Ichthyoplankton community associated with oceanic fronts in early winter on the continental shelf of the southern East China Sea

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ABSTRACT

Ichthyoplankton communities associated with oceanic features on the continental shelf of the southern East China Sea (ECS) were studied in early winter of the years 2006 to 2009. Species composition of ichthyoplankton and its spatial distribution were classified and compared with oceanic fronts. In total, 1809 fish larval individuals belonging to 76 families and 137 taxa were identified from 5 field surveys. Using the Bray-Curtis dissimilarity index, the identified taxa with abundances of > 0.5% from 36 stations were classified into 4 groups: China coastal group, mixed shelf group, Taiwan Strait group, and Kuroshio group. The shallow-water species of *Sebastiscus marmoratus* dominated the China coastal group; different species components were found in the mixed shelf group (*Saurida* spp., *Trichiurus lepturus*, *Bregmaceros* spp., etc.) and Taiwan Strait group (*Engraulis japonicus* and *Benthosema pterotum*). The dominant species in the Kuroshio group could also be distinguished from the 3 other groups, including *Gonostoma gracile*, unidentified Myctophid larvae, etc. Spatial distributions of ichthyoplankton community groups were further superimposed on a thermal front map in the study area. It clearly revealed that the China coastal front could be a boundary which separated the China coastal group on the west and the mixed shelf group on the east side. In addition, the abundance and diversity of ichthyoplankton were higher in the region close to the Kuroshio front.

Key words: Ichthyoplankton, East China Sea, Kuroshio front, China coastal front.

1. Introduction

The early life stage is the most important stage for determining annual recruitment of fishes supporting various major commercial fisheries, and many studies focused on ecological aspects of the larval stage, such as the distribution, growth, and survival (Houde, 2008). An oceanic condition, such as currents, eddies, and fronts, play important roles in determining the spatial and temporal distributions of ichthyoplankton in the various seas of the world (Okazaki et al., 2002; Richardson et al., 2010). Several studies suggested fronts that occur at shelf break served as retention mechanisms by aggregating ichthyoplankton within the spawning area or drifting towards the coast (Huang and Chiu, 1998; Ross and Rhode, 2004; Sassa and Konishi, 2006; Wang et al., 1991). These biological-physical linkages are frequently observed the shelf break regions where a boundary between coastal and oceanic waters occurs. For example, dynamic interactions between the Kuroshio Current (KC) and shelf waters at the frontal boundary were thought to potentially affect larval fish transport, distribution, and prey availability (Hsieh et al., 2007a; Okazaki and Nakata, 2007; Sassa et al., 2008a, b).

The complexity of hydrographic conditions in the southern East China Sea (ECS) is influenced by seasonal changes in currents (Tang et al., 2000). Well-known physical processes in the ECS are the mechanism of the KC between the ECS and the east of Taiwan, which flows northeasterly along the edge of the continental shelf. It transports warm, saline Kuroshio waters and oceanic materials across the shelf into the southern ECS, which means that the Kuroshio front is an important factor affecting this area. Furthermore, the China Coastal Current (CCC) and Taiwan Strait (TS) water (TSW) also determine the major temperature-salinity structure for water masses in the study area. The upwelling caused by the intrusion of Kuroshio subsurface water to the northeast of Taiwan also provides large amounts of nutrients (Chen et al., 2004; Gong et al., 2003). The ECS features extremely stable, primarily wintertime fronts formed by a broad range of physical processes. These fronts were relatively well studied from satellite data (Belkin et al., 2009; Chang et al., 2008; Hickox et al., 2000) and in situ measurements (Chen, 2009; Lee et al., 2005a).

In winter, the TSW originates from an overshooting of the KC across the continental shelf northeast of Taiwan, and it flows northeasterly over the middle shelf of the ECS (Lie and Cho, 2002), which provides warm and saline water to the area off the southeastern Chinese coast. The CCC, associated with the Changjiang discharge, flows southward along the Chinese coast (Gong et al., 1995; Gong et al., 2003). The southern ECS (Fig. 1) is thus characterized by strong hydrodynamic front effects caused by these currents along the Chinese coast and Kuroshio edge. The China coastal front (CCF) is a boundary of cold coastal water and mixed waters on the shelf (Chang et al., 2008). In addition, the Kuroshio front to the northeast of Taiwan forms between the KC and shelf water, and reflects large variabilities in the path of the KC (Tang et al., 2000).

