Journal of
Marine Science and Technology

Volume 21
Issue 7 *Vol 22, Supplemental*

Article 10

ICHTHYOPLANKTON COMMUNITY ASSOCIATED WITH OCEANIC FRONTS IN EARLY WINTER ON THE CONTINENTAL SHELF OF THE SOUTHERN EAST CHINA SEA

Yi-Chen Wang
Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Wen-Yu Chen
Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C. Coastal and Offshore Resources Research Center, Taiwan Fishery Research Institute, Kaohsiung, Taiwan, R.O.C.

Yi Chang
Institute of Ocean Technology and Marine Affairs, National Cheng Kung University, Tainan, Taiwan, R.O.C.

Ming-An Lee
Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C. Center of Excellence for Oceans, National Taiwan Ocean University, Keelung, Taiwan, R.O.C., malee@ntou.edu.tw

Recommended Citation
Wang, Yi-Chen; Chen, Wen-Yu; Chang, Yi; and Lee, Ming-An (2013) "ICHTHYOPLANKTON COMMUNITY ASSOCIATED WITH OCEANIC FRONTS IN EARLY WINTER ON THE CONTINENTAL SHELF OF THE SOUTHERN EAST CHINA SEA," *Journal of Marine Science and Technology*: Vol. 21: Iss. 7, Article 10.
DOI: 10.6119/JMST-013-1219-6
Available at: https://jmstt.ntou.edu.tw/journal/vol21/iss7/10

ICHTHYOPLANKTON COMMUNITY ASSOCIATED WITH OCEANIC FRONTS IN EARLY WINTER ON THE CONTINENTAL SHELF OF THE SOUTHERN EAST CHINA SEA

Acknowledgements

We are grateful to the National Science Council of the republic of China (ROC) for financial support (NSC 99-2611- M-019-013 and 100-2611-M-019-005). Special thanks are due to Dr. C. T. Shih and I. Belkin for their generous input and guidance through the revision process.

Journal of Marine Science and Technology, Vol. 21, Suppl., pp. 65-76 (2013)
DOI: 10.6119/JMST-013-1219-6

ICHTHYOPLANKTON COMMUNITY ASSOCIATED WITH OCEANIC FRONTS IN EARLY WINTER ON THE CONTINENTAL SHELF OF THE SOUTHERN EAST CHINA SEA

Yi-Chen Wang[1], Wen-Yu Chen[1, 2], Yi Chang[3], and Ming-An Lee[1, 4]

Key words: ichthyoplankton, East China sea, Kuroshio Front, China Coastal Front.

ABSTRACT

The study of ichthyoplankton community associated with oceanic features on the continental shelf of southern East China Sea (ECS) was conducted in early winter from 2006 to 2009. The species composition of the ichthyoplankton and its spatial distribution was classified and compared with oceanic front. A total number of 1,809 fish larvae individuals were sampled from 5 field surveys, and represented 76 families and 137 species. Using the Bray-Curtis dissimilarity, the abundance of species found to exceed 0.5% of the total sample from 36 stations were classified into four groups: China Coastal Group, Mixed Shelf Group, Taiwan Strait Group, and Kuroshio Group. The shallow water species *Sebastiscus marmoratus* dominated the China Coastal Group, while the Mixed Shelf Group was dominated by *Saurida* spp., *Trichiurus lepturus*, and *Bregmaceros* spp. The Taiwan Strait Group was dominated by *Engraulis japonicus* and *Benthosema pterotum*. The dominant species in the Kuroshio Group was found to include *Sigmops gracile* and unidentified Myctophid larvae. The spatial distribution of the ichthyoplankton community groups was superimposed on a thermal front map of the study area. This clearly revealed that the China Coastal Front could be the boundary which separated the China Coastal Group on the west and the Mixed Shelf Group on the east. In addition, ichthyoplankton were found to increase in abundance and diversity in the region close to the Kuroshio Front.

I. INTRODUCTION

The early life stage is the most important stage for determining annual recruitment of fishes and supporting various major commercial fisheries. Many studies have focused on ecological aspects of the larval stage, such as distribution, growth and survival [15]. Oceanic conditions play a major role in determining the patterns of abundance and distribution of larval fish populations. The structures of physical processes including currents, eddies and fronts create varied oceanic conditions which influence the spatial and temporal distributions of ichthyoplankton in the various seas [33, 36]. Several studies have suggested the role of physical processes that occur at shelf break fronts as retention mechanisms for ichthyoplankton by favoring aggregation within the spawning area or drifting towards the coast [20, 37, 38, 49]. These biological-physical linkages are frequently observed in the shelf break region where a boundary between coastal and oceanic water occurs. For example, dynamic interactions between the Kuroshio and shelf waters at the frontal boundary were found to potentially affect larval fish transport and distribution, along with prey availability [16, 32, 41, 42]. Based on horizontal distribution patterns, Sassa *et al.* [40] categorized species into different groups according to the properties of different water masses.

The complexity of hydrographic conditions in the southern East China Sea (ECS) is influenced by the seasonal changing of currents [46]. The well known physical processes in the ECS include the Kuroshio Current (KC) which flows northward along the edge of the continental shelf between the ECS and the east coast of Taiwan. It transports warm and saline Kuroshio waters and oceanic materials across the shelf into the southern ECS, forming the Kuroshio Front which has a significant impact on this area. Furthermore, the China Coastal Current (CCC) and Taiwan Strait Water (TSW) determine the major temperature-salinity structure for water masses in the

---

Paper submitted 10/30/13; revised 12/09/13; accepted 12/19/13. Author for correspondence: Ming-An Lee (e-mail: malee@ntou.edu.tw).

[1] *Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.*
[2] *Coastal and Offshore Resources Research Center, Taiwan Fishery Research Institute, Kaohsiung, Taiwan, R.O.C.*
[3] *Institute of Ocean Technology and Marine Affairs, National Cheng Kung University, Tainan, Taiwan, R.O.C.*
[4] *Center of Excellence for Oceans, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.*

study area. The upwelling caused by the intrusion of Kuroshio subsurface water in the area northeast of Taiwan also provides a large amount of nutrients [5, 12]. The ECS features extremely stable, primarily wintertime fronts formed by a broad range of physical processes. These fronts have been relatively well studied from satellite data [1, 2, 14] and *in situ* measurements [4, 26].

In winter, the TSW originates from overshooting of the Kuroshio Current across the continental shelf northeast of Taiwan and flows northeastward over the middle shelf of the ECS [29], bringing warm saline water to the area off the China coast. The CCC is associated with the Changjiang discharge flow southward along the China coast [10, 12]. The southern ECS characterized by strong hydrodynamic front effects caused by these currents along the China coast and the Kuroshio edge. These features contribute to the formation of thermal fronts between the water masses. The China Coastal Front (CCF) is a boundary of cold coastal water and mixing waters in the shelf [2]. In addition, the Kuroshio Front on the northeast of Taiwan is formed between the KC and shelf water, which reflects the large variability of the Kuroshio path [46].

Previous studies have shown that the KC flow pattern north of Taiwan migrates seasonally. In summer the Kuroshio generally moves offshore from the southern edge of the ECS, splitting into a northeastward mainstream and a westward current. In winter the KC moves close to and sometimes onto Taiwan's northern shelf. The intrusion of the Kuroshio dominates the flow pattern in the region, causing the disappearance or obscuration of the counterclockwise circulation and cold dome [46]. The Kuroshio flow pattern north of Taiwan was found to vary seasonally. Variable transport from the Taiwan Strait and the east of Taiwan have a considerable impact on the intrusion of the Kuroshio onto the shelf. The front intrusion studies discussed the Kuroshio in the present case is produced the comprehensive [11], objectively derived, year-round climatology of ocean thermal fronts in the eastern China Seas [14] and identified the previously known fronts [31]. Lan *et al*. [24] indicated that the seasonal exchanges between coastal and offshore waters could influence the zooplankton whose distribution can be divided into two distinct communities (inshore–offshore) defined by different species dominance. The larval fish fauna found in the southern ECS is a mixture of endemic and exotic species, with the latter originating from the coastal waters of mainland China when the northeasterly monsoon prevails, from the South China Sea during the southwesterly monsoon, and from the Kuroshio waters year-round [19]. Okazaki and Nakata [32] also suggested that the Kuroshio frontal eddy may affect larval distribution, due to the variation of primary production in the frontal region. However, a comprehensive and definitive pattern of the thermal front and its relationship with fish larvae has yet to be established.

