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# Quantity and Quality of Summer Surface Net Zooplankton in the Kuroshio Current-induced Upwelling Northeast of Taiwan

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## ABSTRACT

**This study compares the taxa distribution and biochemical composition of zooplankton from stations in a coastal upwelling caused by the intrusion of the Kuroshio Current into the East China Sea shelf. Surface zooplankton samples were taken during a summer cruise of 1989 from 21 stations using a conical net with a mesh size of 330$\mu$m. In addition to zooplankton taxonomical analysis, biochemical compositions of mixed zooplankton hauls including protein, lipid, ash and lipid classes such as phospholipids, free fatty acids, wax or sterol esters, sterols and triacylglycerides were studied. The results indicate that the copepod-dominant zooplankton biomass responded to the upwelling environment. Stations around the upwelling site showed markedly reduced water temperature, increased $NO_3$-N, chlorophyll a and zooplankton concentrations. Zooplankton samples from the upwelled water contained higher proportions of protein and lipid and lower ash content than those from non-upwelling areas. Higher free fatty acid level and lower phospholipid level were also observed in samples from upwelled water. These results suggest an enhancement in upwelling region of zooplankton production in both quantity and quality. Principal component analysis of zooplankton taxa and biochemical composition both indicated the existence of three distinct water masses, that can be related to the Kuroshio Current, the East China Sea continental shelf, and the upwelling. The existence of detritus in the zooplankton samples, which affected the measurement of zooplankton quality and its ecological implications, are discussed.**

## 1. INTRODUCTION

The qualitative and quantitative characteristics of zooplankton populations are greatly influenced by their environments. While seasonal or vertical migration may markedly affect

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zooplankton populations, other factors such as upwelling and various hydrological changes, with the effects of mixing and stabilization, may produce profound changes in the phytoplankton and in turn on the characteristics of the zooplankton populations. The vertical or horizontal transfer and exchange between superficial and subsurface water layers and the movement of water masses may greatly modify both the abundance and the community structure of the zooplankton. Frequently, especially near coasts, the coastal flow is accompanied by changes in vertical circulation patterns. One such example is the upwelling off the northeastern coast of Taiwan caused by the intrusion of the meandering Kuroshio Current into the continental shelf of the East China Sea.

The description by quantitative and qualitative observation is the first indispensable step in the analysis of the relationships between the zooplankton populations and the variations in environmental conditions (Thiriot, 1978). A second step which should be studied simultaneously with the first, is the knowledge of biology, including biochemical composition of zooplankton. Napp *et al.* (1988a,b) used carbohydrate, protein and lipid contents in particulate matters as indicators to assess the quality of marine particles and examined whether the vertical distribution of food quality was distinct from that of food quantity. Our knowledge concerning the production of zooplankton in upwelling waters have almost entirely concentrated on their temporal and spatial variations in terms of biomass and species. But for the growth of predators of the zooplankton in higher trophic levels, not only the quantity but the quality of their foods are important determinants.

Various ecosystem approaches have been used to estimate how much fish can be produced in a particular area such as in an upwelling system. In one approach, Sheldon *et al.* (1972; 1977; 1982) suggested that the biomass of fish in an area can be estimated from the biomass of phytoplankton. If the growth rate of the fish is known, production and the potential yield to the fishery can be calculated. Implicit in this ecosystem approach, however, is the fact that the growth of fish is greatly influenced by their food quality, not just quantity alone. In an ecosystem where water mixing shift between low and high rates of upwelling over time, such as occurs with alternate seasons of high and low production (e. g. summer vs. winter) (Wyatt, 1980), the significant effects of food quality change on fish production over spatial scale become obvious. The upwelling off northeastern Taiwan fits the description given above. The persistence of upwelling regions in a rather local environment is also as important to fisheries as a more global consideration (Parsons *et al.*, 1988). Although the existence of the pronounced Kuroshio Current-induced fronts has been well recognized (Liu, 1983; Wong *et al.*, 1991), apart from the earlier pioneering work by Tan (1970) and Yu and Lee (1970), relatively few studies have been made with the plankton communities as the primary target of investigation.

This study was designed to describe and compare the horizontal distribution, community structure and biochemical composition of zooplankton assemblages from the said area which contains three different marine environments. One assemblage is from the warm oligotrophic Kuroshio Current. The second one is from the continental shelf of the East China Sea. And the last is from the mixing water of the above two water masses. The purpose of this study was to evaluate the quality of zooplankton as food sources for predators and to link the trophic connections between the primary production and fisheries productions. Biochemical composition of the zooplankton was also used as an indicator to evaluate the upwelling processes and the upwelling-induced responses in zooplankton community.

