor. | 0.060 | -1.229 | -0.548 |
| 50 m fluor. | -0.089 | -0.517 | -0.072 |
| 20 m DO | 0.317 | 0.085 | 0.383 |
| 100 m DO | 0.286 | 0.207 | -1.067 |
| Set 2 (density measures) | | | |
| eggs in number | 0.589 | 1.144 | -0.065 |
| fish in number | 2.598 | -1.533 | -1.274 |
| eggs in weight | -0.198 | -0.435 | -0.225 |
| fish in weight | -1.747 | 1.712 | 1.224 |
| invert. weight | -0.280 | -0.527 | 1.015 |
| Canonical correlations | 0.920 | 0.835 | 0.781 |

## Discussion

The Kuroshio edge exchange area has two types of marine topography, continental shelf and continental slope. The latter leads to an abyss several thousand meters deep. The northward flowing Kuroshio Current confronts shallower neritic waters of the East China Sea. Therefore, a complex marine process occurs in the northeastern waters of Taiwan. Some of the processes caused by water compression include eddy currents and local upwelling (Fang 1980). Although these two expectations remain to be verified, this area, an important commercial fishing ground (Huang 1986), is worth a thorough study for fisheries management purposes.

Comparison of the results from this preliminary study with similar efforts in this area is not possible since some relevant data are still not available. Tseng (1970) reported his zooplankton survey in this area, but no abundance data were given. Irie and Yamaji (1970) described the distribution of zooplankton biomass in the Kuroshio and adjacent regions. Their diagram generally depicted double concentric contours; one from the East China Sea and the other from the coast of Honchu, Japan. In this study, we cannot prove a highly productive upwelling area (Fang 1980; Chern and Wang 1989), but a zone of mixing waters in the area around Stations 8, 9 and 12 (Figs. 3-7) can be inferred.

Hydrographic conditions are considered the major factors governing the distribution pattern of passive moving plankton. The density measures of this study indicate a significant correlation with their hydrographic environments (Table 3). Therefore, further study of ichthyoplankton distribution in the Kuroshio edge exchange area may be useful to understand marine processes such as upwelling, convergence and eddies.

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