Two major oceanographic research projects in Taiwan, the Kuroshio Edge Exchange Processes (KEEP) [50] and Long-term Observations and Research of the East China Sea (LORECS), have investigated the seasonal variations in the hydrographic conditions in the East China Sea [9]. Focused since 1989 on physical and chemical oceanography [11, 50], KEEP is a multidisciplinary study on the internal cycling of material, especially carbon, within the East China Sea Shelf and the exchange of material between this shelf and the adjoining Kuroshio. Many researchers have focused on the abundance, distribution and diversity of ichthyoplankton [25, 7, 20]. Rough sea conditions due to the northeasterly monsoon hampers field work in winter, and Hsieh *et al*. [16] was the first to attempt to use late winter surveys to evaluate the ichthyoplankton distribution related to the thermal front. However, the early winter composition and structure of the larval fish communities on the continental shelf of the southern ECS at the shelf break, and their relation to the spatial variability of the thermal front, is still not well described. Therefore this study attempts to examine the spatial distribution of fish larval assemblage and its relationship to satellite-derived thermal fronts.

II. MATERIALS AND METHODS

The oceanic measurements and organism samples used in this study were collected from the cruise of 1400, 1503, 1598, 1600 and 1692 in December from 2006 to 2009 on board the vessel Ocean Research II (Table 1). Hydrographic data and ichthyoplankton samplings were conducted at 9 fixed stations during each cruise (Fig. 1).

Ichthyoplankton were collected using a plankton net (ORI net) with a mouth diameter of 1.6 m and a mesh size of 330 μm. A flowmeter was tied at the center of the net to measure the filtered water volume. The ORI net was obliquely towed at a speed ca. 1 m s^{-1} at depths ranging from 200 m to the surface. At the shallower stations, the net was towed at depths ranging from 10 m above the bottom to the surface. Ichthyoplankton samples were then preserved in sea water with 5% formalin. Finally, larval fishes were brought to the laboratory for further identification of the lowest taxonomic level.

Water temperature and salinity at different depths for every station were obtained by lowering a CTD profiler from the sea surface to a depth near the bottom. Satellite-derived sea surface temperature (SST) observed by NOAA/AVHRR (National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer) sensors from the Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University were also used. The satellite-derived SST was validated with a small bias of 0.009°C and a root mean square deviation of 0.64°C [27].

The entropy-based edge detection method [43] was used to detect the monthly frontal SST gradient magnitude (GM) in the southern ECS. This method is independent of annual varying geophysical parameters and can detect and retain finer-scale SST fronts, and has been used effectively in coastal seas. The GM is calculated by the following formula:

$$\mathrm{GM} = \sqrt{(\partial \mathrm{T}/\partial \mathrm{x})^2 + (\partial \mathrm{T}/\partial \mathrm{y})^2} \quad (^\circ\mathrm{C}/\mathrm{km}) \tag{1}$$

Table 1. Summary of sampling data, stations, latitude, longitude, and sampling date.

cruise	stations	longitude	latitude	sampling date	cruise	stations	longitude	latitude	sampling date
1400	K1	120.08	26.17	2006/12/7	1598	K6	121.26	25.75	2008/12/10
1400	K2	120.32	26.08	2006/12/7	1598	K7	121.50	25.67	2008/12/10
1400	K3	120.56	26.00	2006/12/7	1598	K8	121.73	25.58	2008/12/10
1400	K4	120.79	25.92	2006/12/7	1598	K9	121.97	25.50	2008/12/10
1400	K5	121.03	25.83	2006/12/8	1600	K1	120.08	26.17	2008/12/20
1400	K6	121.26	25.75	2006/12/8	1600	K2	120.32	26.08	2008/12/20
1400	K7	121.50	25.67	2006/12/8	1600	K3	120.56	26.00	2008/12/20
1400	K8	121.73	25.58	2006/12/8	1600	K4	120.79	25.92	2008/12/20
1400	K9	121.97	25.50	2006/12/8	1600	K5	121.03	25.83	2008/12/20
1503	K1	120.08	26.17	2007/12/11	1692	K1	120.08	26.17	2009/12/23
1503	K2	120.32	26.08	2007/12/11	1692	K2	120.32	26.08	2009/12/23
1503	K3	120.56	26.00	2007/12/11	1692	K3	120.56	26.00	2009/12/23
1503	K4	120.79	25.92	2007/12/11	1692	K4	120.79	25.92	2009/12/23
1503	K5	121.03	25.83	2007/12/12	1692	K5	121.03	25.83	2009/12/24
1503	K6	121.26	25.75	2007/12/12	1692	K6	121.26	25.75	2009/12/24
1503	K7	121.50	25.67	2007/12/12	1692	K7	121.50	25.67	2009/12/24
1503	K8	121.73	25.58	2007/12/12	1692	K8	121.73	25.58	2009/12/24
1503	K9	121.97	25.50	2007/12/12	1692	K9	121.97	25.50	2009/12/24

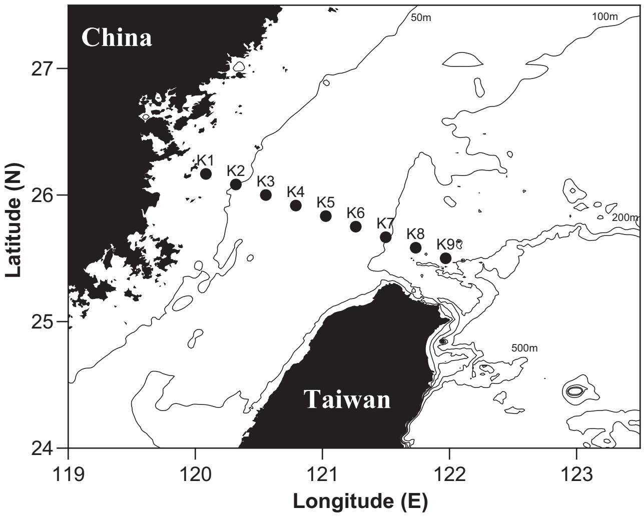

Fig. 1. Sampling stations in southern East China Sea from 2006 to 2009.

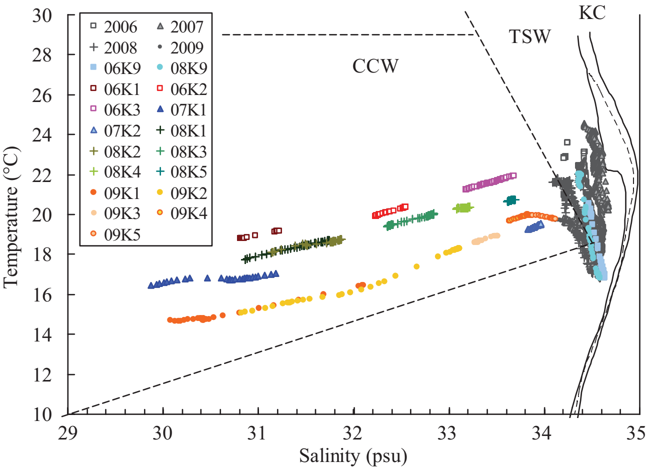

Fig. 2. T-S diagram for Kuroshio Current (KC), Taiwan Strait Water (TSW), China Coastal Current (CCC). The area between the lines denotes the Kuroshio axis current (Gong *et al.*, 1995).

where T is SST, and the x and y axes are respectively directed toward east and north. The GM is computed at all frontal pixels for each image, and the monthly mean of the GM is computed pixel-wise. The GM map enhances frontal patterns and reveals the frontal area more clearly.

Shannon's diversity index was used to calculate species diversity, and Simpson's evenness was further used to estimate the relative abundance of species at each station. Shannon's diversity index and Simpson's evenness were processed using the PRIMER v6 program. Cluster analysis used was transformed to the log (X+1) and performed with the STATISTIA 8 statistical software package. Cluster analysis with normalized Euclidean distances was used to investigate the levels of similarity in species composition among the sampling stations, and Ward's method was used to illustrate the relation of these stations in a dendrogram.

