Variation of Ichthyoplankton Density Across the Kuroshio Edge Exchange Area with Implications as to the Water Masses

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ABSTRACT

Ichthyoplankton in a water column off north-eastern Taiwan, an area referred to as the Kuroshio edge exchange area, was sampled using a conical ichthyoplankton net on board R/V Ocean Research I. The purpose of this survey was to understand the ichthyoplankton community structure and its linkage with the Kuroshio edge exchange process. This preliminary analysis illustrates the spatial density distribution of fish eggs, ichthyoplankton and an incidental catch of zooplankton. Biological densities and their linkage with the hydrological variables were also analyzed.

The principle findings include: 1) that the distribution of ichthyoplankton densities exhibited a consensus pattern of high density in a northwesterly direction near the East China Sea, low density in the southern area of the Kuroshio current proper and moderately high densities in the shore area and 2) that principal component analysis based on hydrological and biological variables produces a clear picture that discriminates between the water mass of mid-shelf origin and those of oceanic origin. Station specific variation of the hydrological variables is also discussed.

1. INTRODUCTION

In the offshore area of north-eastern Taiwan, the waters generally come from two origins; one from the East China Sea (mid-shelf origin) and the other from the Kuroshio (oceanic origin) (Chern and Wang, 1989). This is known to be one of the most productive neritic fishing grounds in Taiwan (Anon., 1988), however, basic biological and environmental information for this area is still very rare.

Ichthyoplankton surveys in the northwestern Pacific for the purpose of fishery development and management have been conducted routinely in Japan for many years (Anon., 1978-1982). However, in Taiwan similar ichthyoplankton

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surveys and life history studies were not launched until very recently. Those studies were by Hu (1974a,b) and Tan and Chen (1975) in the South China Sea; Chen (1985), Huang (1985) and Huang *et al.* (1985) in the coastal waters of Taiwan; and Chiu and Liu (1989) in the eastern waters of Taiwan.

The present study is part of a large integral project (the Kuroshio Edge Exchange Process, KEEP) aimed at realization of the Kuroshio edge exchange process. This presentation is primarily concerned with the density distribution of fish eggs, fish larvae and incidentally caught zooplankton. Variation of ichthyoplankton abundance and incidental hydrological information are valuable for determination of marine processes involved.

2. MATERIALS AND METHODS

The Area

The study area is demarcated by latitudes between 121°30′E and 123°15′E and longitudes between 25°30′N and 26°N. It consists of two types of marine topography, the continental shelf and the continental slope.

The Survey

The present ichthyoplankton survey was conducted during June 5–6, 1989, as part of cruise No. 212 of the R/V Ocean Research I. The sampling stations were designed to represent a distance 15 latitudinal or longitudinal minutes apart (Fig. 1). The sampling range roughly met with the pre-determined KEEP studying area with minor adjustments for specific sampling sites. Ichthyoplankton sampling was conducted 24-hours a day. Information on the location of each sampling station is presented in Table 1.

The sampling gear used in this study for collection of the fish eggs and ichthyoplankton was a 4-m conical net with a mouth opening of 1.3 m (details see Chiu and Liu, 1989). The mesh size of the ichthyoplankton net was 1.0 mm. During sampling, the net was first released at a rate of 40 $m/min.$, thereafter the ship was kept at a speed of approximately 2.0 *knots*, and the net was retrieved at a rate of 20 m/min. The net was towed at about 200 m in depth or within 10 m of the bottom. A hydrological flowmeter was mounted in the center of the mouth of the ichthyoplankton net to estimate the volume of water filtered. Hydrological profiles of temperature, salinity, dissolved oxygen and total fluorescence were measured by in situ sensors attached to a CTD (SBE 9/11, Sea-Bird Electronic, Inc.).

Data analysis

Samples taken were fixed on board with 10% formalin in sea water, and then sorted upon return. All larval or early juvenile fishes were removed for

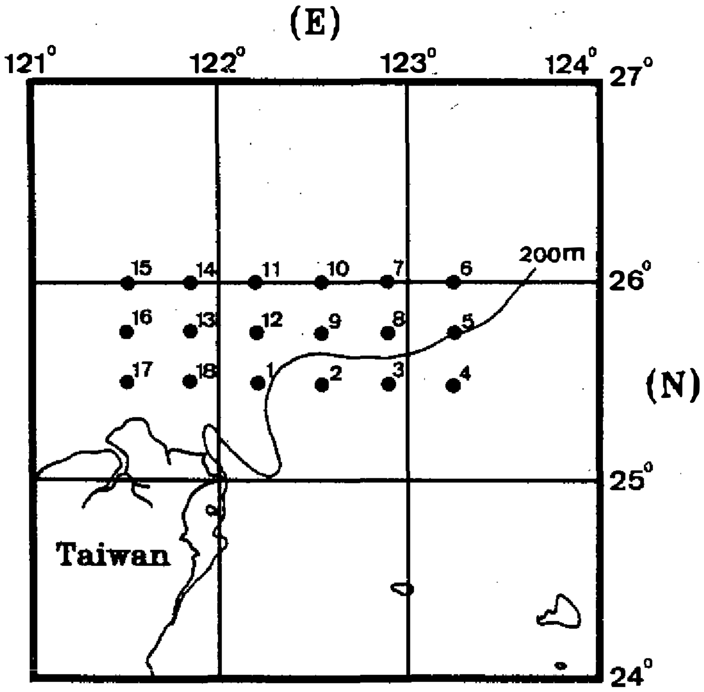

Fig. 1. Sampling stations in the ichthyoplankton survey in the waters off north-eastern Taiwan, June 5–6, 1989.