A previous study revealed that the KC flow pattern to the north of Taiwan migrates seasonally (Tang et al., 2000). In summer, the Kuroshio generally moves offshore from the southern edge of ECS, and splits into northeasterly mainstream and westerly currents. In winter, the KC moves closer to and sometimes onto the northern shelf of Taiwan. The intrusion of the Kuroshio dominates the flow pattern in the region, causing the disappearance or obscuring of the counterclockwise circulation and cold dome (Tang et al., 2000). The Kuroshio flow pattern north of Taiwan was found to vary by season. Variations in transport from the TS and the east of Taiwan have considerable effects on the intrusion of the Kuroshio onto the shelf. Front intrusion studies discussed how the Kuroshio in the present case produces a comprehensive (Gong et al., 1997), objectively derived, year-round climatology of ocean thermal fronts in seas east of China (Hickox et al., 2000) and identified the previously known fronts (Ning et al., 1998). Lan et al. (2008) indicated that seasonal exchanges between coastal and offshore waters could influence the zooplankton, the distribution of which can be divided into 2 distinct communities (inshore and offshore) defined by the dominance of different species. Okazaki and Nakata (2007) also suggested that the Kuroshio frontal eddy may affect larval distributions, due to variations in primary production in the frontal region. However, a comprehensive and definitive pattern of the thermal front and its relationship with fish larvae cannot yet be constructed.

Two major oceanographic research projects in Taiwan, the Kuroshio Edge Exchange Processes (KEEP) (Wong et al., 2000) and Long-term Observations and Research of the East China Sea (LORECS), focused on investigating seasonal variations in hydrographic conditions in the ECS (Gong et al., 2006). The KEEP project has been ongoing since 1989 is a multidisciplinary study, focusing on the physical and chemical oceanography within the ECS Shelf and the exchange of material between this Shelf and its adjoining Kuroshio (Gong et al., 1997; Wong et al., 2000). A number of the KEEP studies investigated in the abundance, distribution and diversity of ichthyoplankton of the study area (Chiu and Hsyu, 1994; Huang and Chiu, 1998; Lee et al., 1990). Hsieh *et al.* (2007a) first tried to evaluate the ichthyoplankton distribution in relation to thermal fronts from a single late winter survey. However, the relation between the structure of the larval fish communities and the spatial variability of the thermal front in the continental shelf of southern ECS are still not well described in early winter. Therefore, we tried to examine spatial distributions of fish larval assemblages and their relationships to satellite-derived thermal front on the continental shelf of southern East China Sea.

2. Material and methods

Oceanic measurements and organism samples used in this study were collected from cruises 1400, 1503, 1598, 1600, and 1692 in December in 2006 to 2009 on board the *Ocean Research II* (Table 1). Hydrographic data and ichthyoplankton samplings were taken at 9 fixed stations on each cruise (Fig. 1). Ichthyoplankton was sampled using an ORI plankton net with a mouth diameter of 1.6 m and a mesh size of 330 μm. A flow meter was tied at the center of the mouth of the net to measure the filtered water volume. The ORI net was towed at ca. 1 m s^{-1} in an oblique way from 200 m deep to the surface. At shallower stations, the net was towed from 10 m above the bottom to the surface. The ichthyoplankton samples were preserved in seawater with 5% formalin. Finally, larval fishes were brought to the laboratory for further identification to the lowest taxonomic level as possible.

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 National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) sensors were also used from the Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University in this study. Satellite-derived SSTs were validated with a small bias of 0.009 °C and root mean square deviation of 0.64 °C (Lee et al., 2005b). An entropy-based edge detection method (Shimada et al., 2005) was used to detect the monthly frontal SST gradient magnitude (GM) in the southern ECS. This method is independent of annual variations in geophysical parameters which can detect and retain finer-scale SST fronts, and has been used efficiently in coastal seas (Shimada et al., 2005). The GM is calculated by the following formula:

$$\text{GM (°C/km)} = \sqrt{(\partial T/\partial x)^2 + (\partial T/\partial y)^2}\ ;$$

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

Shannon's diversity index was used to calculate the species diversity, and Simpson's evenness was further used to estimate the relative abundances of species at each station. Shannon's diversity index and Simpson's evenness were calculated using the PRIMER (vers. 6) program. A cluster analysis was used for log (X+1) transformation performed with the STATISTIA 7 statistical software package. A cluster analysis with normalized Euclidean distances was used to investigate levels of similarity in species compositions among sampling stations, and Ward's method was used to illustrate the relation of these stations in a dendrogram.