III. RESULTS

1. Hydrographic Conditions

The T-S diagram of the study area and compared with the examined results of previous studies [10, 22] (Fig. 2). Following Gong *et al.* [10] the range of the mainstream KC was denoted by a solid line, and the TSW was distributed in the left side of the KC. The dashed line denotesd the

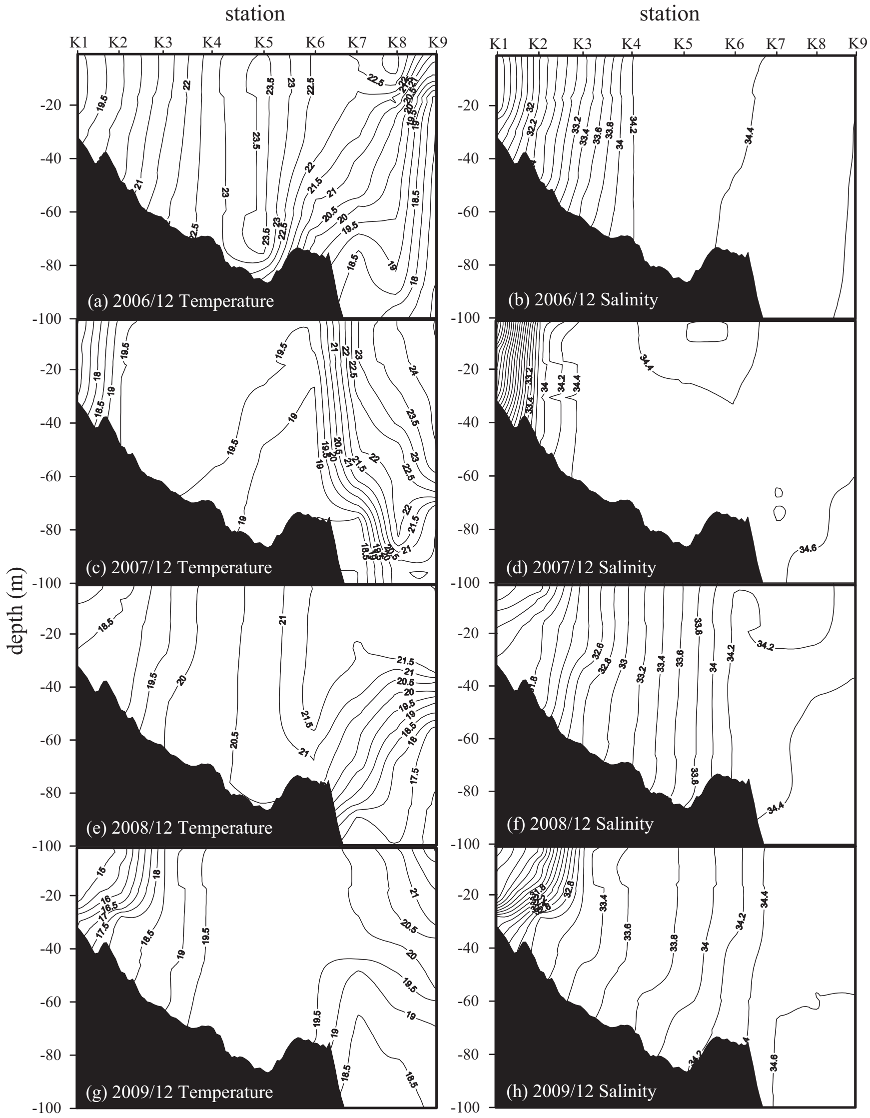

Fig. 3. Vertical profiles of temperature (°C) and salinity (psu) from *in situ* observations in the southern East China Sea from 2006 to 2009.

mainstream of the KC [22]. Most offshore stations in our survey were considered as KC and TSW where water salinity was high. The inner stations adjacent to the China Coast were considered as China Coastal Water where the water was characterized by low temperatures with varied salinity levels.

The vertical profiles of water temperature and salinity of sampling stations during the study period were shown in Fig. 3. In December of 2006 (Figs. 3(a), (b)), the water in the middle of the shelf (between the stations K4 and K7) was occupied by warm shelf water (temperature > 22°C, salinity < 34.4 psu) while, in the offshore region, the right side of station K7 was blocked by KC upwelling water with temperature < 20°C and salinity > 34.4 psu. In 2007, the KC obviously intruded into the self of the southern ECS (stations K5-K7, Figs. 3(c), (d)), which resulted in a clear upwelling of Kuroshio subsurface water with a temperature < 20°C and salinity > 34.4 psu. However, the profiles of 2008 and 2009 (Figs. 3(e)-(h)) revealed that the KC intruded into the shelf but simultaneously repressed its subsurface upwelling water (temperature > 20°C, salinity < 34.4 psu) to the right of station K7. This suggested that the intrusion of KC might occur in early winter but not necessarily coincident with the upwelling of its subsurface water. It was clearly seen that the vertical profiles revealed the annual variation of water masses between the CCC and KC. In 2006 the study area was characterized by warm water from the Taiwan Strait.

2. Distribution of SST Fronts and Ichthyoplankton Abundance

Marked thermal fronts detected from satellite-derived SST data in December were averaged to produce a 4-year monthly composite (Fig. 4). Two significant frontal bands were found in the vicinity of the China coastal area and northeast of Taiwan. The former frontal band was defined as the China

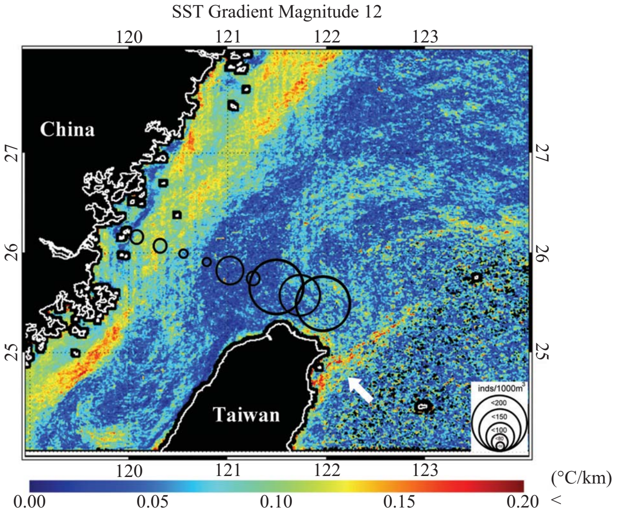

Fig. 4. The average ichthyoplankton abundance (cumulation >50%) of each station superimposed on the SST front composite map in December from 2006 to 2009.

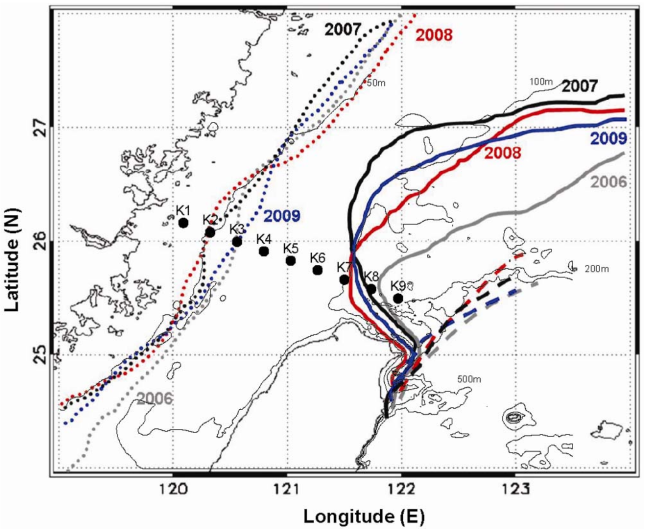

Fig. 5. Annual variations of the SST front from 2006 to 2009. The dotted line indicates the China Coastal Front, while the solid curve and dashed lines respectively indicate the Kuroshio Front and its shelf break parts.

Coastal Front, and the latter was referred to the Kuroshio Front (KF) [14]. The China Coastal Front stretched along the 50-m isobath with a SST gradient >0.15 (°C/km), while the Kuroshio Front was distributed between the 100-m and 200-m isobaths. However, the Kuroshio Front combines two separate frontal bands, one is the curving-blurred band on the shelf and the other is the straight-sharp band near the shelf break (white arrow). Although the curving part of this front was well defined by Hickox *et al.* [14] and Chang *et al.* [3], the straight-sharp band has been rarely discussed previously. This short band of the Kuroshio Front starts from the northern tip of Taiwan and then extends northeastward along the shelf break. We thus suggest this frontal band as the Kuroshio Shelf Break Front (white arrow).

