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EARLY-SUMMER ICHTHYOPLANKTON BIODIVERSITY ASSOCIATED WITH OCEANIC FACTORS ON THE CONTINENTAL SHELF OF THE SOUTHERN EAST CHINA SEA

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Key words: ichthyoplankton, southern East China Sea, diversity.

ABSTRACT

Ichthyoplankton communities associated with oceanic factors on the continental shelf of the southern East China Sea were studied in early summer 2009. Temperature and salinity of the stations in this survey respectively varied 13.78~27.86°C and 33.14~34.77 psu. In total, 1204 fish larval individuals belonging to 62 families and 120 taxa were identified. Using a cluster analysis, the spatial distributions of larval fish were classified into 3 groups: a coastal group, a shelf group, and an offshore group. The offshore group was further divided into 2 subgroups: a mixed shelf group and a Kuroshio group. The coastal group consisted of 5 taxa, namely, sciaenids, gobiids, *Cynoglossus joyneri*, *Engraulis japonicas*, and *Parapercis* spp. The shelf group contained the dominant species *Decapterus* spp., sciaenids, *C. joyneri*, gobiids, *Bregmaceros* spp., *Auxis* spp., *Trachinocephalus myops*, and *Diaphus* A group. The mixed shelf group and the Kuroshio group contained the dominant species of *Decapterus* spp., and *Auxis* spp., respectively. Diversity also varied with the situation of the assemblages in that high diversity was found in offshore areas and low diversity was found in coastal areas. Sciaenids and gobiids were abundant in coastal waters; while *Decapterus* spp. and *Auxis* spp. were respectively abundant in the mixed shelf waters and the Kuroshio waters.

I. INTRODUCTION

Ocean ecosystems provide goods and services of critical importance to human societies; yet they are among the most heavily altered ecosystems with an over-proportional loss of biodiversity. Biodiversity became an important issue beginning with the Convention on Biological Diversity, known informally as the Biodiversity Convention in 1992 [25]. Srivastava and Vellend [25] reported that the past decade had seen a flurry of ecological research on the effects of biodiversity on ecosystem functions. The biodiversity-ecosystem function hypothesis posits that a reduction in biological diversity (variety of species, genotypes, etc.) will cause a reduction in ecosystem-level processes. It is necessary to understand biodiversity-ecosystem functions in order to establish a sufficient background including information on the hydrographic environment, ocean organisms, fisheries, etc.

The East China Sea (ECS) is a large marine ecosystem [1]. It extends from off the coast of Fuzhou, China (26.17°N, 120.08°E) to northeastern Taiwan (25.17°N, 122.91°E). The section is ca. 300 km long, with a mean depth of 78 m in the west, and reaching 1000 m to the northeast of Taiwan. There are several water masses such as the China Cold Current (CCC), the Kuroshio Current (KC) and the Taiwan Strait water (TSW) which meet here in certain seasons [5, 6]. The CCC may determine the hydrographic structure of the ECS in winter, while the TSW determines it in summer [5, 6]. Moreover, there is an enormous input of runoff with an average volume of 28,000 m^3/s from the Yangtze River into the ECS [8]. A cold eddy caused by upwelling of the Kuroshio subsurface water persists throughout the year [31]. Riverine runoff and upwelling together maintain a constant supply of nutrients and therefore sustain high primary productivity which supports the proliferation of marine life. Some reports indicated that economically important pelagic fishes such as the Japanese anchovy, mackerel, and swordtip squid [4, 20, 29] migrate into this area for spawning [14] and aggregating [22]. Therefore, it is also one of the traditional fishing grounds for the torchlight [29], purse seine [33], and trawling fisheries [32] of Taiwan.

Ichthyoplankton, the early life form of fish, is the most important stage for determining the annual recruitment of fishes [26, 34] and supports various major commercial fisheries, and

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Table 1. Summary of sampling date, sampling location (latitude, longitude), and bottom depth.

cruise	Ship	Date	Time	Station	Longitude	Latitude	sea bottom	ctd bottom
CR1641	OR2	Jun 16 2009	12:16:17	9	121.97	25.50	127	110
CR1641	OR2	Jun 16 2009	19:32:28	10	122.21	25.42	264	251
CR1641	OR2	Jun 16 2009	23:03:47	11	122.44	25.33	547	252
CR1641	OR2	Jun 17 2009	02:07:10	12	122.67	25.25	1029	251
CR1641	OR2	Jun 17 2009	05:12:48	13	122.91	25.17	1684	251
CR1641	OR2	Jun 17 2009	21:51:03	8	121.73	25.58	135	126
CR1641	OR2	Jun 18 2009	00:09:49	7	121.50	25.68	93	86
CR1641	OR2	Jun 18 2009	02:06:41	6	121.26	25.75	79	77
CR1641	OR2	Jun 18 2009	03:57:49	5	121.02	25.84	87	81
CR1641	OR2	Jun 18 2009	05:45:33	4	120.79	25.92	79	75
CR1641	OR2	Jun 18 2009	07:42:55	3	120.55	26.00	68	61
CR1641	OR2	Jun 18 2009	09:41:57	2	120.32	26.08	51	50
CR1641	OR2	Jun 18 2009	11:48:09	1	120.08	26.17	35	31