3. Results

3.1. Hydrographic conditions

The temperature-salinity (T-S) diagram of the study area is shown in Fig. 2 and compared with the results of previous studies (Gong et al., 1995; Jan et al., 2006). According to Gong et al. (1995), the range of the mainstream KC was denoted by a solid line, and the TSW was distributed to the west of the KC. The dashed line also denotes the KC mainstream (Jan et al., 2006). Most stations in the offshore region in our survey were considered to be KC and TSW with high water salinities (Fig. 2). Inner stations adjacent to the Chinese coast were considered to be China coastal water, with low temperatures and various salinities.

Figure 3 shows vertical profiles of water temperature and salinity along the transect of sampling stations during the study period. In December 2006 (Fig. 3a, b), water in the middle of the shelf (at stations K4~K7) was composed of warm shelf water (temperature > 22 °C, salinity < 34.4 psu), while the offshore region, to the east of station K7, was blocked by KC upwelling water with temperatures of < 20 °C and salinities of > 34.4 psu. It was noted that in 2007, the KC had obviously intruded onto the shelf of the southern ECS (stations K5~K7, Fig. 3c, d), which resulted in clear upwelling of Kuroshio subsurface water with temperatures of < 20 °C and salinities of > 34.4 psu. However, the profiles in 2008 and 2009 (Fig. 3e, h) revealed that the KC had intruded onto the shelf, but the subsurface upwelling water (temperatures of > 20 °C, salinities of < 34.4 psu) was repressed at the same time and to the east of station K7. This suggests that the intrusion of the KC might have occurred in early winter, but upwelling of the subsurface water did not necessarily occur. The vertical profiles can clearly reveal annual variations in water masses between the CCC and KC. In 2006, the study area was characterized by warm water from the TS.

3.2. Distributions of SST fronts and ichthyoplankton abundances

Marked thermal fronts, shown in Fig. 4, detected from satellite-derived SST data of December, were averaged to produce a 4-year monthly composite. Two significant frontal bands were found, one in the vicinity of the Chinese coast and another to the northeast of Taiwan. The former frontal band was defined as the China coastal front, and the latter was referred to as the Kuroshio front. The China coastal front was obvious along the 50-m isobath with an SST gradient > 0.15 °C/km, while the Kuroshio front was located between the 100- and 200-m isobaths. However, it was noted that the Kuroshio front was a combination of 2 separate frontal bands: one was a curving, blurred band on the shelf and the other was a straight, sharp band near the shelf break (white arrow) with an SST GM of > 0.2 °C/km. This short band of the Kuroshio front began near the northern tip of Taiwan and then extended northeasterly along the shelf break; we thus suggest that this frontal band is the Kuroshio shelf break front. However, this short front showed its strongest SST GM only to the west of 123°E, but it was rarely found in offshore waters.

The 4-year monthly mean abundances of larval fish species a cumulative abundance of > 50% at each station were superimposed on the SST frontal map (Fig. 4); the different scales of the circles indicate different abundances. The abundance near the China coastal front was distinctively lower (with an average abundance of < 80 individuals (ind.)/1000 m^3), but the abundance clearly increased (average abundance of > 150 ind./1000 m^3) at stations close to the Kuroshio front, and in the middle of the shelf was ca. 100 ind./1000 m^3. Larval fish species with a cumulative abundance of > 50% were abundant at the Kuroshio front. This suggests that the Kuroshio front was an exceptional phenomenon which made the water very suitable for some species.

The maximum value of the SST GM for every frontal boundary in each year from 2006 to 2009 was extracted as frontal boundary lines and superimposed on Fig. 5. The boundaries of the China coastal front, Kuroshio front, and Kuroshio shelf break front are respectively denoted by dotted, solid, and dashed lines. We determined that the boundaries of the China coastal front was permanently distributed along the 50-m isobath with slightly variations and the Kuroshio shelf break front existed along the shelf break. However, the curving Kuroshio front on the shelf significantly varied with year. It was noted that the Kuroshio front moved offshore in 2006 (gray curve), but it intruded more inshore in 2007 (black curve). For 2008 and 2009, the Kuroshio front exhibited normal distributions near the 100-m isobath.