The 4-year monthly mean abundance of the cumulation >50% of larval fish species at each station was superimposed on the SST frontal map (Fig. 4). The abundance near the China Coastal Front was relatively low (average abundance <80 inds/1000 m^3), but the abundance clearly increased (average abundance >150 inds/1000 m^3) at the stations close to the Kuroshio Front. The abundance in the middle of the shelf was around 100 inds/1000 m^3. Among the cumulation >50% of larval fish species were abundant at the Kuroshio Front, suggesting that the Kuroshio Front was exceptional in providing a suitable environment for the subsistence of some species.

The maximum value of the SST GM for each frontal bound in each year from 2006 to 2009 was extracted as a frontal boundary line and superposed as shown in Fig. 5. The boundaries of the China Coastal Front were found to be permanently distributed along the 50-m isobath with slightly variations, while the Kuroshio Shelf Break Front was found to run along the self break. However, the position of the curving Kuroshio Front on the shelf varied significantly each year, moving offshore in 2006 (grey curve), but intruding more inshore in 2007 (black curve). For 2008 and 2009, the Kuroshio Front exhibited a normal distribution near the 100-m isobaths.

3. Distribution of Ichthyoplankton Assemblages

A total of 1,809 individual fish larvae individuals representing 76 families and 137 species were collected in 5 surveys. In the oblique net tows of December from 2006 to 2009, a total of 6060.39 inds/1000 m^3 larvae were captured (Table 2). Thirteen taxa accounted for approximately 75% of total catch, including Myctophid larvae, *Sigmops gracile*, *Sebastiscus marmoratus*, *Benthosema pterotum*, *Bregmaceros* spp., *Engraulis japonicus*, *Saurida* spp., *Encrasicholina punctifer*, *Trichiurus lepturus*, Apogonid larvae, Callionymid larvae, *Scomber* spp. and Serranid larvae. Using a dendrogram based on the Bray-Curtis dissimilarity, taxa identified as accounting for more than 0.5% of the total sample from the 36 stations for tows that caught at least one larva were classified into four groups: A, B, C and D (Fig. 6). According to the geolocations of every station, the defined four groups are further referred to as the China Coastal Group (A), Mixed Shelf Group (B), Taiwan Strait Group (C), and Kuroshio Group (D). The dominant species in the China Coastal Group were *Sebastiscus marmoratus*; while the Mixed Shelf Group was dominated by *Saurida* spp., *Trichiurus lepturus*, and *Bregmaceros* spp., the Taiwan Strait Group was dominated by *Engraulis japonicus* and *Benthosema pterotum*, and the Kuroshio Group was dominated by *Sigmops gracile* and Myctophid larvae (Table 2, bold type).

Stations in the China Coastal Group were located in the region of cold-fresh waters influenced by the CCC. Hydrographic features in the Mixed Shelf Group distribution were distinguished by with a wide variation of water temperatures

Table 2. Dominant species (cumulation >75%) in each group based on the cluster analysis of larval fish referring to Fig. 6.

Family		Kuroshio Group	Taiwan Strait Group	Mixed Shelf Group	China Coastal Group	Cumul %
Myctophidae	Myctophidae	**693.49**	108.13	34.41	16.21	14.06
Gonostomatidae	*Sigmopsgracile*	**804.15**	11.62	4.58	0.00	27.60
Scorpaenidae	*Sebasticusmarmoratus*	121.66	0.00	15.31	**332.23**	35.34
Myctophidae	*Benthosemapterotum*	138.81	**217.26**	56.45	9.41	42.30
Bregmacerotidae	*Bregmaceros* spp.	152.48	53.06	**105.40**	66.29	48.53
Engraulididae	*Engraulisjaponicus*	3.09	**249.70**	0.00	0.00	52.70
Synodontidae	*Saurida* spp.	0.00	0.00	**186.58**	58.41	56.74
Engraulididae	*Encrasicholinapunctifer*	79.35	0.00	47.55	89.94	60.32
Trichiutidae	*Trichiuruslepturus*	86.89	9.75	**125.06**	0.00	63.98
Apongonidae	Apongonidae	181.56	4.69	11.35	0.00	67.24
Callionymidae	Callionymidae	68.78	107.26	9.16	0.00	70.29
Scombridae	*Scomber* spp.	158.84	0.00	16.10	0.00	73.18
Serranidae	*Serranidae*	32.85	30.44	0.00	53.30	75.10
Other larval fishes		1111.53	235.64	99.31	62.30	100
Sum		3633.48	1027.56	711.27	688.08	

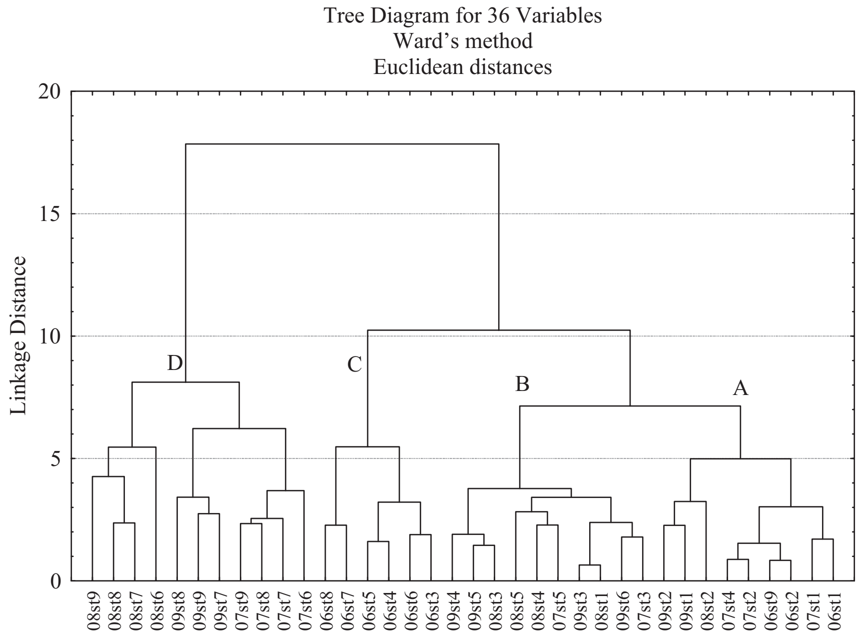

Fig. 6. Dendrogram of species composition similarity among stations using Ward's linkage cluster analysis in the study area in December, 2006 to 2009.

and salinities. The Taiwan Strait Group was only identified from the sampling data in 2006, where the T-S diagram showed the stations were surrounded by the TSW (Figs. 2, 3). The stations in the Kuroshio Group were located between the Kuroshio Front region and the edge of the continental shelf. The water in this region was warm-saline supplied from the intrusion of KC. From 2007 to 2009, the Kuroshio Front intruded inshore between the stations K7 and K8 (Fig. 5), and the Kuroshio Group stayed mostly on the right side of the front. In the mixing zone, the CCC and the KC blended to create a complex temperature and salinity structure in which fish congregated as the Mixed Shelf Group. However, in 2006 the KC receded onto the shelf as warm water from the Taiwan Strait intruded into the middle shelf. In our result the annual variation of water masses caused the discrepancy of larval cluster analysis.

By contrast, a water mass of approximately 23°C intruded into the southern part of the ECS which has been subject to intrusion of TSW waters in 2006. The larval fish distribution in 2006 was most dense in the middle shelf region between stations K3 and K8, with a sparse distribution in the China coastal area. Therefore, our result divided the fish distribution in the middle shelf region into two groups: the China Coastal Group in 2007 to 2009 and the Taiwan Strait Group in 2006. For the China Coastal Group located in the area surrounded by the China coast in 2007 to 2009. This clearly revealed that the