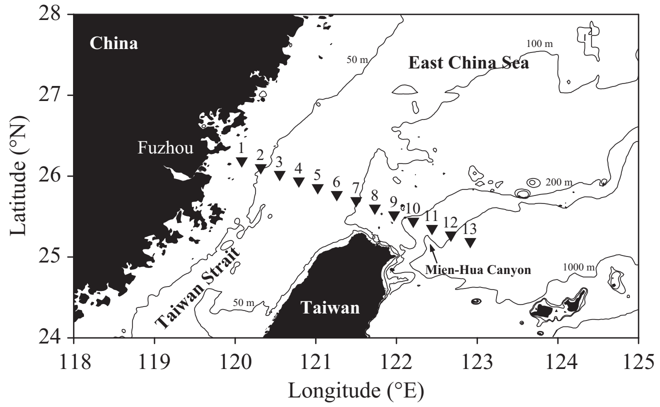

Fig. 1. Topography and locations (Inverted triangles) of sampling stations with isobaths of 50, 100, 200, and 1000 m in the study area.

many studies focused on ecological aspects of the larval stage, such as the distribution, growth, feeding [2], and survival [9]. Swimming abilities of ichthyoplankton, which are planktonic animals with little control over their trajectories, are too limited to independently move [24], in contrast to strongly swimming nektonic animals, and they have only a limited dispersal ability, such that larvae can therefore be treated as passively migrating and are expected to adapt to environmental conditions within local habitats. Understanding the biodiversity and abundance of ichthyoplankton would be helpful for establishing basic information on this area. This survey was thus intended to examine the distribution, species diversity, and assemblage of larval fish, and their associations with oceanic environmental conditions on the continental shelf of the southern ECS.

II. MATERIALS AND METHODS

Hydrographic data and ichthyoplankton samples used in this study were collected at 13 stations on the continental shelf of the southern ECS on June 16~18, 2009 during cruise 1641 of the *Ocean Research II* (Fig. 1; Table 1). Water temperatures and salinities at different depths at each station were obtained by lowering a conductivity-temperature-depth (CTD) profiler (SBE 9/11, Sea-Bird Electronics Inc. Washington, D.C., USA) from the sea surface to 250 m or to a depth near the bottom at shallow stations (Table 1). Biological samples were collected with a Bongo net with a mouth diameter of 60 cm and a mesh size of 330 μm. The filtered water volume was measured by a flow meter attached to the center of the net mouth. The net was towed obliquely from 200 m deep to the surface or from 10 m above the bottom to the surface at shallower stations. Biological samples were preserved in seawater, fixed with 5% buffered formalin, and brought to the laboratory. In the laboratory, the plankton wet weight of all samples was measured in grams. Finally, the ichthyoplankton were sorted and identified to species or the lowest taxonomic level possible in the laboratory. The developmental stages of larvae were classified into 1 of 4 ontogenetic stages as described by Kendall *et al.* [15]: yolk sac, pre-flexion larva, flexion larva, and post-flexion larva. The latter 3 stages were defined by the degree of formation of the caudal fin and concomitant flexion of the notochord.

A description and comparison of the geographic distribution of each species were based on their abundance as expressed as the number of individuals per cubic meter (ind./m^3). A cluster analysis with normalized Euclidean distances was used to measure levels of similarity in species composition among sampling stations, and Ward's method was used to illustrate their relations as a dendogram. Data used were transformed by the logarithmic function, log(X+1) and processed using a cluster analysis in the STATISTICA 7 statistical software package. Simpson's diversity and evenness indices [23] were also calculated using the PRIMER (vers. 6) program. The former was used to calculate the species diversity, and the latter was used to estimate the relative abundances of species at each station. In addition, a canonical correlation analysis (CCA) was used to describe connections between dominant species and oceanographic conditions [27].

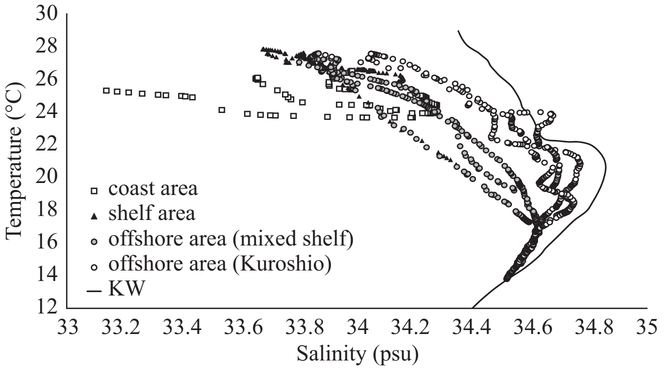

Fig. 2. Temperature-salinity (T-S) diagram of 13 surveyed stations with the Kuroshio water (KW). Squares indicate stations 1~3 which is a coastal area; triangles indicate stations 4~7 which is a shelf area; cycles indicate station 8~13 which is an offshore area.

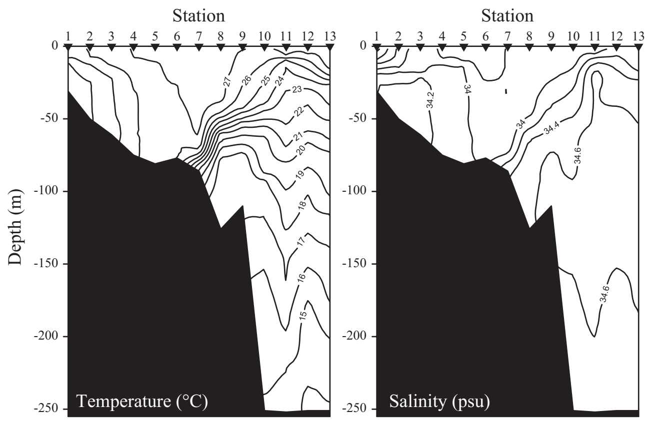

Fig. 3. Vertical profiles of temperature and salinity in the survey area.