3.3. Distribution of ichthyoplankton assemblages

In total, 1809 fish larval individuals representing 76 families and 137 taxa were collected in the 5 surveys. In the oblique net tows in December of the years 2006 to 2009, 6060.39 ind./1000 m^3 larvae were captured (Table 2). Thirteen taxa contributed approximately 75% to the total catch: Myctophid larvae, *Gonostoma gracile*, *Sebastiscus marmoratus*, *Benthosema pterotum*, *Bregmaceros* spp., *Engraulis japonicus*, *Saurida* spp., *Encrasicholina punctifer*, *Trichiurus lepturus*, Apogonid larvae, Callionymid larvae, *Scomber* spp. and Serranid larvae. In the dendrogram using Bray-Curtis dissimilarity, identified taxa with > 0.5% abundance from 36 stations for tows that caught at least 1 larva were classified into 4 groups: A, B, C, and D (Fig. 6). According to geolocations of every single station comprising each group, the defined 4 groups were 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 was *Sebastiscus marmoratus*; this differed from the species in the mixed shelf group (*Saurida* spp., *Trichiurus lepturus*, and *Bregmaceros* spp.) and Taiwan Strait group (*Engraulis japonicus* and *Benthosema pterotum*). The dominant species in the Kuroshio group could also be distinguished from the other 3 groups (*Gonostoma gracile* and Myctophid larvae; Table 2, boldface).

Stations of the China coastal group were located in the region of cold fresh waters that were influenced by the CCC. Hydrographic features where the mixed shelf group was distributed were distinctive with wide variations in water temperatures and salinities. The Taiwan Strait group was only identified from sampling data in 2006, where the T-S diagram showed the stations were surrounded by the TSW (Figs. 2, 3). Stations of the Kuroshio group were located between the Kuroshio front region and the edge of the continental shelf. The water in this region was warm and saline and was supplied from an intrusion of the KC. In 2007 to 2009, the Kuroshio front intruded more inshore and varied between stations K7 and K8 (Fig. 5), and the Kuroshio groups were mostly to the east of the front. Fish congregated in the mixing zone, where the CCC and the KC blended, creating a complex temperature and salinity structure, as the mixed shelf group. However, a special case occurred in 2006 that the KC receded onto the shelf as the Taiwan Strait warm water intruded into the middle shelf area. In our results, the annual variation in water masses caused the discrepancy on the larval cluster analysis.

In contrast, a water mass of approximately 23 °C intruded into the southern ECS where waters of the TSW intruded in 2006. The larval fish distribution in 2006 was densest in the middle shelf region from stations K3 to K8, and only a few larval fish were distributed in the China coastal area. Therefore, our results divided the fish distributions in the middle shelf region into 2 groups: the China Coastal group in 2007 to 2009 and the Taiwan Strait group in 2006. The China coastal group located in the area surrounded by the Chinese coast in 2007 to 2009 clearly revealed that the Chinese coastal front could be the boundary, which separated the China coastal group to the west and the mixed shelf group to the east. In addition, the Kuroshio front on the shelf bounded the Taiwan Strait group in the northern end of the TS, and separated the Kuroshio group in the Kuroshio region in the east.

3.4. Specific taxon distributions, abundances, and diversity

The abundances of the larval assemblages were relatively high in the Kuroshio region and were low in coastal regions (Fig. 4, Table 2). We examined the cross-shelf distribution of dominant fish larvae from 2006 to 2009 (Fig. 7) with vertical dashed lines indicating the China Coastal front and solid line indicating the Kuroshio front (standards marked as the place closest to the Chinese coast referring to Fig. 5). It should be noted that *Sebastiscus marmoratus* was mostly found 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 in the shelf region. As shown in Fig. 7, *Benthosema pterotum* had the highest abundances on both sides of the Kuroshio front region, although part of its assemblage was also distributed at stations K3 to K8 in 2006. *Engraulis japonicus* was distributed at stations K4 to K7 only in 2006, and *Trichiurus lepturus* was abundant at stations K5 and K6 in 2007. *Bregmaceros* spp. were found in waters of all stations, and *Gonostoma gracile* was abundant in the warm Kuroshio stations in 2007, when the surface water of the KC had intruded further onto the shelf.

The variation of larval fish abundance and diversity in relation to the position of Kuroshio front were shown in Fig. 8. The x-axis shows the distance of each station in reference to the Kuroshio front, with negative values indicating the distance of stations to the west of the front, and positive values revealing the region to the east of the front. It was interesting that the abundance of larvae (Fig. 8a) was usually lower in the western region far from the Kuroshio front, but higher at stations close to the front. Shannon's diversity index value of larval fishes (Fig. 8b) gradually increased at stations closer to the Kuroshio front.