## 2. MATERIALS AND METHODS

### 2.1 Zooplankton samples

Zooplankton samples were collected in 20 predetermined P-Box sampling stations (Figure 1) during the cruise 254 (September 17-22, 1990) of R/V *Ocean Researcher I* (National Science Council, Republic of China). Stations near the 200-m isobath were in the regional upwelling plume, which probably resulted from the Kuroshio Current intrusion onto the continental shelf of the East China Sea (Wong *et al.*, 1991). Neighboring stations were 28.3km apart from each other except stations 512A and 542A which were located at the 200-m isobath. The location and water depth of each sampling station are listed in Table 1.

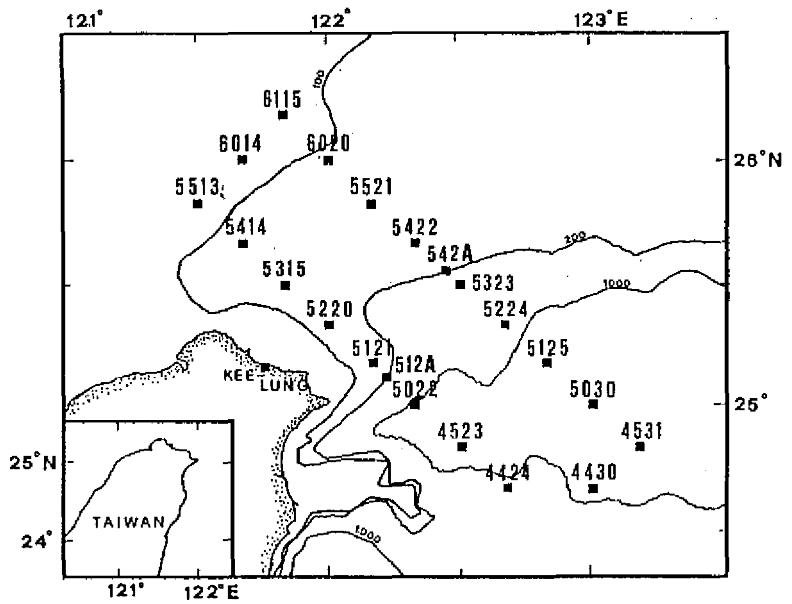


*Fig. 1.* Station locations off northeastern coast of Taiwan with 100m, 200m and 1000m isobaths.

A 4-m conical net with a mouth opening of 1.3m and a mesh size of 330$\mu$m was used to collect zooplankton in a 24-hour a day scheme (Table 1). The net was towed in the upper 0-3m and the mouth opening was kept under surface during cruising. Each tow was conducted for about 10min during which the ship speed was approximately 2 knots. A flowmeter was attached in the mouth of the plankton net to estimate the volume of water filtered. Concurrent hydrological measurements of temperature and related parameters were conducted in situ by a SBE 9/11 CTDP (Sea-Bird Electronics, Bellevue, Washington). Chemical oceanographic and phytoplankton studies were also conducted during the same cruise.

The zooplankton samples were quantitatively subdivided into two unequal portions by a plankton splitter immediately after net retrieval. The small fraction (25%) was preserved with 10% neutralized formalin in sea water. The large fraction (75%) was well-drained, rinsed with a filtered sea water solution containing 6% ammonium formate, packed in plastic bags and quickly frozen at -20°C. The frozen plankton samples were freeze-dried upon return.

Table 1. Location, water depth and plankton net casting time of each sampling station

| Cast No. | Station | Latitude (North) | Longitude (East) | Depth(m) | Time of sampling (hrs) |
|---|---|---|---|---|---|
| 1 | 5022 | 25° 0.0' | 122°20.0' | 1183 | 1700 |
| 2 | 512A | 25° 5.8' | 122°16.7' | 391 | 2140 |
| 3 | 5121 | 25°11.5' | 122°10.8' | 183 | 0010 |
| 4 | 5220 | 25°20.0' | 122° 0.0' | 193 | 0240 |
| 5 | 5315 | 25°30.0' | 121°50.0' | 122 | 0550 |
| 6 | 5414 | 25°40.0' | 121°37.0' | 122 | 0900 |
| 7 | 5513 | 25°50.9' | 121°30.2' | 82 | 1040 |
| 8 | 6014 | 26° 0.0' | 121°40.0' | 110 | 1200 |
| 9 | 6115 | 26°10.4' | 121°50.8' | 106 | 1510 |
| 10 | 6020 | 25°59.5' | 121°59.5' | 104 | 1730 |
| 11 | 5521 | 25°50.0' | 122° 9.0' | 114 | 1930 |
| 12 | 5422 | 25°39.0' | 122°22.0' | 111 | 0050 |
| 13 | 542A | 25°34.4' | 122°24.5' | 220 | 0150 |
| 14 | 5323 | 25°30.0' | 122°30.0' | 424 | 0330 |
| 15 | 5224 | 25°20.9' | 122°40.1' | 776 | 0650 |
| 16 | 5125 | 25° 9.9' | 122°50.3' | 1600 | 0910 |
| 17 | 5030 | 25° 1.0' | 123° 0.0' | 1600 | 1320 |
| 18 | 4531 | 24°50.3' | 123°13.0' | 1726 | 1610 |
| 19 | 4430 | 24°42.4' | 123° 0.0' | 1530 | 2040 |
| 20 | 4424 | 24°40.2' | 122°39.8' | 692 | 2240 |
| 21 | 4523 | 24°51.1' | 122°31.2' | 1450 | 0300 |