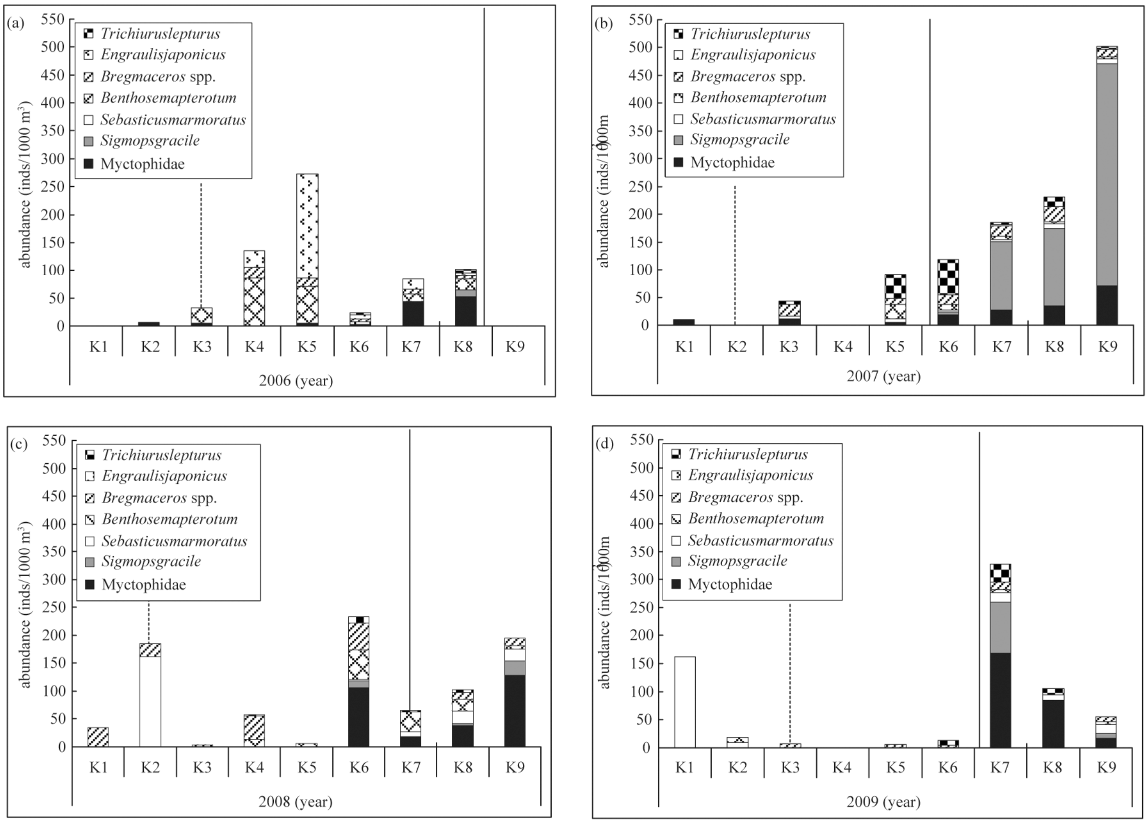

Fig. 7. Spatial distribution and temporal variation of larval fish abundance among the sampling stations. The stacked bars show the abundance of the dominant taxa of each group from 2006 to 2009. The vertical solid line and dashed lines respectively indicate the location of the China Coastal Front and Kuroshio Front.

China Coastal Front could be a boundary separating the China Coastal Group to the left and Mixed Shelf Group to the right. In addition, the Kuroshio Front on the shelf bounded the Taiwan Strait Group in the northern end of Strait, and separated the Kuroshio Group from the Kuroshio region on the right.

4. Specific Taxa Distributions, Abundance and Diversity

The abundances of the larval assemblage were relatively high in the Kuroshio region but were low in the coastal region (Fig. 4; Table 2). The four-year survey results for the cross-shelf distribution of fish larvae are given. Distributions of the dominant larvae captured in 2006 to 2009 and shown in Fig. 7 with vertical dashed lines indicating the China Coastal Front and the solid line indicating the Kuroshio Front (standards marked as the place closest to the China coast refer to Fig. 5). It should be noted that *Sebastiscus marmoratus* were mostly found along the transect in 2008 and 2009 at stations K1 and K2, where an inshore surface intrusion of low temperature water occurred. On the other hand, Myctophid larvae were abundant in the warm water stream from the Kuroshio on the shelf region. As shown in Fig. 7, the *Benthosema pterotum* achieved their highest abundance in both sides of the Kuroshio Front region though, in 2006, part of this assemblage was also distributed in stations K3 to K8. *Engraulis japonicus* were distributed in stations K4 to K7 only in 2006 and *Trichiurus lepturus* were abundant in stations K5 and K6 in 2007. *Bregmaceros* spp. were found in the water of all stations and *Sigmops gracile* were abundant in the warm Kuroshio station in 2007 when the surface water of the KC was intruded further onto the shelf.

The variation of abundance and diversity related to the Kuroshio Front as shown in Fig. 8. The x-axis shows the distance of each station to the Kuroshio Front, with negative and positive values respectively indicating stations to the left and right of the Front. Interestingly, the abundance of larvae was usually lower in the left region far from the Kuroshio Front, but higher at the stations closer to the Front (Fig. 8(a)). The Shannon's diversity index value of larval fishes (Fig. 8(b)) was negatively correlated to distance to the Kuroshio Front.

IV. DISCUSSION

The survival of larval fish is greatly dependent on environmental factors such as fronts and currents [13, 34], frontal eddies [32, 33], and tides [8]. In early winter, hydrographic features are strongly influenced by the KC and CCC on the shelf of ECS. These topographically-associated features

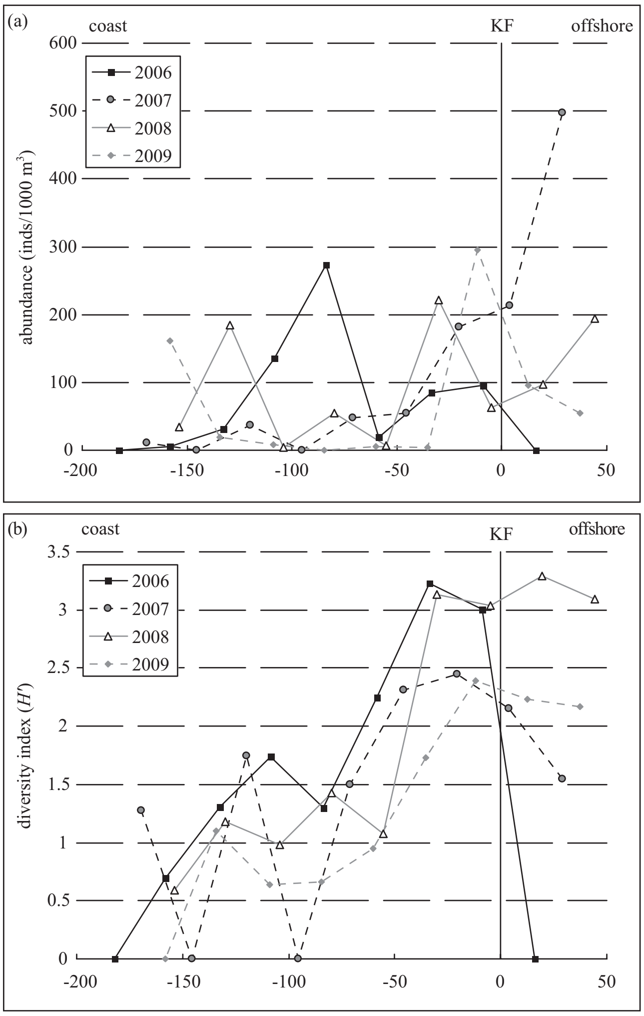

Fig. 8. Variation of abundance (inds/1000 m^3), (cumulation >50%) (a) and diversity index (H') (b) of larval fish related to the position of Kuroshio Front.

contribute to the formation of thermal fronts between the water masses [3]. Comparing our results of fish larvae and hydrographic data, the spatial distribution and species makeup of larval fish could be strongly affected by the variation of water masses on the continental shelf of the southern ECS. Four major assemblages of larval fish were defined in association with particular hydrographic features: the China Coastal Group, Mixed Shelf Group, Taiwan Strait Group and Kuroshio Group. During the sampling period, species abundance varied significantly in each group, with the Kuroshio Group exhibiting higher abundance than the China Coastal Group. In addition, species makeup clearly differed between groups, with detailed comparisons described below.