Table 1. Basic background information for ichthyoplankton samplings.

Station	Position Lat.;Long.	Date *mm/dd/yy*	Time *hhmm*	Depth (*m*)
1	25°30′*N*; 122°12′*E*	06/05/89	0407	127
2	25°30′*N*; 122°33′*E*	06/05/89	0605	298
3	25°30′*N*; 122°54′*E*	06/05/89	0900	1091
4	25°30′*N*; 123°15′*E*	06/05/89	1040	847
5	25°45′*N*; 123°15′*E*	06/05/89	1228	133
6	26°00′*N*; 123°15′*E*	06/05/89	1418	126
7	26°00′*N*; 122°54′*E*	06/05/89	1624	105
8	25°45′*N*; 122°54′*E*	06/05/89	1755	131
9	25°45′*N*; 122°33′*E*	06/05/89	2010	111
10	26°00′*N*; 122°33′*E*	06/05/89	2112	108
11	26°00′*N*; 122°12′*E*	06/05/89	2315	110
12	25°45′*N*; 122°12′*E*	06/05/89	0048	127
13	25°45′*N*; 121°50′*E*	06/06/89	0242	132
14	26°00′*N*; 121°50′*E*	06/06/89	0424	110
15	26°00′*N*; 121°30′*E*	06/06/89	0620	72
16	25°45′*N*; 121°30′*E*	06/06/89	0748	76
17	25°30′*N*; 121°30′*E*	06/06/89	0938	118
18	25°30′*N*; 121°50′*E*	06/06/89	1140	131

further study. Those larvae and juveniles are termed ichthyoplankton. Incidentally caught invertebrate are termed macro-zooplankton (zooplankton for short). Before detailed identification and body measurement, fish eggs, ichthyoplankton, and zooplankton were counted under binoculars and weighed with an electric balance. The count and weight was converted to density according to the readings of the flowmeter following the method described by Kendall and Dunn (1985).

Fifteen variables in this study were subjected to principal component analysis. Those variables were: 1) density of the number of fish eggs; 2) density of the number of ichthyoplankton; 3) density of fish eggs by weight; 4) density of ichthyoplankton by weight; 5) density of zooplankton by weight; 6) bottom depth; 7), 8) and 9) water temperature at surface, at -50 *m*, and at -100 *m* (or bottom temperature when shallower than 100 *m*), respectively; 10) and 11) water salinity at the surface and at -50 *m*; 12) and 13) apparent total fluorescence value (in relative units) at the surface and at -50 *m*; 14) and 15) apparent dissolved oxygen value (relative units) at -50 *m* and -100 *m* respectively. These item numbers shall be referred to as variable numbers hereafter. Among these variables, variables 1 and 3 were removed during selection of the final model due to their low correlation with the other variables.

3. RESULTS

(1) Hydrological Variables

Bottom Depth

The bottom depth of the sample sites ranged from 72 *m* to 1,091 *m*. Stations 2, 3, and 4 were located beyond the continental shelf. A 200 *m* isobathic contour passed through the south-eastern corner of the rectangular study area (Fig. 1). The shallower north-western side had depths of 72 *m* and 76 *m* for Stations 15 and 16, respectively (Table 1).

Temperature and Salinity

The surface temperature of the sampling sites ranged from 22.1°*C* to 27.3°*C*. The fluctuation of the surface temperature paralleled with solar radiation with higher magnitudes found around noon (about 27°*C*) and a lower magnitudes from mid-night to dawn (lower than 24°*C*). Some temperature variation might also be due to the specific water mass, but in this case the primary contributing variable for surface temperature variation was diurnal. The water temperature at a depth of 50 *m* and at a depth of 100 *m* for the sample sites ranged from 19.6°*C* to 26.4°*C* and from 15.5°*C* to 24.7°*C*, respectively. The water temperature at greater depths was generally shown to have a parallel trend with the magnitude of the surface temperature, i.e. higher surface temperature indicated a higher sub-surface temperature except for minor variations at Stations 6, 7, 10, and 11. From Stations 1 to 4, thermal radiation from the surface down was quite homogenous but a thermocline developed at a depth from 50 $\sim$ 100 *m* at Stations 6 and 7, while a reverse temperature distribution occurred at Stations 8 and 9. A shallower thermocline was found at a depth ranging from 0 $\sim$ 50 *m* at Stations 10 and 11. At Stations 12-18, a homogeneous water temperature distribution was found.