## 2.2 Community structure

Zooplankton identification and counting were conducted on the formalin-preserved samples or sub-samples using a dissecting microscope (SZH-ILLD, Olympus Optical Co., Tokyo). The zooplankton were classified into 18 categories (see Table 3). The categories will be referred to as taxa hereafter. The total biomass of zooplankton was estimated from measurements of the wet and dry weights of the frozen sample. Large inorganic particles and filamentous detritus were removed. Plant material and small detritus are a common contaminant of the wet weight/dry weight and chemical composition samples; we were unable to assess their contribution.

## 2.3 Biochemical analyses

Although it is desirable that biochemical analysis is carried out on fresh zooplankton (Raymont, 1983), this was not possible at sea. Samples were deep-frozen and freeze-dried before analysis. Mixed zooplankton hauls were used for biochemical analysis because not a single species nor a group of species is known to exist in the upwelling region and accounts for many of the "special" characteristics associated with the upwelling system. Moreover, it was impossible to sort the samples under a microscope at sea. The purpose of this study was to examine the quality of zooplankton as food sources as a whole; it is, thus, justified to use mixtures of species.

Freeze-dried zooplankton samples were used to determine their protein, lipid and ash contents by the Official Methods of Analysis (AOAC, 1984). A nitrogen-to-protein conversion factor of 6.25 has been employed to demonstrate the order of magnitude of nitrogenous organic material in the sample. The results are expressed as percent of dry weight. Lipid class analysis was conducted according to the method described previously (Chen and Jenn, 1991) using a TLC/FID analyzer (Mark IV, Iatron Co., Tokyo, Japan). The lipids in the subsamples of freeze-dried zooplankton were extracted by the Folch method (Christie, 1982). The separation of lipid classes was performed on Chromarods III. The lipid samples were spotted on the rods in volumes of 0.1$\mu$l and developed with chloroform/methanol/water (70/35/3.5, v/v) for the separation of polar lipids and hexane/ether/formic acid (85/15/0.04, v/v) for neutral lipids. The lipid classes investigated included free fatty acids, phospholipids, wax and sterol esters, sterols and triacylglycerides. Wax esters and sterol esters were grouped as one category because they could not be separated in the solvent system applied. An integrator (CR-3A, Shimadzu Inc., Kyoto, Japan) attached to the chromatograph was used to quantify the analysis. The results of lipid class analysis are expressed as weight percent of total lipid and by means of three repeated analyses.

### 2.4 Statistical analyses

It was necessary to find an objective way to determine how the biochemical composition and taxa distribution of zooplankton were related to other variables, especially, plant biomass (chlorophyll a), seawater nutrient content ($NO_3$-N), or in situ seawater temperature. Principle component analysis (PCA) and stepwise regression were chosen to counter the multiple testing problems. Data of chlorophyll-a distribution and surface seawater temperature and $NO_3$-N measurements (Gong and Liu, 1991) were included in the statistical analyses. PCA was employed to describe the distributions of biochemical compositions and taxa of zooplankton. Stepwise regression was used to extract the relationship between chemical composition and zooplankton taxa as well as environmental variables including seawater temperature and concentrations of chlorophyll a and $NO_3$-N.