4. Discussion

The survival of larval fishes greatly depends on environmental factors such as fronts and currents (Grioche and Koubbi, 1997; Okazaki et al., 2003), frontal eddies (Okazaki and Nakata, 2007; Okazaki et al., 2002), and tides (Epifanio and Garvine, 2001). In this study, the spatial distributions and species components of larval fishes may have been strongly affected by variations in water masses on the continental shelf of the southern ECS. The hydrographic features on the shelf of the ECS during the early winter are strongly influenced by the KC and CCC. These features associated with the topography contribute to the formation of thermal fronts between the water masses. The China coastal front is a long frontal band along the Chinese coast, which acts as a boundary between cold, fresh coastal water and warm, saline mixed shelf water (Chang et al., 2006). On the other hand, the Kuroshio front forming on the shelf could be attributed to the Kuroshio intrusion, and its subsurface upwelling interacted with mixing shelf water, thus simultaneously resulting in thermal fronts and high chlorophyll concentrations (Chang et al., 2008). Although the curving part of this front was well defined by Hickox et al. (2000) and Chang et al. (2006, 2008), the straight, sharp band was rarely discussed previously. It is suggested that the short distribution of the Kuroshio shelf break front on the west side of 123°E might resulted from the interaction between the KC and uplifted topography at the northern tip of Taiwan. While the Kuroshio flows into the Okinawa Trough from 123°E, the topography sharply decreases, which would made the water mass more stable, resulting in a rarely occurring thermal front.

In addition, 4 major assemblages of larval fishes were defined based on hydrographic features and thermal fronts in this study. They are the China coastal group, mixed shelf group, Taiwan Strait group, and Kuroshio group. During sampling periods, abundances varied significantly in each group, while the Kuroshio group had higher abundances than the China coastal group. Moreover, species components also revealed significant differences among the groups, with detail comparisons described bellow.

4.1. China coastal group

The China coastal assemblage was distinguished by a greater abundance of *Sebastiscus marmoratus* (i.e., rockfish), which prefers shallow near-shore water or rocky bottoms (Okiyama, 1988). This ovoviviparous species has a long spawning period. Its larvae can be found from November to May (Okiyama, 1988); but it is abundant during December to March in waters near Taiwan (Takano et al., 1991). Although fish eggs and larvae may have been transported from elsewhere or aggregated by environmental factors (Sassa et al., 2006), the distribution of the larval fish relative to the front suggests adaptive spawning strategies in response to environmental conditions (Ross and Rhode, 2004). However, because it is ovoviviparous, there were no eggs of *S. marmoratus*, but larval fishes after hatching were at the pre-flexion stage. Nevertheless, pre-flexion stage larvae still have no swimming ability. Therefore, the survival of *S. marmoratus* larvae still depends on environmental factors. Wu (2000) studied the effect of several environmental factors on the life, growth, and survival of *S. marmoratus* larvae. His results showed that *S. marmoratus* larvae schooled, were attracted to weak light, and were transported by currents. Results also suggested that the optimal survival temperature of this species was in a water mass at 10~14 °C. To compare hydrographic data in our study, the CCC (temperature < 19 °C, salinity < 33 psu) flowed southward and extended more offshore in 2008 and 2009 (Fig. 3e-h) than in the other 2 years. The spatial distribution of dominant species in Fig. 7 also revealed that abundances of *S. marmoratus* were higher at stations K1 and K2 in 2008 and 2009 (Fig. 7c, d), which was bounded by the China coastal front (gray dashed line) to the west. As a consequence, the temporal-spatial distribution of the southerly CCC and abundance of *S. marmoratus* seemed to be highly related. In addition, brood fishes of *S. marmoratus* ascribed as being ovoviviparous would select a beneficial environment for their larvae to survive and remain. As a result, the shallow, low-temperature water along the Chinese coast is the best choice for them. We thus suggest that the southerly movement of the CCC with temperatures of < 19 °C might make a suitable environment for *S. marmoratus*, such that its great abundance was found near the Chinese coast in years with strong intrusion of the CCC.