The salinity at the surface to a 50 *m* depth, ranged from 33.8‰ to 34.5‰ and from 34.1‰ to 34.7‰, respectively. Surface waters generally had lower salinity than sub-surface waters did, except at Station 4 which was located at the outer edge of the sampling area.

The T-S curves from stations on the first transet line across the Kuroshio edge exchange area are shown in Fig. 2. The water around Stations 3 and 4, where the continental shelf located and their T-S curves merge, could be treated as the Kuroshio proper. At Stations 17 and 18 the sea water density was lower than that of Stations 3 and 4. The water of Stations 17 and 18 could be treated as of shelf origin. The T-S curves of Stations 1 and 2 was located between Stations 3 and 4 and Stations 17 and 18. Therefore the waters of Stations 1 and 2 could be categorized as a mix of the Kuroshio and the shelf waters. At Stations 1 and 2 when the depth was greater than 200 *m*, the water properties were closer to those of the Kuroshio.

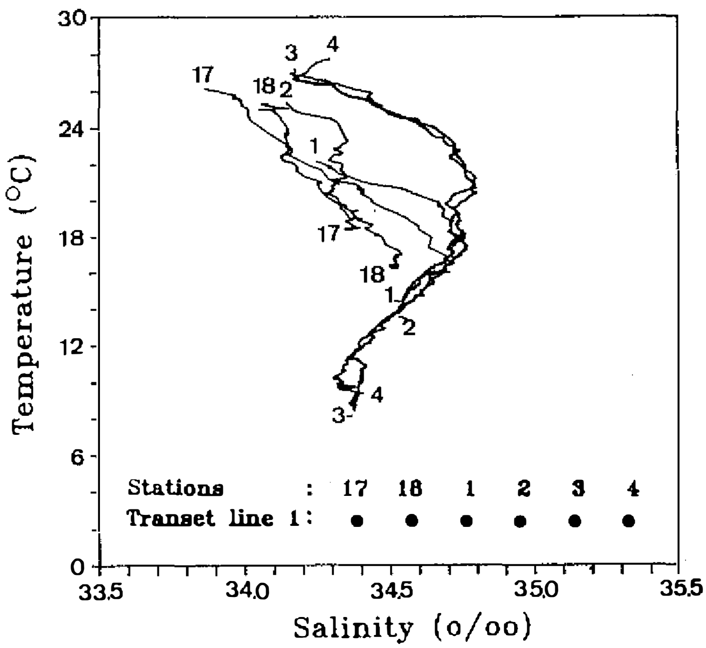

Fig. 2. The relationship between temperature and salinity of the waters from stations of transet line 1.

The T-S curves for stations on the second transet line are shown in Fig. 3. All stations on this transet line are located on the continental shelf. These curves were aligned in a sequence from the shelf toward the slope. Water from Stations 5, 8 and 9 has a pattern of T-S curves similar to that of Stations 3 and 4 when the water temperature is greater than 17° *C*. Water from Stations 5, 8 and 9 can be recognized as water that came from the Kuroshio. Water from the upper layer of Stations 12, 13 and 16 is similar and should be categorized as from the shelf. On the other hand, water on the lower layer of Station 12 had an intermediate salinity between that of the Kuroshio and the shelf. The phenomenon of water mass mixing on the lower water layer at Station 12 can be inferred.

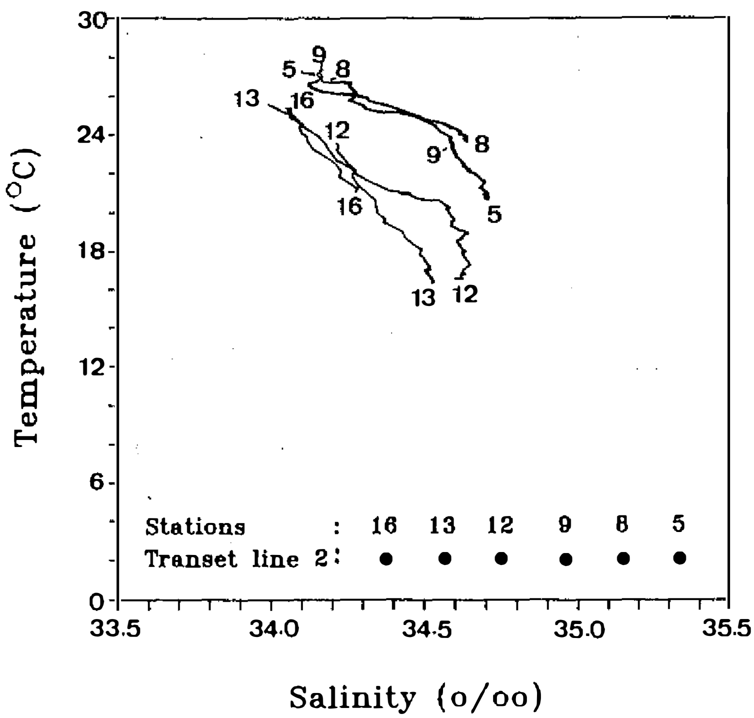

Fig. 3. The relationship between temperature and salinity of the waters from stations of transet line 2.