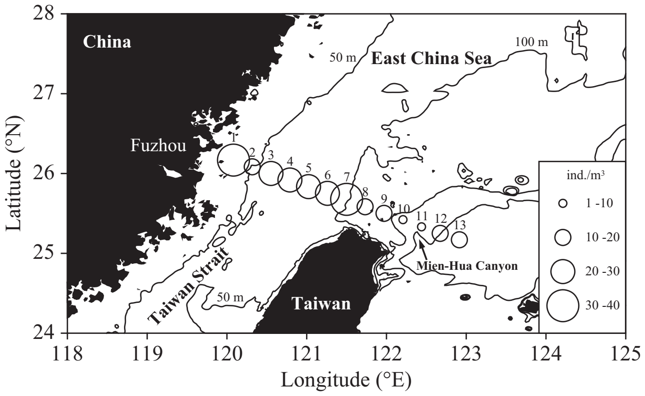

Fig. 4. Abundances of ichthyoplankton at 13 stations in the southern East China Sea in June 2009.

III. RESULTS

1. Hydrographic Conditions

A temperature-salinity (T-S) diagram of the study area is shown in Fig. 2, and temperatures varied 13.78~27.86°C and salinities varied 33.14~34.77 psu on the continental shelf of the southern ECS during the period of June 16~18, 2011. The T-S diagram shows 2 kinds of curves. One is warmer temperatures in a narrow range of ca. 24~28°C and salinities of ca. 33.2~34.2 psu at western stations 1~3 in the coastal area (Fig. 2, squares). The other one is a wide range of temperature (ca. 14~28 °C) and salinities of ca. 33.8~34.8 psu at eastern stations 8~13 in the offshore area (Fig. 2, white and gray circles).

Vertical distributions of temperature and salinity derived from the CTD data are shown in Fig. 3 as profiles along sampling stations during the survey period. Temperatures and salinities of stations in onshore waters (sea bottom < 100 m) ranged 20.8~27.86°C and 33.14~34.34 psu, respectively, while temperatures and salinities were higher at stations in offshore waters (sea bottom > 100 m), and temperature decreased with increasing depth. It was noted that the KC had obviously intruded onto the shelf of the southern ECS, which resulted in clear upwelling of Kuroshio subsurface water with temperatures of < 27°C and salinities of > 34.4 psu. This indicated that there were eastwardly increasing trends in temperature and salinity.

2. Abundance and Species Composition of Ichthyoplankton

In this study, we determined an abundance of 238.29 ind./m^3 of larval fishes. The average larval abundance was 18.33 ind./m^3 (SD, 10.2 ind./m^3), with the highest abundance of 39.3 ind./m^3 at station 1 and the lowest abundance of 4.87 ind./m^3 at station 11. Higher abundances were found in inshore waters, which decreased along the transition to the offshore area, particularly near the Mien-Hua Canyon (Fig. 4). Results of the regression analysis of abundances of larval fish and wet weights of zooplankton (Fig. 5(a)) indicated that the abundance of larval fish was positively related to the zooplankton biomass ($R^2 = 0.48$, $p < 0.05$). The combined abundance of larval fish and wet weights of zooplankton were higher throughout onshore waters (sea bottom < 100 m), and the highest wet weight of zooplankton reached 2 g/m^3 at station 1 which also had the highest larval abundance; similarly the lowest wet weight of zooplankton was 0.32 g/m^3 at station 11 (Fig. 5(b)). Compared to other stations, the abundance of larval fish at offshore water stations well fit with the decreasing trend with increasing wet weight of zooplankton from stations 9 to 13. In contrast, the wet weight of zooplankton in the coastal region varied erratically, and no tendency between stations 2 to 7 was detected, apparently a result of movements of local water masses.

In total, 1204 fish larval individuals representing 62 families and 120 taxa were collected in this survey. Some larvae could not be identified due to a mutilated condition of the specimens or yolk sac developmental stages. Larvae of each of the carangid, sciaenid, scombrid, myctophid, gobiid, and cynoglossid contributed > 5% and together accounted for 62% of the total number of larvae (Table 2). Carangids, the

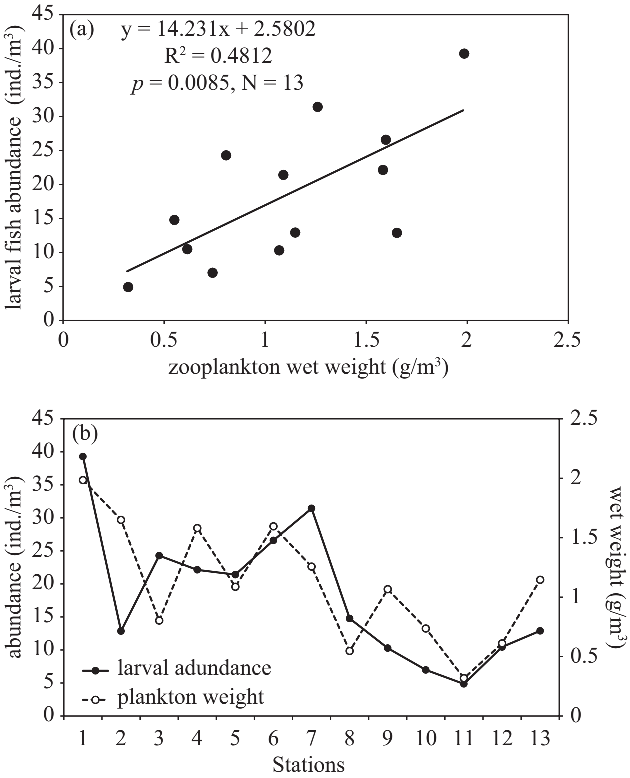

Fig. 5. (a) Relationship between larval fish abundances and zooplankton wet weight. (b) Larval fish abundances (ind./m^3) and zooplankton wet weight (g/m^3) at each station.

most dominant family that numerically accounted for 17.34% of the total sample, mainly consisted of *Decapterus* spp. (Table 2). Sciaenids were the second dominant family and accounted for 14.34% of the total sample in number. *Auxis* spp. and the *Diaphus* A group were the dominant species of scombrids and myctophids, and contributed 8.57% and 7.73%, respectively. Larvae of the 16 most abundant taxa, which individually contributed > 1%, made up approximately 77.28% of the total sample in number (Table 2).