## 3. RESULTS

### 3.1 Zooplankton biomass and environmental variables

The distribution of zooplankton biomass (either wet weight or dry weight because they were significantly correlated, r=0.983) appeared to have a consistent relationship with the upwelling process. Stations around the 200-m isobath, such as 5422, 542A, 5323, 5121 512A and 5220 (Figure 1), show markedly reduced water temperature (22.22-25.89°C) and increased $NO_3$-N (0.3-3.8$\mu$mol/L) and chlorophyll a (99-653$\mu$g/L) concentrations (Table 2). The pattern of these environmental variables indicated upwelled water mixing at these stations. Zooplankton biomass was correlated with these upwelling indicators. Stepwise regression analysis indicated significant positive correlations between zooplankton biomass and seawater $NO_3$-N ($r=0.69$, $p<0.01$) and between zooplankton and chlorophyll a concentration ($r=0.59$, $p<0.01$). There was, however, a negative correlation between zooplankton biomass and seawater temperature ($r=-0.67$, $p<0.01$). The results suggest the abundant occurrence of zooplankton in upwelled water where the temperature was low and nutrients were high. Chlorophyll a concentration also increased in response to the upwelling process.

Table 2. Surface water temperature, concentrations of $NO_3$-N[1], chlorophyll a and zooplankton wet biomass for each sampling station

| Station | Temperature (°C) | $NO_3$-N (μmol/L) | Chlorophyll *a* (μg/L) | Zooplankton (mg/m³) |
|---|---|---|---|---|
| 4430 | 27.15 | 0 | 27 | 53.3 |
| 4424 | 26.51 | 0.2 | 27 | 68.4 |
| 4523 | 27.74 | 0.1 | 82 | 69.1 |
| 5022 | 27.08 | 0.2 | 18 | 92.7 |
| 512A | 27.12 | 0.2 | 432 | 272.1 |
| 5121 | 25.89 | 0.6 | 99 | 281.4 |
| 5220 | 25.14 | 0.3 | 401 | 713.0 |
| 5315 | 26.78 | 0.1 | 378 | 107.3 |
| 5414 | 26.67 | 0.2 | 417 | 114.5 |
| 5513 | 26.67 | 0.1 | 277 | 137.5 |
| 6014 | 26.70 | 0 | 301 | 38.0 |
| 6115 | 26.71 | 0.1 | 183 | 175.4 |
| 6020 | 26.93 | 0 | 224 | 440.1 |
| 5521 | 26.91 | 0 | 217 | 217.8 |
| 5422 | 22.94 | 2.5 | 653 | 1318.2 |
| 542A | 22.22 | 3.8 | 620 | 331.8 |
| 5323 | 22.64 | 3.5 | 633 | 1080.2 |
| 5224 | 22.92 | 0 | 77 | 96.0 |
| 5125 | 27.29 | 0 | 82 | 53.5 |
| 5030 | 27.71 | 0 | 93 | 42.5 |
| 4531 | 26.99 | 0 | 33 | 57.6 |

[1] Gong and Liu, 1991

In contrast to the stations in the upwelling area, the stations influenced by the Kuroshio Current, such as stations 5125, 5030, 4531 and 4430 (Figure 1), had oligotrophic water ($NO_3$-N: not detected; chlorophyll a: 27- 93μg/L) and relatively high surface seawater temperature (26.99-27.71°C) (Table 2). Plankton were scarce in these waters. Sea water from the stations influenced by coastal water of the East China Sea, such as stations 5513, 6014, 6115 and 6020 (Figure 1), was of the intermediate type (Table 2) with near zero $NO_3$-N concentrations (0-0.1μmol/L) and higher plankton biomass (chlorophyll a: 183-301μg/L) than the Kuroshio Current stations.

### 3.2 Distribution of zooplankton biomass and individual taxa

Copepods clearly stand out as the most dominant organism. Their median and range of percentage frequency of occurrence in all sampling stations and percentage frequency of occurrence at three representative stations, together with those of other taxa are listed in Table 3. Many taxa were present only in very small numbers or were even absent in many cases. Exceptionally large quantities of radiolarians were collected from stations 5315 (51.4% of all organisms), 5414 (36.7%) and 5513 (49.5%) which were strongly influenced by the shelf coastal water (Figure 1). High percentages of occurrence (7.4-18.4%) of fish eggs were found at stations 4531, 4430, 4424, 4523 and 5022 which were located in the main-stream of the Kuroshio Current. Two other stations (5030 and 5125) also located in the Kuroshio Current, on the other hand, had high occurrences of foraminiferans (30.3% and 10.7%, respectively).