The T-S curves for stations from the third transet line are shown in Fig. 4. All stations on this transet line are located on the continental shelf. These T-S curves were aligned in an in-shelf-off-shelf sequence. The waters of Stations 14 and 15 were representative of the shelf water and those of Stations 6 and 7 of the Kuroshio. The lower water layer of Stations 10 and 11 converged. On the other hand, the upper limb of the T-S curves for Stations 10 and 11 exhibited intermediate properties between those of the shelf and the Kuroshio. Therefore, water mixing on the upper layer of Stations 10 and 11 can be inferred.

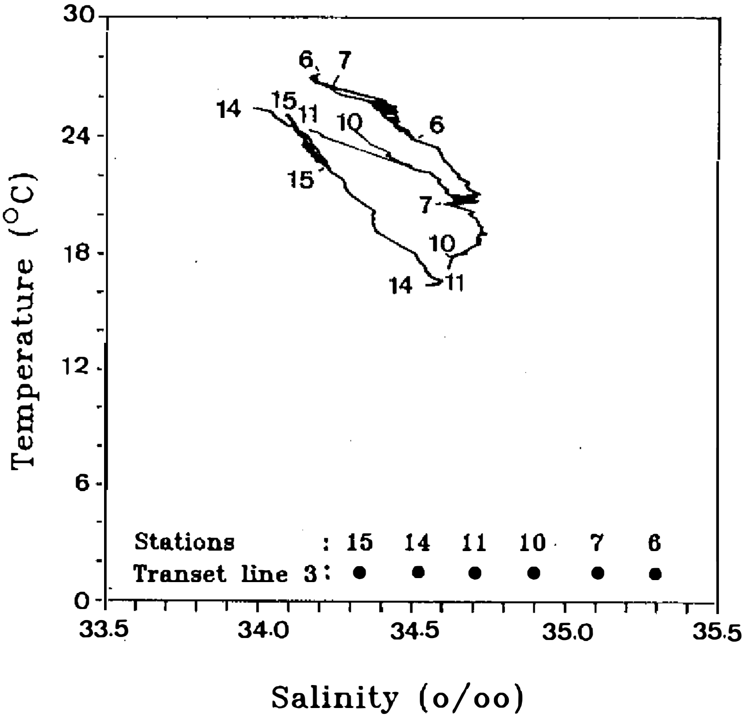

Fig. 4. The relationship between temperature and salinity of the waters from stations of transet line 3.

(2) Density Distribution Patterns

Individual Densities

The density of the number of fish eggs from each sampling station ranged from 0 to 31,765 $eggs/1,000\ m^3$ (Table 2). Two patches were found with fish eggs, and their centers located at Stations 2 (24,133 $eggs/1,000\ m^3$) and 15 (31,764 $eggs/1000\ m^3$), respectively. No eggs were found at Stations 8, 10 and 12, suggesting a high patchiness. The general pattern found was that a high density distribution occurred in the waters of mid-shelf origin (on the north-western side) and a low one in waters of oceanic origin.

The density of ichthyoplankton from 18 sampling stations ranged between 242 and 19,649 $inds/1,000\ m^3$. The ichthyoplankton density indicated also a patchy distribution peaking at Station 15, where densely distributed fish eggs were also recorded. A concentric ichthyoplankton distribution around Station 15 might indicate a centrifugal dispersion of fish. The ichthyoplankton density was significantly higher on the north-western side (mid-shelf origin) than the south-eastern side (oceanic origin). When the distribution of ichthyoplankton was compared with that of fish eggs, it was found that the distribution of eggs was less even. In addition, no zero catches for ichthyoplankton were ever

Table 2. Density of fish egg, fish larva and incidentally caught zooplankton.

St.	Depth (m)	Density in number per 1,000 m^3		Density in weight (g) per 1,000 m^3		
		eggs	larvae	eggs	larvae	zooplankton
1	127	246	242	0.17	0.72	113.15
2	298	24113	632	7.05	0.69	80.58
3	1091	51	263	0.06	0.35	68.50
4	847	778	1047	0.50	1.34	108.18
5	133	117	686	0.13	0.73	110.04
6	126	2088	267	1.13	0.41	171.64
7	105	65	332	0.08	0.43	0.62
8	131	0	1497	0.00	1.62	2.63
9	111	470	550	0.33	1.55	67.85
10	108	0	1395	0.00	2.92	198.44
11	110	309	521	0.17	1.06	144.69
12	127	0	1059	0.00	1.30	330.49
13	132	111	1876	0.10	2.62	269.44
14	110	1001	10202	0.60	11.69	503.10
15	72	31765	19649	22.68	25.04	2126.92
16	76	530	13812	1.16	18.98	1591.16
17	118	476	8202	0.68	6.34	658.45
18	131	491	2241	0.42	2.61	267.95

observed at any sampling station. Therefore, a drift of ichthyoplankton during their ontogenic process can be inferred.