3. Assemblages, Development Stages, and Biodiversity

Similarities of the composition of larval fish among sampling stations were analyzed based on larval fish families. According to the dendogram obtained from the cluster analysis, the 13 stations were divided into 3 groups at a distance of 14 (Fig. 6). Group A was comprised of stations 1~3 located on the western side of the survey region; group B was comprised of stations 4~7 in the middle area; and group C was comprised of stations 8-13 on the eastern side. According to the geolocations of every station comprising each group, the 3 defined groups were further referred to as the coastal group (A), shelf group (B), and offshore group (C). The coastal group (group A) consisted of 5 taxa, namely, sciaenids, gobiids, *Cynoglossus joyneri*, *Engraulis japonicas*, and *Parapercis* spp. which numerically accounted for nearly 75% of the total A group samples (Table 3). The shelf group (group B) contained the

Table 2. Larval abundances (individuals (ind.)/1000 m^3) of the major larval families (> 1%).

Family	Gen. species	abundance	sum abundance	%
Carangidae	*Decapterus* spp.	39.00	41.32	17.34
Carangidae	*Elagatis bipinnulata*	0.79		
Carangidae	*Caranx* spp.	0.58		
Carangidae	spp.	0.43		
Carangidae	*Decapterus macarellus*	0.28		
Carangidae	*Seriola dumerili*	0.13		
Carangidae	*Trachurus japonicus*	0.12		
Sciaenidae	spp.	34.18	34.18	14.34
Scombridae	*Auxis* spp.	18.16	20.42	8.57
Scombridae	*Scomber* spp.	1.71		
Scombridae	*Gymnosarda unicolor*	0.55		
Myctophidae	*Diaphus* A group	6.87	18.42	7.73
Myctophidae	*Benthosema pterotum*	5.31		
Myctophidae	*Diaphus* B group	2.45		
Myctophidae	*Lampanyctus* spp.	1.66		
Myctophidae	*Myctophum asperum*	0.44		
Myctophidae	*Myctophum orientale*	0.41		
Myctophidae	*Myctophum obtusirostre*	0.23		
Myctophidae	*Hygophum reinhardtii*	0.22		
Myctophidae	*Hygophum proximum*	0.19		
Myctophidae	*Benthosema* spp.	0.18		
Myctophidae	*Hygophum* spp.	0.07		
Myctophidae	*Lampadena* spp.	0.07		
Myctophidae	*Benthosema suborbitable*	0.06		
Myctophidae	*Myctophum spinosum*	0.06		
Myctophidae	spp.	0.20		
Gobiidae	spp.	16.79	17.99	7.55
Gobiidae	*Heteroplopomus barbatus*	0.80		
Gobiidae	*Bathygobius cotticeps*	0.40		
Cynoglossidae	*Cynoglossus joyneri*	15.68	15.75	6.61
Cynoglossidae	*Symphurus orientalis*	0.06		
Bregmacerotidae	*Bregmaceros spp.*	7.62	7.62	3.20
Engraulididae	*Engraulis japonicus*	5.40	6.48	2.72
Engraulididae	*Encrasicholina heteroloba*	0.60		
Engraulididae	*Encrasicholina punctifer*	0.48		
Mugiloididae	*Parapercis* spp.	4.33	4.39	1.84
Mugiloididae	spp.	0.06		
Synodontidae	*Trachinocephalus myops*	3.47	3.53	1.48
Synodontidae	spp.	0.06		
Serranidae	spp.	3.25	3.52	1.48
Serranidae	*Chelidoperca hirundinacea*	0.27		
Bothidae	spp.	3.11	3.18	1.33
Bothidae	*Arnoglossus* spp.	0.06		
Labridae	spp.	2.24	2.56	1.07
Labridae	*Xyrichthys* spp.	0.13		
Labridae	*Halichoeres* spp.	0.12		
Labridae	*Cirrhilabrus* spp.		0.06	
Mugilidae	spp.	2.52	2.52	1.06
Mullidae	spp.	2.40	2.40	1.01
other fishes		54.00		22.50
Sum		238.29		100.00

Table 3. Ichthyoplankton compositions of different groups as defined in Fig. 6.