Table 3. Percentage frequency of occurrence (presented as median and range) of zooplankton taxa among all stations and of three representative stations each located at the Kuroshio Current (5030), the East China Sea (5513) and the upwelling mixing water (542A), respectively

| Taxon | Median (%) | Range (%) | Statin 5030 (%) | Station 5513 (%) | Station 542A (%) |
|---|---|---|---|---|---|
| Foraminifera | 1.5 | 0-30.7 | 30.7 | 1.5 | 0 |
| Radiolaria | 0 | 0-51.4 | 1.0 | 49.5 | 0 |
| Medusae | 0 | 0-1.0 | 0 | 0 | 0.3 |
| Chaetognatha | 0.7 | 0-2.2 | 0.7 | 0 | 1.4 |
| Polychaeta | 0 | 0-0.2 | 0 | 0 | 0 |
| Crustacea | | | | | |
| Cladocera | 0.6 | 0-0.1 | 1.0 | 0.2 | 0.7 |
| Ostracods | 0.6 | 0-1.4 | 0.2 | 0 | 0.7 |
| Copepods | 70.7 | 43.7-89.0 | 54.8 | 44.3 | 79.5 |
| Amphipods | 1.3 | 0-6.0 | 1.0 | 0.2 | 5.5 |
| Euphausiids | 0.2 | 0-19.2 | 0 | 0 | 2.1 |
| Mysids | 0 | 0-12.0 | 0 | 0 | 0 |
| Luciferids | 0.5 | 0-3.7 | 0.2 | 0 | 0 |
| Larvae | 0.9 | 0-2.4 | 0 | 0.4 | 1.7 |
| Pteropoda | 1.2 | 0-5.2 | 5.2 | 1.4 | 0 |
| Heteropoda | 0.4 | 0-6.7 | 0.7 | 0 | 0.3 |
| Thalia | 0 | 0-0.2 | 0.2 | 0 | 0 |
| Fish eggs | 5.3 | 0.5-18.4 | 2.5 | 1.7 | 6.2 |
| Others | 0.4 | 0-2.4 | 1.7 | 0.6 | 1.7 |

The distributions of zooplankton taxa, thus, could reflect the existence of different water masses. This impression was confirmed with the PCA of taxa distributions.

The results of PCA of the taxanomic zooplankton data show 34.8% of the variation within the zooplankton community to be accounted for by the first 2 component axes (Table 4). The first axis (PCA 1) is basically accounted for by the variation of copepods, amphipods, decapod larvae, chaetognaths (all positively correlated) and radiolarians (negatively correlated). The second axis describes the variation mainly due to foraminiferans, chaetognaths (positively correlated) and euphausiids (negatively correlated).

Scattering in the plot of PCA 2 against PCA 1 (Figure 2) shows that the 21 stations of taxanomic zooplankton data can roughly be divided into 3 clusters. Cluster A is composed of stations (542A, 5220, 5323, 5521, 512A, 5422 and 5121) in the upwelling region. Cluster B corresponds to stations (5030, 5125, 5224, 5022, 4531, 4523 and 4424) strongly influenced by the Kuroshio Current, whereas stations in Cluster C (6020, 6014, 5513, 5315 and 5414) are on the shelf and are mainly affected by waters from the East China Sea. These results indicate that the zooplankton community in the upwelled water, for example station 542A (see Table 2), had higher percentages of copepods, amphipods, decapod larvae and chaetognaths than those in the coastal water. They also had a higher frequency of occurrence for euphausiids and a lower one for foraminiferans than those in the Kuroshio Current.

Table 4. Correlations between the Principle Component (PCA) scores and the original variables of the zooplankton taxa data.

| Variables | Component axes | |
|---|---|---|
| | PCA1 | PCA2 |
| Foraminifera | -0.2632 | 0.5033 |
| Radiolaria | -0.7984 | -0.2491 |
| Medusae | 0.2629 | 0.3650 |
| Chaetognatha | 0.5188 | 0.6435 |
| Polychaeta | 0.2048 | 0.0709 |
| Crustacea | | |
| Cladocera | 0.3872 | -0.2274 |
| Ostracods | 0.2107 | -0.2463 |
| Copepods | 0.6849 | 0.1427 |
| Amphipods | 0.6583 | -0.3333 |
| Euphausiids | 0.3412 | -0.6449 |
| Mysids | 0.2666 | -0.2975 |
| Luciferids | 0.2376 | 0.2334 |
| Larvae | 0.7479 | -0.4683 |
| Pteropoda | -0.3626 | 0.2459 |
| Heteropoda | -0.4145 | -0.2316 |
| Thalia | 0.0046 | 0.3942 |
| Fish eggs | 0.5488 | 0.4781 |
| Others | 0.1448 | 0.5110 |
| %Variance | 20.07 | 14.72 |