Density of the Biomass

The total fish egg biomass in the specified sample sites ranged from 0 to 22.68 $g/1,000\ m^3$ (Table 2). Two patches centered around Station 2 (7.05 $g/1,000\ m^3$) and 15 (22.68 $g/1,000\ m^3$), were found that were composed of eggs from two different origins as described by density measured by individual counts. Additionally, those eggs from Station 15 had a higher average individual biomass.

The ichthyoplankton biomass from the 18 sampling stations ranged from 0.35 to 25.04 $g/1,000\ m^3$. The ichthyoplankton distribution pattern indicated by its biomass was similar to that measured by the total fish count, i.e. a general distribution pattern with high density in the waters of mid-shelf origin and lower in those of oceanic origin was again indicated.

The station specific biomass for all zooplankton taken by the ichthyoplankton sampling gauge ranged from 0.62 to 2,126.92 $g/1,000\ m^3$. The highest zooplankton density measured from the biomass depicted a patchy distribution at Station 15, where dense ichthyoplankton also occurred. This concentric zooplankton distribution around Station 15 might indicate a dispersion of zooplankton due to eddy convection.

(3) The Isopleth Density Diagram

The isopleth density diagrams of fish egg by weight are shown in Fig. 5. This pattern indicates that the steepest peak comes from the northwestern corner. The isopleth line relief axis bends in a northeasterly direction as the gradient drops. The southern flushing from the Kuroshio caused the density drop. Another radiation axis pointed in a northerly direction. The dilution effect from this southern flushing resulted in sparsly distributed eggs of a density as low as 0.1 $g/1,000\ m^3$ in the area between $25.5°N \sim 26°N$ and $122°E \sim 123°E$. The second and the third minor concentrations were found at $25°N$, $122.5°E$ and $26.5°N$, $123.5°E$, respectively. These minor centers were influenced by water masses from coastal zones in the neighborhood of small islands.

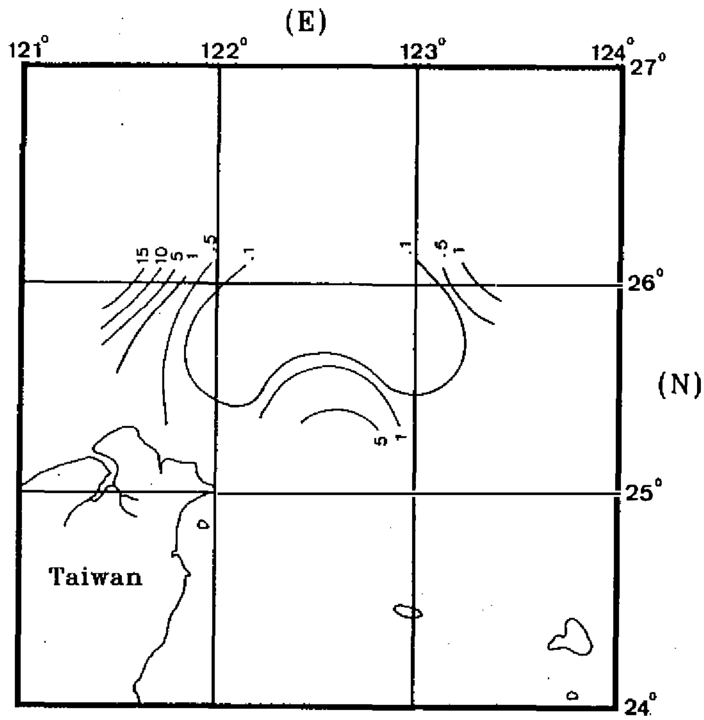

Fig. 5. Isopleth diagram of fish egg measured in $g/1,000\ m^3$. A higher density contour toward the East China sea was found. In addition, A dilution effect of the Kuroshio was apparent around $26°N$, $122°30'E$.

The isopleth diagrams of the number of larval fishes are shown in Fig. 6. A similar pattern is also seen for weight density. Its peak is in the northwestern corner and the relief axis points first toward the southeast, and then around $25.5°N$ and $122.5°E$, the contour representing 500 $inds/1,000\ m^3$ was intersected by the Kuroshio current. The Kuroshio current pushed the contour line