Family	Species	Agroup (st. 1, 2, 3)	Bgroup (st. 4, 5, 6, 7)	C$_1$ group (st. 8, 9, 10)	C$_2$ group (st. 11, 12, 13)
Acanthuridae	*Naso unicornis*	0	0.29	0	0
Acanthuridae	spp.	0	0.27	0.10	0.16
Ammodytidae	*Embolichthys mitsukurii*	0	0.76	0	0
Anguillidae	spp.	0	0.55	0.10	0
Apogonidae	spp.	0	0.80	0.10	0
Aulopodidae	*Aulopus japonicus*	0	0.24	0.18	0
Blenniidae	*Omobranchus* spp.	0	0	0	0.07
Bothidae	*Arnoglossus* spp.	0	0	0	0.06
Bothidae	spp.	0.36	1.83	0.47	0.45
Bramidae	spp.	0	0	0.22	0.46
Bregmacerotidae	*Bregmaceros* spp.	3.57	3.42	0.41	0.22
Callionymidae	spp.	0	0	0.45	0
Carangidae	*Caranx* spp.	0	0.58	0	0
Carangidae	*Decapterus macarellus*	0	0	0	0.28
Carangidae	*Decapterus* spp.	5.00	24.92	8.40	0.68
Carangidae	*Elagatis bipinnulata*	0	0.79	0	0
Carangidae	*Seriola dumerili*	0	0	0	0.13
Carangidae	*Trachurus japonicus*	0	0	0.12	0
Carangidae	spp.	0	0	0.17	0.25
Cepolidae	*Acanthocepola krusensterni*	0.54	0	0	0
Chaetodontidae	*Chaetodon unimaculatus*	0	0	0	0.09
Champsodontidae	spp.	0	0	0.10	0
Cirrhitidae	*Cyprinocirrhites polyactis*	0	0	0.25	0
Cirrhitidae	*Neocirrhites armatus*	0	0.24	0	0.19
Clupeidae	spp.	0	1.84	0	0
Coryphaenidae	*Coryphaena hippurus*	0	0.27	0.20	0.39
Coryphaenidae	spp.	0	0.29	0	0
Cynoglossidae	*Cynoglossus joyneri*	7.86	7.37	0.45	0
Cynoglossidae	*Symphurus orientalis*	0	0	0	0.06
Diodontidae	*Diodon holocanthus*	0	1.15	0.36	0
Emmelichthyidae	*Emmelichthys struhsakeri*	0	0	0	0.06
Emmelichthyidae	spp.	0	0	0	0.14
Engraulididae	*Encrasicholina heteroloba*	0.36	0.24	0	0
Engraulididae	*Encrasicholina punctifer*	0	0	0	0.48
Engraulididae	*Engraulis japonicus*	5.00	0.27	0.12	0
Gempylidae	*Gempylus serpens*	0	0	0	0.23
Gobiidae	*Bathygobius cotticeps*	0	0.27	0.12	0
Gobiidae	*Heteroplopomus barbatus*	0	0.28	0.43	0.09
Gobiidae	spp.	10.00	5.10	1.13	0.56
Gonostomatidae	*Cyclothone alba*	0	0.52	0.22	0.09
Gonostomatidae	*Cyclothone atraria*	0	0	0	0.07
Gonostomatidae	*Cyclothone pseudopallidae*	0	0	0	0.06
Gonostomatidae	*Sigmops elongatum*	0	0.28	0	0
Gonostomatidae	*Sigmops gracilis*	0	0	0.06	0.20
Gonostomatidae	spp.	0	0	0	0.19
Labridae	*Cirrhilabrus* spp.	0	0	0	0.06
Labridae	*Halichoeres* spp.	0	0	0.12	0
Labridae	*Xyrichthys* spp.	0	0	0	0.13
Labridae	spp.	0.71	1.32	0.20	0
Leiognathidae	*Leiognathus leuciscus*	0	0	0.12	0
Leiognathidae	spp.	0	0.55	0.06	0.25
Lethrinidae	*Lethrinus nematacanthus*	0	0.24	0	0
Lutjanidae	spp.	0	0.85	0	0.41
Menidae	*Mene maculata*	0	0.28	0.25	0
Menidae	spp.	0	0	0	0.13
Monacanthidae	*Aluterus* spp.	0	0.48	0	0
Monacanthidae	spp.	0	0	0	0.09
Mullidae	spp.	0.36	1.52	0.52	0
Mugilidae	spp.	2.14	0.28	0.10	0
Mugiloididae	*Parapercis* spp.	3.93	0.27	0.12	0
Mugiloididae	spp.	0	0	0.06	0
Muraenesocidae	spp.	0	1.00	0	0
Myctophidae	*Benthosema pterotum*	1.96	1.88	0.40	1.06
Myctophidae	*Benthosema suborbitable*	0	0	0	0.06
Myctophidae	*Benthosema* spp.	0	0	0.11	0.06
Myctophidae	*Diaphus* A group	0.54	2.45	1.88	2.02
Myctophidae	*Diaphus* B group	0	1.65	0	0.81
Myctophidae	*Hygophum proximum*	0	0	0	0.19
Myctophidae	*Hygophum reinhardtii*	0	0	0	0.22
Myctophidae	*Hygophum* spp.	0	0	0	0.07
Myctophidae	*Lampadena* spp.	0	0	0	0.07
Myctophidae	*Lampanyctus* spp.	0	0	0.32	1.34
Myctophidae	*Myctophum asperum*	0	0	0	0.44
Myctophidae	*Myctophum spinosum*	0	0	0	0.06
Myctophidae	*Myctophum obtusirostre*	0	0	0	0.23
Myctophidae	*Myctophum orientale*	0	0.28	0	0.13
Myctophidae	spp.	0	0	0	0.20
Nemipteridae	spp.	0	0	0	0.21
Nettastomatidae	*Nettenchlys gephyra*	0	0.24	0	0
Notosudidae	*Scopelosaurus* spp.	0	0	0	0.06
Nomeidae	*Cubiceps* spp.	0	0	0.10	0
Nomeidae	*Psenes* spp.	0	0	0	0.09
Nomeidae	spp.	0	0	0.11	0.16
Ophichthidae	spp.	0	1.68	0.10	0
Paralepididae	*Lestidiops* spp.	0	0	0	0.06
Paralepididae	*Stemonosudis elegans*	0	0.29	0	0
Percichthyidae	*Synagrops philippinensis*	0	0	0.12	0
Percichthyidae	spp.	0	0.28	0	0
Phosichthyidae	*Vinciguerria nimbaria*	0	1.08	0.18	0.45
Platycephalidae	spp.	0	0.52	0	0.09
Pleuronectidae	spp.	0	0	0.22	0.06
Priacanthidae	*Priacanthus* spp.	0	1.07	0.52	0.41
Scaridae	*Scarus* spp.	0	0.58	0	0
Scaridae	spp.	0	1.10	0	0
Sciaenidae	spp.	23.04	9.26	1.68	0.20
Scombridae	*Auxis* spp.	1.79	2.07	5.68	8.63
Scombridae	*Gymnosarda unicolor*	0	0.55	0	0
Scombridae	*Scomber* spp.	0.36	0.24	1.05	0.06
Scorpaenidae	*Minous monodactylus*	0	0.29	0.12	0
Scorpaenidae	spp.	0	0.24	0.63	0.19
Serranidae	*Chelidoperca hirundinacea*	0	0.27	0	0
Serranidae	spp.	0	1.93	0.63	0.69
Soleidae	*Aseraggodes kobensis*	0	1.11	0	0
Sparidae	spp.	0	0.58	0.22	0.13
Sphyraenidae	spp.	0	0	0	0.09
Stomiidae	*Stomias* spp.	0	0	0	0.07
Stomiidae	spp.	0	0	0	0.09
Synodontidae	*Trachinocephalus myops*	0	3.47	0	0
Synodontidae	spp.	0	0	0.06	0
Synanceiidae	spp.	0	0	0	0.09
Teraponidae	spp.	0	0	0	0.06
Tetraodontidae	spp.	0	0	0.12	0
Trichonotidae	*Trichonotus filamentosus*	0	0	0.06	0
Trichonotidae	*Trichonotus setigerus*	0	0.48	0	0
Trichonotidae	*Trichonotus* spp.	0	0.27	0	0
Trichiuridae	*Benthodesmus elongatus*	0	0	0	0.06
Trichiuridae	*Trichiurus lepturus*	0.36	0.82	0	0.06
Uranoscopidae	spp.	0	0	0.12	0
Zanclidae	spp.	0	0	0	0.07
unidentified		8.57	7.53	1.86	2.42