1. China Coastal Group

The China Coastal assemblage was distinguished by a greater abundance of *Sebastiscus marmoratus* (rockfish), which prefer shallow water near shore or rocky bottoms [35]. This species has a long spawning period and is ovoviviparous. Larvae can be found from November to May [35], but is most abundant from December to March in the waters near Taiwan [44]. Although fish eggs and larvae may come from outside the region from elsewhere or be aggregated by environmental factors [39], the distribution of the larval fish relative to the front suggests adaptive spawning strategies in response to local environmental conditions [37]. Therefore, the survival of the *Sebastiscus marmoratus* larvae depends on environmental factors. Wu [51] studied the effect of several environmental factors on the growth and survival of *Sebastiscus marmoratus* larvae. According to his results showed that the *Sebastiscus marmoratus* larvae were schooling, weak light and distributed with currents. It was also suggested that the optimal survival condition of this species is water masses between 10°C to 14°C. According to the hydrographic data collected in our study, the CCC (temperature <19°C, salinity <33 psu) flowed southward and extended further offshore in 2008 and 2009. The spatial distribution of the dominant species (Fig. 7) also revealed that *Sebastiscus marmoratus* were more abundant at stations K1 and K2 in 2008 and 2009 which are bounded by the China Coastal Front (grey dashed line) on the left. As a consequence, the temporal-spatial distribution of the southward CCC and the abundance of *Sebastiscus marmoratus* seem to be highly related. In addition, the ovoviviparous brood fishes of *Sebastiscus marmoratus* found the low temperatures and shallow waters along the China coast to be beneficial to the survival of its larvae and stayed. We thus suggest that the southward movement of the CCC with temperatures <19°C might make a suitable environment for *Sebastiscus marmoratus*, given its great abundance near the Chinese coast in years featuring a strong intrusion of the CCC.

2. Mixed Shelf Group

The Mixed Shelf assemblage was largely made up of *Trichiurus lepturus*, *Saurida* spp., and *Bregmaceros* spp. In general, *Trichiurus lepturus* is found throughout tropical and temperate waters, and its larvae prefer the muddy bottoms of shallow coastal waters and often enter estuaries for feeding. *Saurida* spp. larvae are usually distributed in shallow water and shelf estuaries [28]. *Bregmaceros* spp. larvae are found in shallow to deeper waters around Taiwan [17, 30], but most adult *Bregmaceros* spp. prefer deeper waters. In addition, the mixed Shelf region features a complex environment, where inner shore and outer shore waters mix together. *Trichiurus lepturus*, *Saurida* spp., and *Bregmaceros* spp., were found to be widely distributed in the ECS shelf, and were thus defined as the Mixed Shelf Group in this study. However, the distribution of these fish larvae seemed to be associated with local topographies and currents. *Trichiurus lepturus* was distributed at the northern end of Taiwan Strait, on the left of Kuroshio Front. The abundance of *Trichiurus lepturus* reached its maximum at stations K5 and K6 (Fig. 7(b)) characterized by mixing shelf water. A high abundance of *Trichiurus lepturus* was also found in [16] at similar locations. Our results further revealed that *Trichiurus lepturus* were more abundant in 2007

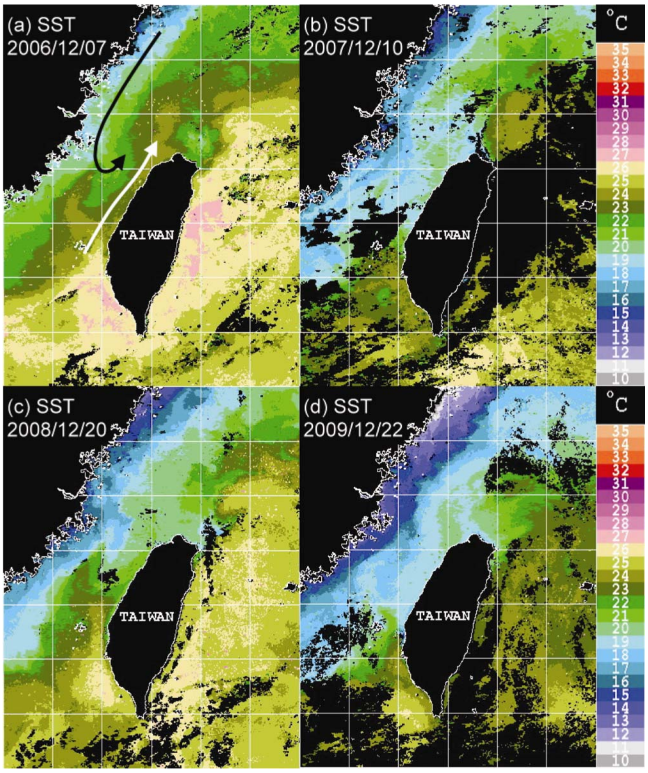

Fig. 9. SST images derived from NOAA/AVHRR shows the hydrotropic features during the sampling period in (a) 2006, (b) 2007, (c) 2008, and (d) 2009. The black and white arrows in (a) respectively denote the portion of the CCC reflux and TSW.

than in other years. Adult *Trichiurus lepturus* were widely disrupted with multi-spawning times in the ECS and Taiwan Strait [6, 17, 48]; however, such annual variation of larval fish abundance in this region has been largely neglected. We thus suggest that the intrusion of the KC might compress the habitat of *Trichiurus lepturus* larvae in the shelf region, thus increasing larvae density. This might result in the great abundance found in the middle shelf in years featuring a strong intrusion of the KC. However, further studies are needed to detail the mechanism of larval spatial distribution related to oceanography.

3. Taiwan Strait Group

The Taiwan Strait assemblage was dominate by *Engraulis japonicus* and *Benthosema pterotum*, which were abundant in the northern end of Taiwan Strait in 2006 only. In general, *Benthosema pterotum* is a kind of lanternfish which favors benthopelagic and mesopelagic habitats on slopes and near continental and island waters. According to Huang and Chiu [20] and Chiu and Hsyu [7] *Benthosema pterotum* are abundant in winter in the southern ECS and are the most common lantern fish species. Huang and Chiu [20] also indicated that *Benthosema pterotum* was widely distributed in the waters around Taiwan, especially in the Taiwan Strait, which corresponds with our results. However, the warm TSW only appeared in 2006 and showing the Taiwan Strait larval group.

Engraulis japonicus was found in abundance in the northern end of the Taiwan Strait where water temperatures were about 22°C. It is well known that *Engraulis japonicus* are a major species in continental shelf areas and inshore waters. They form large schools near the surface, mainly in coastal waters but occasionally as far as 1,000 km or more from shore. Spatial patterns in the distribution and abundance of *Engraulis japonicus* eggs were studied in the area off the Changjiang River, where a large spawning ground had developed [21]. In addition, Takasuka *et al.* [45] examined the growth rate of larval samples at optimal temperatures of 22°C collected at different locations during various seasons. They were generally transferred and aggregated in the estuary area for feeding [25]. According to the winter circulation patterns in the Taiwan Strait [23], a portion of the southward penetration of CCC is deflected by the Chang-Yuen Ridge and turns back northeastward. As seen in SST images (Fig. 9(a)), the TSW was intruded significantly northward into the northern Taiwan Strait in 2006, but this intrusion was absent in the other three years. The northward TSW might bring a reflux of the CCC (arrows) from the northern Chang-Yuen Ridge to the northern Strait. Therefore, the interaction between the northward intrusion of the TSW and this portion of the CCC could play an important role in ichthyoplankton transportation in the study area (Fig. 9). Comparing the result of fish larval distributions and hydrographic features in this study, we suggest that *Engraulis japonicus* spawned off the Changjiang River would be driven southward to the Taiwan Strait by the CCC after hatching. In addition, the northward current mixed by the reflux portion of the CCC and TSW should thus transport *Engraulis japonicus* and *Benthosema pterotum* to the southern ECS from the Taiwan Strait.

4. Kuroshio Group

The Kuroshio assemblage was dominated by *Sigmops gracile* and Myctophid larvae, making it quite unique from the other groups. The major species of *Sigmops gracile* in Kuroshio Group was significantly abundant at stations to the right of the Kuroshio Front in 2007. The abundance of *Sigmops gracile* and Myctophid larvae observed in the present study corresponded to the spatial distribution reported by [17, 47]. Indeed, *Sigmops gracile* and Myctophid larvae are both lanternfish, a mesopelagic species which is one of the most widely distributed, populous, and diverse of all vertebrates, playing an important ecological role as prey for larger organisms. Some species of Myctophidae and Gonostomatidae have been used as indicator species for the KC because they occur mostly within the KC and adjacent areas [18]. However, in 2006, the Kuroshio Group was not observed in the southern ECS while the Kuroshio Front was formed far from the shelf.