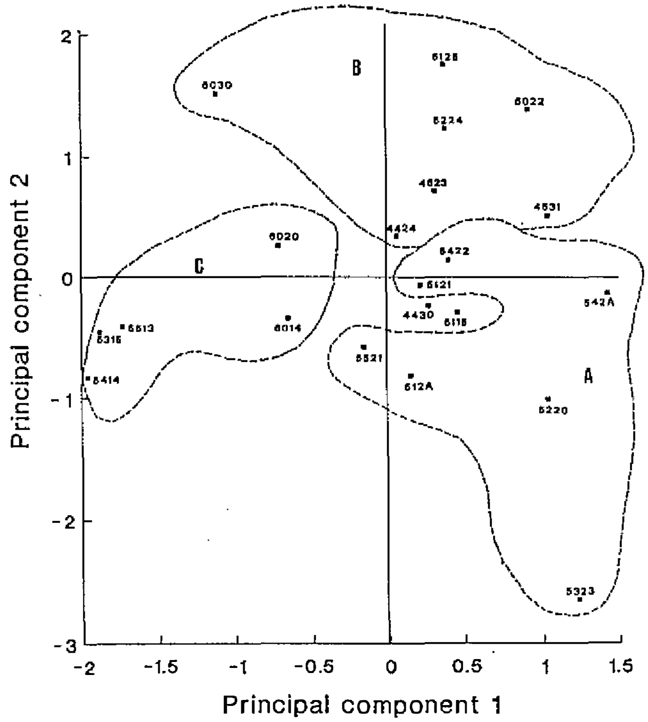


*Fig. 2.* Scatter diagram of plots on the first two PCA axes of the zooplankton taxa data (34.8% of the variance explained). Numbers indicate the sampling stations. See text for explanation of Clusters A, B and C.

### 3.3 Biochemical composition of zooplankton

Biochemical composition analysis of zooplankton yielded results which suggested conclusions similar to those of zooplankton taxa analysis. A summary of the biochemical compositions of the zooplankton is listed in Table 5. Zooplankton from the upwelled water, e. g. station 542A, had higher biomass, protein, lipid and free fatty acid contents and lower ash and phospholipid contents than those from the other two areas. This strongly indicates an improved quality of zooplankton biomass in terms of being a potential food for higher predators. Results of PCA of the zooplankton biomass and biochemical composition data matrix (Table 6) indicate the first axis to be an expression of biomass (both wet and dry weight) and body contents of protein, lipid, free fatty acids, ash and phospholipids (except for the last two components which are negatively correlated, all other components are positively correlated). The second axis (Table 6) is a description of changes mainly in levels of wax and sterol esters, sterols and phospholipids. The first 2 axes alone account for 70.2% of the total variation in the chemical composition data. Scattering in the plot of PCA 2 against PCA 1 (Figure 3) shows that the 21 stations can be roughly divided into three clusters similar to those obtained in the analysis of zooplankton taxa data. Each of the clusters represents the Kuroshio Current water, the coastal shelf water and the upwelled water, respectively. Cluster A is composed of stations in the upwelled water such as 5422, 5323, 542A, 5220, 5521, 512A and 5121. The stations included in the Kuroshio Current group (Cluster B) are 5125, 5030, 4424, 4523, 4531 and 4430. Cluster C corresponds to the shelf stations including 5414, 5513, 6115, 6020 and 6014.

Table 5. Biomass (wet and dry weight), protein, lipid, ash and lipid class composition (presented as median and range) of zooplankton for all stations and three representative stations located at the Kuroshio Current (5030), the East China Sea (5513) and the upwelling mixing water (542A), respectively.

| | Median | Range (min-max) | Station 5030 | Station 542A | Station 5513 |
|---|---|---|---|---|---|
| Wet weight ($mg/m^3$) | 114.5 | 38.0-1318.2 | 42.5 | 331.8 | 137.5 |
| Dry weight ($mg/m^3$) | 8.1 | 2.3-134.9 | 2.3 | 30.2 | 6.5 |
| Proximate analysis (percent of dry weight) | | | | | |
| Protein | 63.0 | 31.1-71.3 | 31.1 | 71.3 | 51.1 |
| Lipid | 7.9 | 5.6-11.7 | 7.9 | 11.3 | 5.9 |
| Ash | 24.1 | 12.6-39.7 | 39.7 | 12.6 | 38.1 |
| Lipid class (percent of total lipid) | | | | | |
| Free fatty acids | 21.2 | 11.9-33.8 | 12.7 | 33.8 | 27.5 |
| Phospho-lipids | 58.8 | 41.9-69.2 | 58.8 | 45.2 | 53.9 |
| Wax & sterol ester | 8.9 | 5.2-31.2 | 16.0 | 11.1 | 7.1 |
| Sterols | 6.7 | 4.0-8.3 | 5.4 | 5.9 | 7.2 |
| Triacylgly-cerides | 4.0 | 1.6-7.1 | 7.1 | 3.1 | 4.4 |