Table 4. Chi-squared tests with successive roots removed, variance extracted and factor structure.

	R	R^2	X^2	df	*p*	Bio-variance		Hydro-variance		Factor Structure			
						extracted	Reddncy.	extracted	Reddncy.	SST	SSS	SMT	SMS
factor 1	0.9946	0.9893	55.5440	20.0000	**0.0000**	0.4962	0.4909	0.2619	0.2591	0.2384	-0.2566	**0.9962**	**-0.9326**
factor 2	0.9319	0.8684	23.7886	12.0000	**0.0218**	0.3494	0.3035	0.5103	0.4432	**-0.9458**	**-0.7056**	0.0151	-0.0707
factor 3	0.8013	0.6421	9.5905	6.0000	0.1430	0.1261	0.0810	0.0875	0.0562	0.0659	0.6400	-0.0606	0.2947
factor 4	0.5386	0.2901	2.3987	2.0000	0.3014	0.0282	0.0082	0.0685	0.0199	-0.2101	0.1632	-0.0604	-0.1961

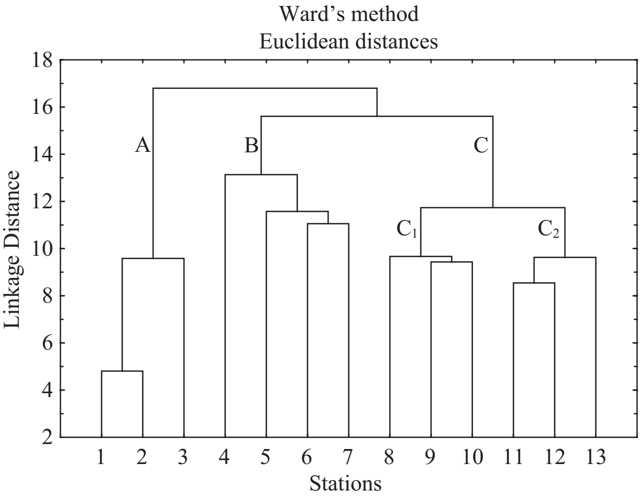

Fig. 6. Dendogram of station associations from a cluster analysis using Euclidean distances to measure levels of similarity in larval families among 13 sampled stations, as linked by Ward's method. (A, coastal group; B, shelf group; C, offshore group; C_1, mixed shelf group; and C_2, Kuroshio group).

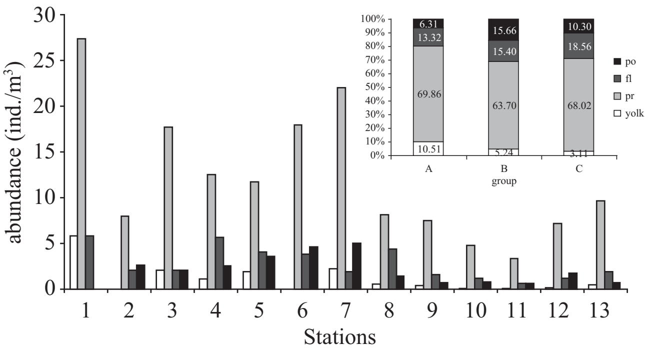

Fig. 7. Frequency distribution of development stages of each station and group.

