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UNDP/GEF Yellow Sea
Large Marine Ecosystem

IMPLEMENTING THE STRATEGIC ACTION PROGRAMME FOR THE YELLOW SEA LARGE
MARINE ECOSYSTEM: RESTORING ECOSYSTEM GOODS AND SERVICES AND CONSOLIDATION OF
A LONG-TERM REGIONAL ENVIRONMENTAL GOVERNANCE FRAMEWORK
(UNDP/GEF YSLME Phase II Project)

**Stocktaking report of biological and ecological
significance of the Yellow Sea Cold Water Mass
(YSCWM) and existing and potential threats using
ecological connectivity as key criteria**

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Introduction

The Yellow Sea, located between mainland China and the Korean Peninsula, is a productive semi-closed marginal sea of the Pacific Ocean, with depths ranging from 90 m in the central trough to less than 20m within 50 km off the coast (Zhao et al., 2013). As a typical temperate continental sea, the Yellow Sea is characterized by marked seasonality under the control of the East Asian Monsoon climate and complex hydrodynamics (Quan et al., 2011). From late spring to early autumn a combination of strong solar heating and weak wind forces induces strong stratification in the central Yellow Sea (Dai et al., 2006). In the upper mixed layer, nutrients are depleted after spring bloom and, beneath the thermocline, the low temperature and nutrient-rich Yellow Sea Cold Water Mass (YSCWM) is found, the most noticeable phenomenon in the summer bottom layer of the Yellow Sea (Li et al., 2006). The combined impacts of these threats as well as the potential impacts of climate change and ocean acidification have placed thousands of species at risk of extinction, and have impaired the structure, function, productivity and resilience of marine ecosystems.

Ecologically and Biologically Significant Areas (EBSAs) are important content of large marine ecosystem management on the guarantee for sustainable supply of ecological services. As one of the most important services of ecosystems, maintaining biodiversity can provide ecological

and biological products for human society (MA, 2002), and the natural ecological system plays an irreplaceable role to meet the needs of economic and social sustainable development.

Identifying and classifying habitats are the foundation and precondition for formulating management policies for biodiversity conservation. Marine habitat landscapes are not as rich as that on land, which have low visibility of species distribution. Therefore, habitat identification and classification are more complex and difficult in marine ecosystems, and which makes the EBSAs as the core of Marine management (Gregr et al., 2012).

The YSCWM locates at the central region of the Yellow Sea Large Marine Ecosystem, which occupy an important status in the Yellow Sea, and its ecological and biological importance should be accessed as the EBSAs criterion. The concept and criterion of EBSAs are one of the most effective measures for classifying and identifying significant marine habitats. With the increasing attention on the protection of biodiversity, these measures have gradually evolved to the classification based on biology and ecology (Gregr et al., 2012). Compared with other regions, those regions with important ecological or ecological significance need to implement more strict management or protection measures to avoid environmental risks. The classification methods and standards of EBSAs have become an important measurement for the classifying and

identifying significant Marine habitats in relevant international organizations and countries.

At the present time, the world's oceans are seriously under protected, with only approximately 0.8% of the oceans and 6% of territorial seas being within protected area systems. Measures are being taken to increase protection and sustainable management. In order to support effective policy action by countries and competent international and regional organizations, it is critical to build a sound understanding of the most ecologically and biologically important ocean areas that support healthy marine ecosystems.

1. Biological and Ecological Significance of the YSCWM

1.1 Criterion for EBSAs

(1) Notion of EBSAs

The Biologically and Ecologically Significant Areas (EBSAs) are special areas in the ocean that serve important purposes, in one way or another, to support the healthy functioning of oceans and the many services that it provides. EBSAs are geographically or oceanographically discrete areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics.

EBSAs are important content of large marine ecosystem management on the guarantee for sustainable supply of ecological services. The identification of EBSAs is an important tool for highlighting areas that have particularly high ecological or biological importance for the overall ecosystem. The ocean is under increasing threat from various human activities. The most pressing threats come from overfishing, destructive fishing practices, and illegal, unreported and unregulated fishing activities. Other emerging problems include marine debris, ship-based marine pollution, transfer of alien invasive species, illegal dumping

and the legacy of historical dumping, seabed mineral extraction, and noise pollution.

As one of the most important services of ecosystems, maintaining biodiversity can provide ecological and biological products for human society (MA, 2002), and the natural ecological system plays an irreplaceable role to meet the needs of economic and social sustainable development. Identifying and classifying habitats are the foundation and precondition for formulating management policies for biodiversity conservation. Marine habitat landscapes are not as rich as that on land, which have low visibility of species distribution. Therefore, habitat identification and classification are more complex and difficult in marine ecosystems, and which makes the EBSAs as the core of Marine management (Gregr et al., 2012).

(2) Criterion for EBSAs

Since the 1980s a variety of national agencies, NGOs, and academic researchers have published or promulgated suites of criteria for the identification of areas of biological or ecological importance in the open ocean. The Convention on Biological Diversity took up the call to identify such areas in 2006 at the eighth meeting of the Conference of Parties, and called for the convening of an expert workshop to “Refine and develop a consolidated set of scientific criteria for identifying ecologically or

biologically significant marine areas in need of protection, in open ocean waters and deep-sea habitats, building upon existing sets of criteria used nationally, regionally and globally”.