The schematic map revealed that the straight-sharp Kuroshio Self Break Front was persistent near the 200-m isobath, while the curving Kuroshio Front on the shelf exhibited clear annual variation. It is well known that frontal band caused by the topographic uplift and the Kuroshio intrusion is a unique feature along the northeast coast of Taiwan [46], which is an important region for the transportation of marine organisms. Previous studies have indicated that the Kuroshio collides with the continental shelf break of the ECS with temporal variations on daily, monthly to annually scales [2, 26, 46]. Lee *et al*. [26] further suggested that the northward intrusion of the TSW from the Taiwan Strait could result in the more offshore distribution of the Kuroshio Front in the waters northeast of Taiwan. This corresponds well with the SST images (Fig. 9) in this study that show the TSW current intruded further northward in 2006. According to Okazaki and Nakata [32], the abundance and diversity of larval fish was positively correlated to water temperature. Lan *et al*. [24] also indicated that the abundance and Shannon's diversity index value of plankton increased near the Kuroshio Front area. Thus provides a clearer picture of the relationship between the Kuroshio Front and the spatial distribution of biodiversity. As a consequence, we suggest that the proximity of the formation of the Kuroshio Front to corresponds to an increased abundance of *Sigmops gracile* in the Kuroshio region.

V. CONCLUSION

The spatial distribution of the dominant species of *Sebastiscus marmoratus* increased close to the China coast and was bounded by the China Coastal Front. Our data further showed that the abundance of *Sebastiscus marmoratus* was highly correlated to the strong southward movement of the CCC, and the environment may suitable for the survival of *Sebastiscus marmoratus* larvae. Although *Trichiurus lepturus* is widely distributed in the ECS shelf (defined as Mixed Shelf Group in this study), its distribution seemed to be associated with the intrusion of the Kuroshio Front. However, the relationship between the mixing water and the larval assemblage of *Trichiurus lepturus* is not yet understood. In addition, it is suggested that the unique distribution of *Engraulis japonicus* observed in 2006 is due to the interaction between the CCC at the Chang-Yuen Ridge and the northward TSW. We suggest that larval *Engraulis japonicus* are driven southward along the Chinese coast by the CCC, and transported to the northern end of the Taiwan Strait by the reflux portion of the CCC and TSW. In addition, the migration of the Kuroshio Front caused the annual variability of the spatial distribution of *Sigmops gracile* and Myctophid larvae. The Kuroshio Front is accompanied by the interaction of KC intrusions into the inner shelf and the mixing shelf water flowing from the Taiwan Strait, thus the generation of the Kuroshio Front may result in the cross-frontal transport of marine organisms and larval fishes in the study area. As a consequence, the abundance of the Kuroshio Group's dominant species was strongly related to the intrusion intensity of the KC. The greater the KC intrusion, the more abundant the Kuroshio species will be. Based on the above, the front plays an important role in the distribution of larval fishes in wintertime.

In summary, our results indicate that the horizontal distribution of larval fish in the shelf region of the southern ECS is highly influenced by the dynamics of the intrusion of the Kuroshio Front. Although we did not confirm the other season of larval fish, different patterns of other seasonal variations in the water would affect the horizontal distribution of larval fish. Indeed, larval fish were found in greater abundance in the Kuroshio Front region rather than in the inner shelf region, but the relative abundance of different species varied significantly between on-shelf and off-shelf. Thus, we conclude that cross-shelf advections associated with the Kuroshio Front strongly affect the survival strategies adopted in early life stages by both larval transports. Future studies must clarify the seasonal variation of fish larvae in relation to hydrographic conditions in the southern ECS.

ACKNOWLEDGMENTS

We are grateful to the National Science Council of the republic of China (ROC) for financial support (NSC 99-2611-M-019-013 and 100-2611-M-019-005). Special thanks are due to Dr. C. T. Shih and I. Belkin for their generous input and guidance through the revision process.

REFERENCES

1. Belkin, I. M., Cornillon, P. C., and Sherman, K., "Fronts in large marine ecosystems," *Progress in Oceanography*, Vol. 81, pp. 223-236 (2009).
2. Chang, Y., Lee, M. A., Shimada, T., Sakaida, F., Kawamura, H., Chan, J. W., and Lu, H. J., "Wintertime high-resolution features of sea surface

temperature and chlorophyll-a fields associated with oceanic fronts in the southern East China Sea," *International Journal of Remote Sensing*, Vol. 29, pp. 6249-6261 (2008).