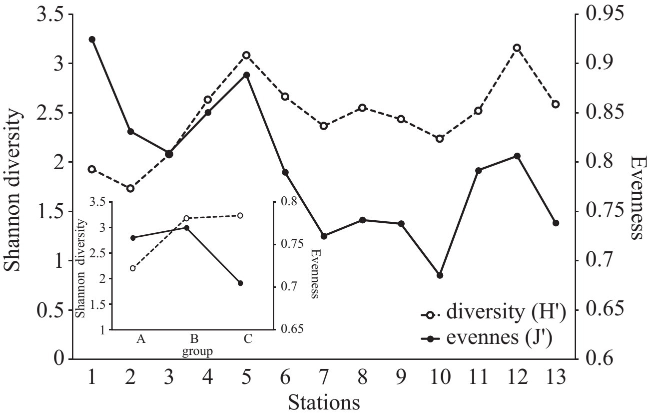

Fig. 8. Shannon's diversity and evenness of each sampling station and group.

dominant species *Decapterus* spp., as well as sciaenids, *C. joyneri*, gobiids, *Bregmaceros* spp., *Auxis* spp., *Trachinocephalus myops*, and *Diaphus* A group. The offshore group (group C) was further divided into 2 subgroups of C_1 containing stations 8~10 and C_2 containing stations 11~13. Subgroups C_1 and C_2 were further referred to as the mixed shelf group and Kuroshio group, and they respectively contained the dominant species *Decapterus* spp. and *Auxis* spp.

Frequency distributions of different development stages are shown in Fig. 7. The development stage of larval fish at each station was almost all pre-flexion (55.05%~75.54%), while the average of flexion and post-flexion stages contributed 16.23% and 12.09%, respectively; the abundance of the yolk-sac stage was higher at station 1. The yolk-sac stage was more abundant in group A (10.51%), but flexion and post-flexion stages were more abundant in groups B and C. The species diversity and evenness of larval fish at each sampling station are shown in Fig. 8. Diversity indices were highest at station 5 and lowest at station 12; while evenness indices were highest at station 1 and lowest at station 10. Diversity varied along the section from stations 1 to 13 and was higher in group B. Evenness significantly changed with the section (solid circles in Fig. 8) and was lower in group C. Responses of diversity and evenness were related to location. Specifically, diversity was enhanced at offshore sites and reduced at inshore sites.

4. Relationship between Larval Fishes and Oceanic Features

The CCA diagram derived from the abundances of the first 5 dominant larval fish taxa illustrated correlations of environmental variables associated with the distributions of larval fishes. Table 4 indicates that this diagram of the first 2 canonical variables accounted for 92.8% of the total variance. The first 2 canonical axes of the CCA factors showed significant relationships of larval fish with hydrographic variance ($p < 0.05$), and explained 88.35% of the hydrographic variance and 77.83% of the biological variance (Table 4). Fig. 9 shows

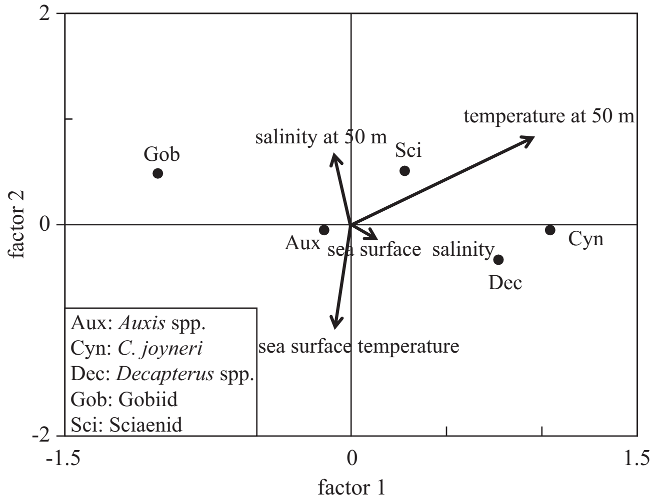

Fig. 9. Biplots of canonical correlation analysis for 5 taxa of larval fish abundances (symbols) in relation to environmental factors (arrows).

the structure of temperature and salinity associated with the dominant taxa. Species of sciaenid larvae were allocated to stations 1 to 3 in the 1st quadrant of the relatively low-salinity area. *Cynoglossus joyneri*, and *Decapterus* spp. were allocated to stations 4 to 7 in the 4th quadrant of the relatively high-temperature area. *Auxis* spp. were allocated to stations 11 to 13 in the 3rd quadrant with relatively high sea surface temperature (SST) and salinity (SSS).

IV. DISCUSSION AND CONCLUSIONS

This study focused on the species composition, abundance, and horizontal distribution of ichthyoplankton in continental shelf waters of the southern ECS in early summer 2009. In total, 1204 fish larval individuals representing 62 families and 120 taxa were collected in this survey. Based on a cluster analysis, a specific pattern of species compositions was found among the station groups. The grouping of larval fishes was affected by environmental factors [16, 17]. Moreover, the hydrographic environment was a key factor in several aspects of the dispersal, congregation, and diversity of fish larvae. Therefore, larval assemblages of this survey were defined based on the geographic and oceanic features. Our results suggested the following assemblages: a coastal group (A), a shelf group (B), a mixed shelf group (C_1), and a Kuroshio group (C_2). The assemblage results are similar to a report by Hsieh *et al*. [10] that monitored the 3 groups in the northern waters of Taiwan using a cluster analysis. Those authors found the boundary of the coastal group to be around the 50-m isobath, while the boundary of the Kuroshio edge group was deeper than the 100-m isobath [10]. Moreover, species components also revealed significant differences among groups, with detailed comparisons described below.