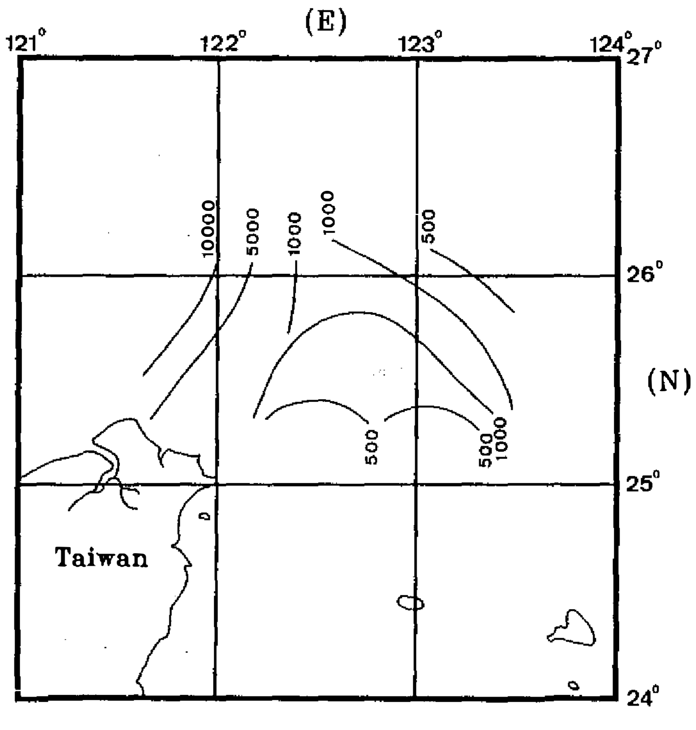

Fig. 6. Isopleth diagram of ichthyoplankton measured in $inds/1,000\ m^3$. A higher density contour toward the East China sea was found. In addition, A dilution effect of the Kuroshio was apparent around $26°N$, $122°30'E$. The Kuroshio pull the isopleth contour of $1,000\ inds/1,000\ m^3$ toward the direction of Japan.

of $1,000\ inds/1,000\ m^3$ north-easterly and finally pulled the $500\ inds/1,000\ m^3$ contour line away from the study area in the direction of the Japanese coastal zone.

The isopleth diagram of incidentally caught zooplankton as indicated by the biomass is shown in Fig. 7. One major concentration occurred in the north-western corner. The dilution effect of the Kuroshio current was apparent in the area of $25.5°N \sim 26°N$ and $122°E \sim 123°E$. A high density on the eastern side of the study area was found to be as much as $100\ g/1,000\ m^3$. Apparently the dilution effect of the Kuroshio current to the density of zooplankton was marginal when compared to the ichthyoplankton pattern.

(4) Principal Component Analysis

Thirteen valid variables were subjected to a final principal component analysis. The first two indicated a variance of 35.8% and 29.4%. Variable loading of these first two principal component axes are illustrated in Fig. 8. An apparent reverse tendency can be traced to the magnitude of water temperature

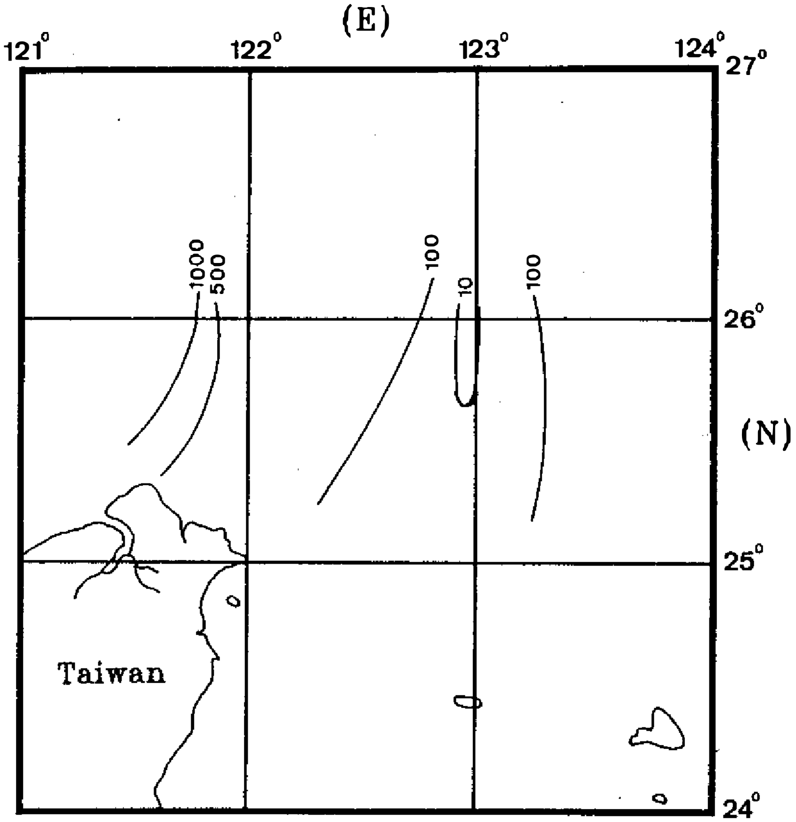

Fig. 7. Isopleth diagram of zooplankton measured in $g/1,000\ m^3$. A higher density contour toward the East China sea can also be found. In addition, the dilution effect of the Kuroshio was apparent.

at $-100\ m$ (variable 9) and density scores of ichthyoplankton and zooplankton (variables 2, 4, and 5). The position of the stations for the first two principal component axes is shown in Fig. 9. This scatter plot of sampling stations exhibites a straight line alignment, which indicates a good relationship between the first two principal component scores. In this diagram the lower-left of the coordinate system implies attributes of the Kuroshio proper (Stations 1, 2, 3, 4, 5, 6, 7, 8 and 9). In keeping with this major tendency, the distance away from the lower-left corresponds to a decreasing trend of the Kuroshio influence. Therefore, those stations scored law with the principal component system indicating that their elements (variables) came from the Kuroshio. On the other hand, the higher scores came from water of East China Sea origin (Stations 14, 15, 16, 17 and 18) and these modest scores indicated a mixture of two type of waters (Stations 10, 11, 12 and 13). This combination of biological and environmental data can therefore be useful as a tool to define water origin and probably vice versa.