3. Chang, Y., Shimada, T., Lee, M. A., Lu, H. J., Sakaida, F., and Kawamura, H., "Wintertime sea surface temperature fronts in the Taiwan Strait," *Geophysical Research Letters*, Vol. 33 (2006).
4. Chen, C. T. A., "Chemical and physical fronts in the Bohai, Yellow and East China Seas," *Journal of Marine Systems*, Vol. 78, pp. 394-410 (2009).
5. Chen, Y. L. L., Chen, H. Y., Gong, G. C., Lin, Y. H., Jan, S., and Takahashi, M., "Phytoplankton production during a summer coastal upwelling in the East China Sea", *Continental Shelf Research*, Vol. 24, pp. 1321-1338 (2004).
6. Chiou, W. D., Chen, C. Y., Wang, C. M., and Chen, C. T., "Food and feeding habits of ribbonfish *Trichiurus lepturus* in coastal waters of south-western Taiwan," *Fisheries Science*, Vol. 72, pp. 373-381 (2006).
7. Chiu, T. S. and Hsyu, Y. H., "Interannual variation of ichthyoplankton density and species composition in the waters off northeastern Taiwan," *Marine Biology*, Vol. 119, pp. 441-448 (1994).
8. Epifanio, C. E. and Garvine, R. W., "Larval transport on the Atlantic continental shelf of North America: a review," *Estuarine Coastal and Shelf Science*, Vol. 52, pp. 51-77 (2001).
9. Gong, G. C., Chang, J., Chiang, K. P., Hsiung, T. M., Hung, C. C., Duan, S. W., and Codispoti, L. A., "Reduction of primary production and changing of nutrient ratio in the East China Sea: Effect of the Three Gorges Dam?" *Geophysical Research Letters*, Vol. 33, p. 4 (2006).
10. Gong, G. C., Liu, K. K., and Pai, S. C., "Prediction of nitrate concentration from 2 end-member mixing in the southern East-China-Sea", *Continental Shelf Research*, Vol. 15, pp. 827-842 (1995).
11. Gong, G. C., Shiah, F. K., Liu, K. K. Chuang, W. S., and Chang, J., "Effect of the Kuroshio intrusion on the chlorophyll distribution in the southern East China Sea during spring 1993," *Continental Shelf Research*, Vol. 17, pp. 79-94 (1997).
12. Gong, G. C., Wen, Y. H., Wang, B. W., and Liu, G. J., "Seasonal variation of chlorophyll a concentration, primary production and environmental conditions in the subtropical East China Sea," *Deep-Sea Research Part II-Topical Studies in Oceanography*, Vol. 50, pp. 1219-1236 (2003).
13. Grioche, A. and Koubbi, P., "A preliminary study of the influence of a coastal frontal structure on ichthyoplankton assemblages in the English Channel," *ICES Journal of Marine Science*, Vol. 54, pp. 93-104 (1997).
14. Hickox, R., Belkin, I., Cornillon, P., and Shan, Z., "Climatology and seasonal variability of ocean fronts in the east China, Yellow and Bohai Seas from satellite SST data," *Geophysical Research Letters*, Vol. 27, pp. 2945-2948 (2000).
15. Houde, E. D., "Emerging from Hjort's shadow," *Journal of Northwest Atlantic Fishery Science*, Vol. 41, pp. 53-70 (2008).
16. Hsieh, F. J., Lee, M. A., Pan, J. Y., Wang, Y. T., Lan, K. W., and Lan, Y. C., "Winter distribution and composition of ichthyoplankton associated with thermal front on the continental shelf of the southern East China Sea," *Journal of the Fisheries Society of Taiwan*, Vol. 34, No. 1, pp. 69-85 (2007).
17. Hsieh, H. Y., Lo, W. T., Liu, D. C., Hsu, P. K., and Su, W. C., "Winter spatial distribution of fish larvae assemblages relative to the hydrograph of the waters surrounding Taiwan," *Environmental Biology of Fishes*, Vol. 78, pp. 333-346 (2007).
18. Hsieh, H. Y., Lo, W. T., Liu, D. C., and Su, W. C., "Influence of hydrographic features on larval fish distribution during the south-westerly monsoon in the waters of Taiwan, western North Pacific Ocean," *Journal of Fish Biology*, Vol. 76, pp. 2521-2539 (2010).
19. Hsieh, H. Y., Lo, W. T., Wu, L. J., Liu, D. C., and Su, W. C., "Monsoon-driven succession of the larval fish assemblage in the East China Sea shelf waters off northern Taiwan," *Journal of Oceanography*, Vol. 67, pp. 159-172 (2011).
20. Huang, J. B. and Chiu, T. S., "Seasonal and hydrographic variations of ichthyoplankton density and composition in the Kuroshio edge exchange area off northeastern Taiwan," *Zoological Studies*, Vol. 37, pp. 63-73 (1998).
21. Iseki, K. and Kiyomoto, Y., "Distribution and settling of Japanese anchovy (*Engraulis japonicus*) eggs at the spawning ground off Changjiang River in the East China Sea," *Fisheries Oceanography*, Vol. 6, pp. 205-210 (1997).
22. Jan, S., Sheu, D. D., and Kuo, H. M., "Water mass and throughflow transport variability in the Taiwan Strait," *Journal of Geophysical Research: Oceans (1987-2012)*, Vol. 111 (2006).
23. Jan, S., Wang, J., Chern, C. S., and Chao, S. Y., "Seasonal variation of the circulation in the Taiwan Strait," *Journal of Marine Systems*, Vol. 35, pp. 249-268 (2002).
24. Lan, Y. C., Lee, M. A., Liao, C. H., Chen, W. Y., Lee, D. A., Liu, D. C., and Su, W. C., "Copepod community changes in the southern East China Sea between the early and late northeasterly monsoon," *Zoological Studies*, Vol. 47, pp. 61-74 (2008).
25. Lee, M. A., Lee, K. T., and Ou, H. C., "The Larval anchovy fishing ground formation in relation to osmotic pressure changes of the coastal waters along southern Taiwan," *Journal of the Fisheries Society of Taiwan*, Vol. 17, No. 4, pp. 233-245 (1990).
26. Lee, M. A., Chang, Y., Lee, K. T., Chan, J. W., Liu, D. C., and Su, W. C., "A satellite and field view of the winter SST variability in the Taiwan strait," *IEEE International Geoscience and Remote Sensing Symposium*, Vol. 4, pp. 2621-2626 (2005).
27. Lee, M. A., Chang, Y., Sakaida, F., Kawamura, H., Cheng, C. H., Chan, J. W., and Huang, I., "Validation of satellite-derived sea surface temperatures for waters around Taiwan," *Terrestrial Atmospheric and Oceanic Sciences*, Vol. 16, pp. 1189-1204 (2005).
28. Leis, J. M. and Rennis, D. S., *The Larvae of Indo-Pacific Coral Reef Fishes*, New South Wales University press and University of Hawaii Press (1983).
29. Lie, H. J. and Cho, C. H., "Recent advances in understanding the circulation and hydrography of the East China Sea," *Fisheries Oceanography*, Vol. 11, pp. 318-328 (2002).
30. Lo, W. T., Hsieh, H. Y., Wu, L. J., Jian, H. B., Liu, D. C., and Su, W. C., "Comparison of larval fish assemblages between during and after northeasterly monsoon in the waters around Taiwan, western North Pacific," *Journal of Plankton Research*, Vol. 32, pp. 1079-1095 (2010).
31. Ning, X., Liu, Z., Cai, Y., and Fang, M., "Physicobiological oceanographic remote sensing of the East China Sea: Satellite and in situ observations," *Journal of Geophysical Research-Oceans*, Vol. 103, pp. 21623-21635 (1998).
32. Okazaki, Y. and Nakata, H., "Effect of the mesoscale hydrographic features on larval fish distribution across the shelf break of East China Sea," *Continental Shelf Research*, Vol. 27, pp. 1616-1628 (2007).
33. Okazaki, Y., Nakata, H., and Kimura, S., "Effects of frontal eddies on the distribution and food availability of anchovy larvae in the Kuroshio Extension," *Marine and Freshwater Research*, Vol. 53, pp. 403-410 (2002).
34. Okazaki, Y., Nakata, H., Kimura, S., and Kasai, A., "Offshore entrainment of anchovy larvae and its implication for their survival in a frontal region of the Kuroshio," *Marine Ecology-Progress Series*, Vol. 248, pp. 237-244 (2003).
35. Okiyama, M., *An Atlas of the Early Stage Fishes*, Japan Tokai University Press (1988).
36. Richardson, D. E., Llopiz, J. K., Guigand, C. M., and Cowen, R. K., "Larval assemblages of large and medium-sized pelagic species in the Straits of Florida," *Progress in Oceanography*, Vol. 86, pp. 8-20 (2010).
37. Ross, S. W. and Rhode, F. C., "The gobioid fishes of North Carolina (Pisces: Gobioidei)," *Bulletin of Marine Science*, Vol. 74, pp. 287-323 (2004).
38. Sassa, C. and Konishi, Y., "Vertical distribution of jack mackerel *Trachurus japonicus* larvae in the southern part of the East China Sea," *Fisheries Science*, Vol. 72, pp. 612-619 (2006).
39. Sassa, C., Konishi, Y., and Mori, K., "Distribution of jack mackerel (*Trachurus japonicus*) larvae and juveniles in the East China Sea, with special reference to the larval transport by the Kuroshio Current," *Fisheries Oceanography*, Vol. 15, pp. 508-518 (2006).
40. Sassa, C., Moser, H. G., and Kawaguchi, K., "Horizontal and vertical

distribution patterns of larval myctophid fishes in the Kuroshio Current region," *Fisheries Oceanography*, Vol. 11, pp. 1-10 (2002).

41. Sassa, C., Tsukamoto, Y., and Konishi, Y., "Diet composition and feeding habits of *Trachurus japonicus* and *Scomber* spp. larvae in the shelf break region of the East China Sea," *Bulletin of Marine Science*, Vol. 82, pp. 137-153 (2008).
42. Sassa, C., Tsukamoto, Y., Nishiuchi, K., and Konishi, Y., "Spawning ground and larval transport processes of jack mackerel *Trachurus japonicus* in the shelf-break region of the southern East China Sea," *Continental Shelf Research*, Vol. 28, pp. 2574-2583 (2008).
43. Shimada, T., Sakaida, F., Kawamura, H., and Okumura, T., "Application of an edge detection method to satellite images for distinguishing sea surface temperature fronts near the Japanese coast," *Remote Sensing of Environment*, Vol. 98, pp. 21-34 (2005).
44. Takano, K., Takemura, A., Furihata, M., Nakanishi, T., and Hara, A., "Annual reproductive cycle and spawning cycles of female *Sebastiscus marmoratus*," *Environmental Biology of Fishes*, Vol. 30, pp. 39-48 (1991).
45. Takasuka, A., Oozeki, Y., and Aoki, I., "Optimal growth temperature hypothesis: Why do anchovy flourish and sardine collapse or vice versa under the same ocean regime?" *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 64, pp. 768-776 (2007).
46. Tang, T. Y., Tai, J. H., and Yang, Y. J., "The flow pattern north of Taiwan and the migration of the Kuroshio," *Continental Shelf Research*, Vol. 20, pp. 349-371 (2000).
47. Tzeng, W. N., "Preliminary studies on species composition of fish larvae and juveniles in the kuroshio waters adjacent to Taiwan with reference to water mass and diurnal variation," *Acta Oceanographica Taiwanica*, Vol. 22, pp. 102-115 (1989).
48. Wang, Y. T., Lee, C. L., Pan, C. I., Wu, S. H., Tseng, C. T., and Cheng, Y. X., "Species composition and distribution of fish larvae and juveniles in the waters off northeastern Taiwan in spring 2005 with particular reference to mackerel and scad," *Journal of Taiwan Fisheries Research*, Vol. 14, No. 2, pp. 27-44 (2006).
49. Wang, Y. T., Tzeng, W. N., and Lee, S. C., "A preliminary study on species composition and seasonal abundance of fish eggs and larvae from the coastal waters adjacent to the Tansui River Estuary, Taiwan (1984-1985)," *Journal of the Fisheries Society of Taiwan*, Vol. 18, No. 1, pp. 7-20 (1991).
50. Wong, G. T. F., Chao, S. Y., Li, Y. H., and Shiah, F. K., "The Kuroshio edge exchange processes (KEEP) study - an introduction to hypotheses and highlights," *Continental Shelf Research*, Vol. 20, pp. 335-347 (2000).
51. Wu, C. W., "The effect of several environmental factors on the survival rate of *Sebastiscus marmoratus* larvae," *Journal of Zhejiang Ocean University*, Vol. 1 (2000).