4.2. Mixed shelf group

The mixed shelf assemblage was distinguished by *Trichiurus lepturus*, *Saurida* spp. and *Bregmaceros* spp. In general, *T. lepturus* is found throughout the tropical and temperate waters of the world, and its larvae are usually inhabited in muddy bottoms of shallow coastal waters and often enter estuaries for feeding. *Saurida* spp. are usually distributed in shallow waters and estuaries on the shelf (Leis and Rennis, 1983). *Bregmaceros* spp. larvae are distributed from shallow to deep waters around Taiwan (Hsieh et al., 2007b; Lo et al., 2010), but most adults of *Bregmaceros* spp. are distributed in deeper waters. In addition, the environment of the mixed shelf region was complex, where mixing of inner-shore and outer-shore waters occurred. Therefore, *T. lepturus*, *Saurida* spp., and *Bregmaceros* spp., were widely distributed on the ECS shelf, so these 3 taxa were defined as mixed shelf group in this study. However, the distribution of these fish larvae seemed to be associated with topographic features and currents. *T. lepturus* was distributed at the northern end of Taiwan Strait, to the west of the Kuroshio front during the study period. Abundances of *T. lepturus* reached a maximum at stations K5 and K6 (Fig. 7b), which are occupied by mixed shelf water. High abundances of *T. lepturus* were also found by Hsieh et al. (2007a) at similar locations. Our results further revealed that *T. lepturus* was more abundant in 2007 than in other years. Adult *T. lepturus* is widely distributed with multi-spawning times in the ECS and Taiwan Strait (Chiou et al., 2006; Hsieh et al., 2007b; Wang et al., 2006); however, such annual variations of its larval fish abundances in this region were rarely discussed. We thus suggest that the intrusion of the KC might compress the space where *T. lepturus* larvae exist thus increasing the density of the larvae in the shelf region. This might have caused the great abundance found in the middle shelf in the year with strong intrusion of the KC. However, studying the detail mechanisms of larval spatial distributions related to oceanography still remains for the future.

4.3. Taiwan Strait group

The Taiwan Strait assemblage was distinguished by *Engraulis japonicus* and *Benthosema pterotum* larvae, which were only abundant in the northern end of the TS in 2006. In general, *B. pterotum* is a kind of lanternfish, the habitat of which is in benthopelagic and mesopelagic areas of the slope and in continental and island waters. According to Huang and Chiu (1998) and Chiu and Hsyu (1994), *B. pterotum* is abundant in winter and is the most common lanternfish species in the southern ECS. Huang and Chiu (1998) also indicated that *B. pterotum* was widely distributed around the waters of Taiwan, especially in the TS, which corresponds with our results. However, the warm TSW only appeared in 2006 and showed the TS larval group.

It was also found that *E. japonicus* was abundant in the northern end of the TS where the water temperature was about 22 °C. It is well known that *E. japonicus* is a major species in the inshore waters of the continental shelf area. It comes in large schools near the surface, mainly in coastal waters but as far out as over 1000 km from the shore. Spatial patterns in the distribution and abundance of *E. japonicus* eggs were studied in the area off the Changjiang River, China where a large spawning ground exists (Iseki and Kiyomoto, 1997). In addition, Takasuka et al. (2007) examined the growth rate of larval samples at the optimal temperature of 22.0 °C collected at different locations during various seasons. They generally moved to and aggregated in estuarine areas for feeding, where water temperatures varied 22.6~30 °C (Lee et al., 1990). According to the circulation patterns of the TS in winter (Jan et al., 2002), a portion of the southward penetration of the CCC is deflected by the Chang-Yuen Ridge and turns back northeastward. As show in SST images (Fig. 9a), it was noted that in 2006, the TSW significantly intruded northward to the northern TS, while the feature was not found in the other 3 years. The northward TSW might bring a reflux of the CCC (arrows) from the northern Chang-Yuen Ridge to the northern TS. Therefore, the interaction between the northerly intrusion of TSW and a portion of the CCC could play an important role in ichthyoplankton transport in the study area. Judging from the fish larval distributions and hydrographic features in this study, we suggest that *E. japonicus* which spawns offshore of the Changjiang area may be driven southerly to the TS by the CCC after the fish have hatched. In addition, the northward current mixed with a reflux portion of the CCC and TSW could thus transport *E. japonicus* and *B. pterotum* to the southern ECS from the TS.