Table 6. Correlations between the Principle Component (PCA) scores and the original variables of the zooplankton chemical composition data.

| Variables | Component axes | |
|---|---|---|
| | PCA1 | PCA2 |
| Wet biomass | 0.8577 | 0.2978 |
| Dry biomass | 0.8596 | 0.3107 |
| Protein | 0.8155 | -0.4645 |
| Lipid | 0.8241 | 0.1777 |
| Ash | -0.8173 | 0.2413 |
| Free fatty acids | 0.8430 | 0.0554 |
| Phospholipids | -0.6427 | -0.6234 |
| Wax & sterol esters | -0.2607 | 0.8969 |
| Sterols | 0.4719 | -0.6360 |
| Triacylglycerides | -0.1705 | 0.0350 |
| %variance | 49.30 | 20.93 |

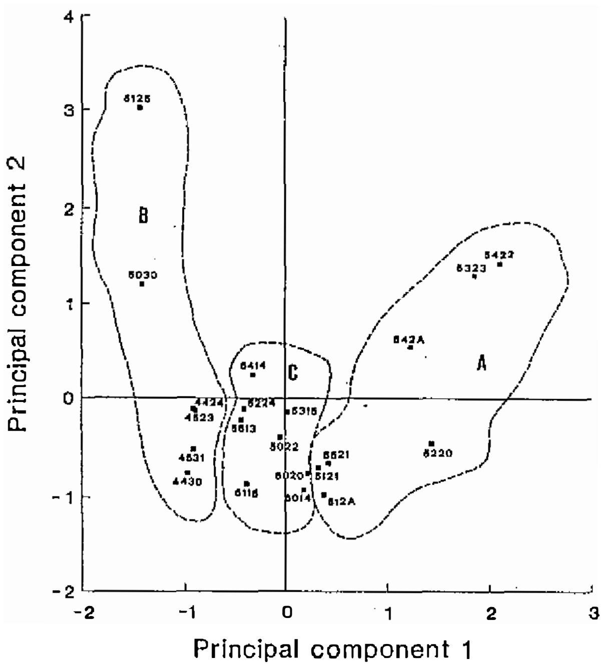


*Fig. 3.* Scatter diagram of plots on the first two PCA axes of the zooplankton biomass and biochemical composition data (70.2% of the variance explained). Numbers correspond to the sampling stations. See text for explanation of clusters.

### 3.4 Factors affecting biochemical composition of zooplankton

The protein ($PRO$) level of zooplankton was highly related to the upwelling environmental variables and zooplankton taxa. When examined independently with each variable, it is positively related to chlorophyll a ($CHL$) concentration and negatively correlated to the occurrence frequencies of pteropods ($PTE$), thaliaceans ($THA$) and fish eggs. Because of the high correlation among these taxa, a single regression equation could not include all correlated variables. A representative equation derived from stepwise regression analysis is presented:

$$PRO = 57.98 + 18.89CHL - 321.99PTE - 1903.44THA(R^2 = 0.682)$$

Zooplankton lipid content is also related to upwelling process. There was a positive correlation between lipid content and concentrations of $NO_3$-N and chlorophyll a, but a negative one with seawater temperature. Zooplankton taxa also affected its lipid composition ($LIP$). The occurrences of pteropods, polychaetes ($POL$), radiolarians ($RAD$) and medusae, significantly reduced the lipid content. On the other hand, occurrences of decapod larvae and mysids are positively correlated with zooplankton lipid content. Because high correlation were also observed, a representative stepwise regression equation depicted their relationship:

$$LIP = 8.32 - 4.46RAD - 1014.95POL + 4.64CHL - 45.83PTE(R^2 = 0.703)$$

The concentration of phospholipids, a functional lipid class associated mainly with cell membrane structure, was not related to zooplankton taxa but was negatively related to temperature and concentrations of $NO_3$-N and chlorophyll a. These results indicate a relatively low phospholipid composition in zooplankton occurring in upwelled water. In contrast, the content of free fatty acids, a storage lipid class, was high in zooplankton from the upwelling region. There is a positive correlation between level of free fatty acids and the concentrations of $NO_3$-N and chlorophyll a in the environment. The free fatty acid content is also positively related to amphipods and negatively to foraminiferans and fish eggs.