Specifically, group A was comprised of station 1~3 and was characterized by coastal water with a higher abundance and diversity of fish larvae. Sciaenids, gobiids, and *C. joyneri*, common in coastal areas, were important taxa in group A. The coastal assemblage was distinguished by a greater abundance of sciaenids. They are well-known bottom-dwelling carnivores that feed on benthic invertebrates and small fishes [3]. The Gobiidae and *C. joyneri* usually inhabit waters over sandy bottoms. Moreover, the CCA results indicated that relative low salinities of 33.2~34.2 psu were located at stations 1~3 of the 1st quadrant where sciaenids occurred and were possibly influenced by coastal waters in the coastal area (Fig. 3, dark gray), while Group B, characterized by mixed coastal and offshore waters, was dominated by *Decapterus* spp., species of sciaenids, and *C. joyneri*. The species composition was similar to that of group A. *Cynoglossus joyneri* and *Decapterus* spp. occurred in the 4th quadrant with high temperatures of 25.9~27.9°C located at stations 4~7 of the northern Taiwan Strait. In summertime, this area is mainly affected by the Taiwan Strait current [30]. In contrast, group C was dominated by *Decapterus* spp. and *Auxis* spp. which are 2 important and common commercial fish genera in Taiwan; the genus *Auxis* occurs worldwide in tropical and temperate waters [7]. These results were similar to those of Hsieh *et al.* [11] and Huang and Chiu [12] who also found that *Auxis* spp. were abundantly distributed in the KC edge exchange area off northeastern Taiwan in summer. This suggests that the species composition of group C with a relatively low abundance and diversity was possibly affected by low temperatures of upwelling water induced by the subsurface water of the KC. In addition, the 3rd quadrant contained high SST and SSS but low temperatures at 50 m in depth where *Auxis* spp. occurred and was possibly influenced by the Kuroshio (Fig. 3, white). It is interesting that small percentages of Myctophid larvae such as *Myctophum asperum* and *M. obtusirostre* were found and distributed in the offshore water (Table 3). These larvae are of well-known species that have diel migratory behavior [19]. However, it is hard to examine the diel vertical migration due to a lack of bio-sampling at different depths.

Moreover, the larval compositions exhibit an annual situation and seasonal variations in this water [10-12]. The first 8 dominant taxa in the present study were *Decapterus* spp., sciaenids, *Auxis* spp., gobiids, *C. joyneri*, *Bregmaceros* spp., *Diaphus* A group, and *E. japonicas*. These results were similar to previous results of Huang & Chiu [12] in the spring-summer period, for which *Decapterus* spp. and *Auxis* spp. were the dominant species. However, in a report by Hsieh *et al.* [10], the dominant taxa were *Scomber australasicus*, *Trachurus japonicas*, *E. japonicas*, *Amblychaeturichthys* spp., *M. asperum*, *Trichiurus lepturus*, serranids, and other myctophids. These results show that the species compositions significantly differed by season, and only 1 species (*E. japonicas*) was common to both seasons. The compositions of larval fish communities in these 2 studies [10, 12] reflect different seasonal hydrographic conditions. Although a previous study by Hsieh *et al.* [10] in the same area was conducted during the winter and this study was conducted in early summer, patterns of larval fish distributions were consistent. During the sampling periods, the abundance and diversity significantly varied in different regions, while the coastal area had higher abundance and diversity than the offshore area.

In addition, the overlapping area consisting of the continental shelf, Kuroshio edge, nearshore environment, and adjacent Chinese coast is the spawning ground for larval fishes, which are subsequently transported to nursery areas. Preflexion and yolk-sac larval fishes were common in the coastal region and nearshore habitats indicating that these areas provide important habitat for recently hatched individuals. Usually, many species spawn in relatively shallow waters of the continental shelf, as supported by prior studies [13, 18]. In this study, this trend was not significantly observed, because in this area, extensive spawning migrations of many species ensure that eggs and early larvae are broadly distributed and mixed across habitats such as those of *T. japonicas* and *Somber* spp. [21]. Thus, distribution patterns of various developmental stages of larvae suggest that some species spawn and lay eggs in warm offshore waters [28].

Besides the development stage, in this study, spatial distributions of ichthyoplankton were similar to the spatial variations of zooplankton. It was hypothesized that larval fishes may rely on finding dense patches of zooplankton prey, because the average densities usually observed in the field appeared insufficient to support positive larval fish growth, thereby contributing to increased biological production and larval fish survival [9]. We thus suggest that the abundance and distribution of fish larvae are closely connected with their food sources. Similar results were reported by several previous studies. Previous studies showed that zooplankton are the initial prey items for almost all fish larvae as they switch from yolk sacs to external feeding. These varying patterns are generally correlated with fluctuations of a limited food source; as Hsieh *et al*. [11] suggested, fish larvae are generally more abundant in neritic waters, and the combination of chlorophyll a, zooplankton, and nitrite best explained the relationship of larval fish distributions. Those authors demonstrated that spatial differences in larval fish abundances in summer were closely correlated with food sources.

In conclusion, this survey expands our knowledge of the spatial diversity and distribution of fish larvae in early summer associated with environmental conditions in the southern ECS. In this study, carangid, sciaenid, scombrid, myctophid, gobiid, and cynoglossid larvae were the 6 most abundant families which individually contributed > 5% and collectively accounted for 62% of the total number of larvae. Larval fishes at all stations had a high occurrence rate of the pre-flexion development stage, and percentages of larval development stages varied with the situation of the section. In addition, diversity also varied with the situation of the assemblage; thus high diversity occurred in offshore areas and low diversity occurred in coastal areas. The horizontal distribution of larval fish was related to station associations possibly affected by oceanographic features. Taiwan Strait waters and the Kuroshio are the major oceanographic features of this area with the potential to influence spatial distributions of fish larvae and changes in species compositions of larval assemblage in summertime. Sciaenids and gobiids were abundant in coastal waters; while *Decapterus* spp. and *Auxis* spp. were respectively abundant in mixed shelf and Kuroshio waters.

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