4.4. Kuroshio group

The Kuroshio assemblage was distinguished by *Gonostoma gracile* and Myctophid larvae, and was unique from the other groups. Figure 7b shows that in 2007, the major species of *G. gracile* in the Kuroshio group was significantly abundant at stations to the east of the Kuroshio front. Abundant *G. gracile* and Myctophid larvae observed in the present study corresponded to spatial distributions reported by Hsieh et al. (2007b) and Tzeng (1989). Indeed, *G. gracile* and Myctophid larvae are both lanternfishes, a kind of mesopelagic species among the most widely distributed, populous, and diverse of all vertebrates, which play important ecological roles as prey for larger organisms. Some species of the Myctophidae and Gonostomatidae are used as indicator species of the KC because they mostly occur within the KC and adjacent areas (Hsieh et al., 2010). However, in 2006, the Kuroshio group was not observed in the southern ECS as the Kuroshio front had formed far from the shelf (gray contour in Fig. 5).

The schematic map in Fig. 5 reveals that the straight-sharp Kuroshio shelf break front was persistent near the 200-m isobath; however, the curving Kuroshio front on the shelf changed with clear annual variations. It is well known that the frontal band caused by the topographic uplift and Kuroshio intrusion is a unique feature in waters northeast of Taiwan (Tang et al., 2000), an important region for the transport of marine organisms. Previous studies indicated that the Kuroshio collides with the continental shelf break of the ECS with different scales of temporal variations from daily, monthly to annually (Chang et al., 2008; Lee et al., 2005a; Tang et al., 2000). Lee et al. (2005a) further suggested that the more-northerly intrusion of TSW from the Strait can result in a more-offshore distribution of the Kuroshio front in northeastern Taiwan. This corresponds well with the SST images in this study (Fig. 9a), i.e., the TSW current had intruded further northward in 2006. According to Okazaki and Nakata (2007), the abundance and diversity of larval fishes were less at lower temperatures and increased with increasing temperature of these waters. Lan et al. (2008) also indicated the abundance and Shannon’s diversity index value of plankton increased near the Kuroshio front area. Figure 8 thus provides clearer features of the relationship between the Kuroshio front and spatial distribution of biodiversity. As a consequence, we suggest that when the Kuroshio front forms more inshore, a greater abundance of *G. gracile* will be found in the Kuroshio region.

5. Conclusion

The spatial distribution of the dominant species of *Sebastiscus marmoratus* was higher in the region close to the Chinese coast and was bounded by the China coastal front. Our data further showed that abundance of *S. marmoratus* was highly related to the strong southerly movement of the CCC where the environment may be suitable for the survival of *S. marmoratus* larvae. Although *Trichiurus lepturus* is widely distributed on the ECS shelf, which was defined as the mixed shelf group in this study, its distribution seemed to be associated with the Kuroshio front intrusion. However, the relationship between the mixed water and larval assemblage of *T. lepturus* is not understood yet. In addition, the unique distribution of *Engraulis japonicus* observed in 2006 was suggested to be caused by an interaction between a portion of the CCC at the Chang-Yuen Ridge and the northward TSW. We suggest that larval *E. japonicus* is driven southerly along the Chinese coast by the CCC, and is transported to the northern end of the TS by a reflux portion of the CCC and TSW. Based on the above information, the front plays an important part in larval fishes. The migration of the Kuroshio front causes annual variability in the spatial distributions of *Gonostoma gracile* and Myctophid larvae. The Kuroshio front is accompanied by an interaction with KC intrusions into the inner shelf and the mixed shelf water flowing from the TS; thus, generation of the Kuroshio front may result in cross-frontal transport of marine organisms and larval fishes in the study area. As a consequence, abundances of Kuroshio group dominant species were strongly related to the intrusion intensity of the KC. In other words, the more the KC intruded, the more abundant were Kuroshio species.

The CCC front and its reflux water caused different patterns of larvae belonging to the China coastal group. *Sebastiscus marmoratus'* distribution and the latter contribute to the abundance of *Engraulis japonicus*. 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 Kuroshio front intrusions. In addition, although we did not examine larval fish distribution in other seasons, it is likely that different patterns of seasonal variations in the water would affect the horizontal distributions of larval fishes. Moreover, larval fish abundances were higher in the Kuroshio front region than in the inner shelf region, but abundances of relatively different species significantly varied between the shelf and off the shelf. Thus, cross-shelf advection associated with the Kuroshio front was concluded to strongly affect the survival strategy of the early life stages by larval transport. Future studies need to clarify seasonal variations of fish larvae in relation to hydrographic conditions in the southern ECS.

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