## 4. DISCUSSION

The results of this study clearly demonstrate that marked changes observed in the distribution of taxa and biochemical composition of zooplankton are closely related to upwelling. In an area of such hydrobiological instability, the zooplankton exhibits a marked variability in quantity and quality. There is much literature indicating that upwelling frontal zones may support increased phytoplankton and zooplankton populations (e. g. Walsh *et al.*, 1980, Armstrong *et al.*, 1987), and in turn large fish populations (Longhurst and Pauly, 1987). As the upwelled water reaches the photic zone from below the thermocline, phytoplankton cells undergo light-induced "shift up" to a physiological state of high nutrient demand, and growth rates become maximal until nutrient levels in the water are depleted. Zooplankton populations associated with an upwelling area, similarly, have to develop viable populations sufficiently early in the upwelling squence to utilize the production of plant cells.

Although the present results indicate the improved quality of zooplankton because of upwelling, the use of protein, lipid and other biochemical analyses as an indicator of quality may have been impeded by the existence of nonliving organic aggregates, or detritus, in the 'zooplankton' samples. A rough visual inspection of the samples indicated that the samples from upwelled water contained much less detritus than those from non-upwelled area. Although the proportions of the detritus in the samples were not quantified in this study, its contribution to the results of the quality measurement of the zooplankton should not be overlooked. The existence of detritus in the zooplankton samples diluted the concentrations of the biochemical parameters employed because detritus are usually less 'nutritious' than the living organisms (Menzel and Ryther, 1964). The results that the levels of biochemical parameters in the upwelled area where less detritus exist were higher (i. e., more nutritious for their predators) than those of non-upwelling area could just be a reflection of the dilution (or contamination) of the samples by detritus. It is, however, justified to conclude that the quality of 'whole zooplankton sample' (including both the plankton and detritus) from the upwelled water is greatly improved.

In the present study only surface plankton were sampled and analyzed. The samples could not be considered representative of the water mass or ecosystem because of the habit of most plankton of undergoing daily vertical migration according to the cycle of light. Stratified tows that cover the entire water column over the shelf will be needed to collect all taxa to take into account the effect of migration. The sampling schemes used in the present study tended to underestimate the contributions of the major vertical migrators. It is striking that even with the certain bias introduced by the sampling, the three water masses of the region were reasonably clearly delineated.

In the present study, the measurement of zooplankton quality was somewhat jeopardized by the contamination of detrital aggregates. The result of zooplankton quality obtained actually is the combined results of zooplankton and detritus. However, when we consider ocean detritus also as a source of food for producers of higher trophic levels (Parsons and Strickland, 1962), the quality data obtained still stand out to pinpoint the difference of zooplankton in quality as a food source for predatory fishes. Thus, in upwelled waters, fish growth enhancement is caused either by the increased supply of food or by the improvement of food quality. The increments of zooplankton protein level from 30-50% in non-upwelling waters to higher than 70% in upwelled area and lipid from 6-8% to 11% could greatly enhance fish growth. Fish production in an upwelling area, thus, has to be evaluated by both quantity and quality of food sources. Since half of the world fish production is from upwelling waters, the contribution of improved zooplankton (and detritus) quality and the need for these data in evaluating the potential of fish production in upwelled water become obvious.

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# 台灣東北湧升流海域夏季表層網採浮游動物之數量與品質

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## 摘要

本研究探討台灣東北海域由黑潮入侵大陸棚所引發的湧升流及其附近區域浮游動物之大類分布與其生化組成。採樣爲海研一號１９８９年９月２５４航次，共計二十一測站，使用３３０微米網目之錐形網採取表層浮游生物。樣品除經種類分析外，並進行蛋白質、脂肪、灰分與脂質成份分析，其中脂質成份分析細分爲磷脂質，游離脂肪酸，石蠟及固醇之酯化物，固醇類和三甘油脂。研究結果發現以橈腳類爲主的浮游動物質量明顯符合湧升流之現象。湧升流水域測站具有低水溫，高硝酸鹽、高葉綠素量及高浮游動物量之特性。湧升流水域浮游動物之蛋白質與脂肪含量較非湧升流水域者高，灰分含量則較低。就脂質成份而言，湧升流浮游動物之游離脂肪酸含量較高，但磷脂質含量則較低。凡此均顯示湧升流水域浮游動物不僅在數量上增加，在品質（就營養學而言）上亦較爲優良，而優良的浮游動物品質必會對該海域漁業海洋學特性，如魚類的成長與生殖，有相當的影響。以浮游動物種類組成及生化組成各別進行主成份分析，結果均顯示研究海域具有三不同特性之水團，並可能分別受黑潮、南中國海陸棚及湧升流的影響，因此，浮游動物生化組成的研究對於了解湧升流海域之海洋現象有正面的意義。