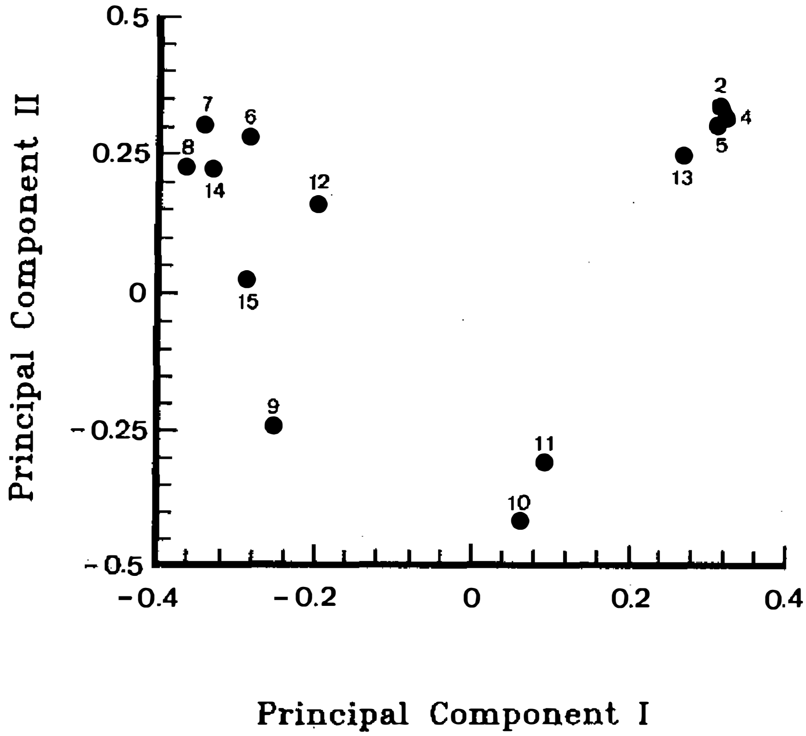

Fig. 8. Weights of 13 selected variables on the first two principal component axes. Those coded variables are: 1) density of fish eggs in number; 2) density of ichthyoplankton in number; 3) density of fish eggs in weight; 4) density of ichthyoplankton in weight; 5) density of zooplankton in weight; 6) bottom depth; 7), 8), 9) water temperature at surface, -50 *m*, and -100 *m* respectively; 10), 11) water salinity at surface and -50 *m*; 12) and 13) apparent total fluorescence value at surface and -50 *m*; 14) and 15) apparent dissolved oxygen value at -50 *m* and 100 *m*. Among those variables variable 1 and variable 3 have been deleted due to lower correlation with the other variables. The first two principal components collected 35.8% and 29.4% variance. An apparent reverse tendency can be traced on the water temperature at -100 *m* (variable 9) and gathering of ichthyoplankton and zooplankton (variables 2, 4, and 5).

4. DISCUSSION

The Kuroshio edge exchange area has two types of marine topography, continental shelf and continental slope. The latter emerges from the shelf boundary leading to an abyss of several thousand meters in depth. The shallow shelf bottom and coastal water forces the Kuroshio water off its straight course paralleling the eastern coast of Taiwan thus forming a convergence with marine waters. Consequently due to this convergence there may occur a biological cosmopolitan area. In addition, the compression of sea water may cause eddy currents forming a local upwelling (Fang, 1980). These two expectations still

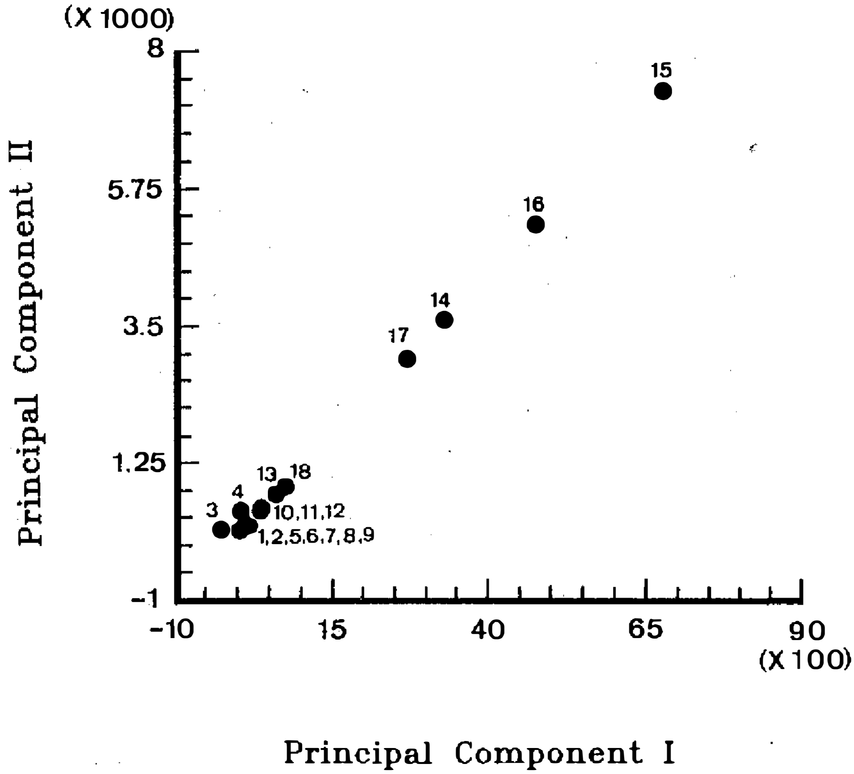

Fig. 9. Plot of stations on the first two principal component axes by linear combination of 13 biological and environmental variables. An alignment of stations on a straight line indicated a good relation between the first two PC scores and the distance away from the Kuroshio influence. The highest scores are depicted by the water of the East China Sea origin, the modest scores are indicated by the mixture of two type of waters.

remained to be thoroughly verified. On the other hand, the fact that this area is an important commercial fishing ground (Huang, 1986), makes it worthwhile to undertake further studies from the viewpoint of fishery management.

Comparison of results from this preliminary study with similar attempts in this area are not possible since some relevant data are still not available. Tseng (1970) reported a zooplankton survey for this area but the distribution was made through specific occurrence with no abundance estimation, which handicaps the contrast of oceanic and mid-shelf attributes. Irie and Yamaji (1970) described the distribution of the zooplankton biomass in the Kuroshio and adjacent regions. Their diagrams generally depict double concentric contours; one for the East China Sea and the other for coastal areas of Honchu, Japan. Tzeng (1988) quoted Uda's (1960) generalized oceanographic features for interpretation of mackerel fishing grounds, where surface coastal waters from both the East China Sea and northeastern Taiwan went southeastward, a sub-surface area of highly saline waters went northwestward and therefore an ocean front formed along the shelf-slope boundary. Fang (1980) and Chern and Wang (1989) have made thorough surveys of temperature distributions or T-S diagrams in the northeastern waters off Taiwan and upwelling can be tentatively detected. These temperature profiles were similar to density isoplethes of ichthyoplankton or zooplankton in our study indicating that a non-active mobile or limited mobile article had similar distribution patterns after strong flushing from the Kuroshio current. This preliminary result also agrees with the conclusions of Irie and Yamaji (1970) but with a higher resolution which may point to a local realization on water exchange processes sensu Uda (1960). In fact, the zooplankton distribution pattern of Irie and Yamaji (1970) can be treated as the "big" island supplier to the Kuroshio which distributes those organisms to a wider range of habitats. More examples of the island supplier effect have been illustrated by isopleth diagrams, such as that for ichthyoplankton. From the supplier-distributor point of view, the Kuroshio current has played an important role in the faunal transport of north eastern Pacific fish species.

Principal component analysis is a powerful tool for multiple separation of attributes from different water masses. The author used this method to try to discriminate between water masses of different origins. It appears that discrimination between two water types using principal analysis and T-S curves analysis are equally valid. In this study, those variables for the ichthyoplankton, zooplankton densities and apparent total fluorescence value, which were closely related to primary productivity, can be positively loaded high in the first two principal components. Therefore, these variables were relevant candidates for further water mass identification. The fish eggs density variables were deleted in the scatter plot of the stations owing to their low resolution. The noise tied to the density of eggs is an additional subject for further study. More detailed results and higher resolutions for biological water mass identification still remain for continued elaboration.

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以穿越黑潮邊緣交換區的浮游魚類密度變動暗示不同的水團來源

丘臺生

摘要

臺灣東北海域特性，可被稱爲黑潮交換區。我們使用海研一號以錐形浮游魚類採集網採集浮游魚類，其目地在於瞭解浮游魚類的群社結構及其與黑潮邊緣交換過程的關係。這個初期報告分析了魚卵、浮游魚類及同時捕獲浮游動物的空間密度分布；再以生物的密度及水文資料同時考慮以暗示水團的來源。

主要的結果是： 1) 浮游魚類的密度分布顯示， a) 西北方指向東海陸棚的密度最高， b) 黑潮本體部較低， c) 其間在較接近岸邊的測站爲中等密度； 2) 以生物密度及水文因子所進行的主成分分析，可以清晰地劃分中陸棚水團及外洋水團。