Table 1.1.1 Core indicators for ecological or biological significant criterion

Ecological or Biological Significant	Core Indicators
Criterion	
Biological productivity	<ul style="list-style-type: none"> ● High Chlorophyll concentration ● High phytoplankton cell abundance ● High zooplankton abundance/biomass ● High benthos abundance/biomass ● High productivity ● High fishery resource
Biodiversity (species and genetic diversity)	<ul style="list-style-type: none"> ● High biodiversity ● High community diversity ● High habitat diversity
Reproductive areas	<ul style="list-style-type: none"> ● High larva/egg abundance ● Spawn ground
Non-reproductive bottleneck areas	<ul style="list-style-type: none"> ● Overwintering ground ● Migration paths
Habitat for endangered/threatened species	<ul style="list-style-type: none"> ● Habitat for endangered species ● Habitat for threatened species

Applicable site-specific considerations refer to uniqueness or rarity
 Special importance for life history, stages of species, importance for
 threatened, endangered or declining species and/or habitats, vulnerability,
 fragility, sensitivity or slow recovery, biological productivity, biological

diversity and naturalness. The specific criterion is showed in Table 1.1.1 and 1.1.2, including core and additional indicators.

Table 1.1.2 Additional indicators for ecological or biological significant criterion

Ecological or Biological Significant Criterion	Additional Indicators
Naturalness	<ul style="list-style-type: none"> ● Less disturbed by human activity ● Difficult for humans to reach ● Low concentrations of pollutants
Fragility/ sensitivity	<ul style="list-style-type: none"> ● Especially sensitive to human activities ● Habitats or species recover slowly after disturbance ● Easy to accumulate pollutants ● Areas prone to Marine disasters
Significance	<ul style="list-style-type: none"> ● Significance on a large spatial scale

1.2 Chlorophyll and phytoplankton community in YSCWM

1.2.1 Significance

Chlorophyll concentration and phytoplankton cell abundance are the core indicators of biodiversity and biological productivity in the biological and ecological significant criterion. The subsurface chlorophyll maximum (SCM) is one of the most consistent features of the planktonic ecosystems in stratified water in YSCWM area and its position is strongly related to the opposing gradients of light and nutrients (Cullen, 2015).

Seasonally stratified areas in temperate shelf seas are usually characterized by a strong spring bloom, followed by limited production within the surface mixed layer as nutrients are depleted in the post bloom period. Research has often focused on the spring phytoplankton bloom, and the related ecosystem processes, in for example the Yellow Sea, as the most prominent phenomenon in temperate seas. However, some studies suggest that sub-surface new production may be greater than that of the spring bloom in the stratified areas of the North Sea (Richardson et al., 2000), while others have found that the carbon fixed in the SCM over the summer stratified season is approximately the same as that fixed by the spring bloom (Hickman et al., 2012). As this process occurs in the sub-surface, it is captured only by ship-based measurements and not by remote sensing techniques. The spatial and temporal behaviors of the SCM-related processes are therefore less well known.

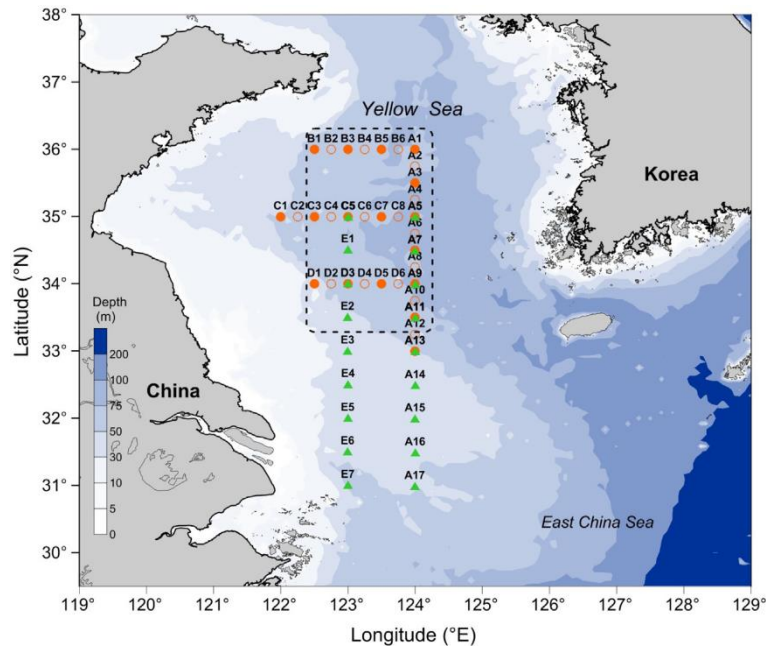


Fig.1.2.1 Sampling stations in the central Yellow Sea during the summer of 2011 and 2013 (Fu et al., 2016)

In previous studies, the SCM has been widely observed, but only briefly described in the YSCWM area (Jang et al., 2013). Most attention has been paid to the spring phytoplankton bloom processes (e.g., Shi et al., 2017) instead of the vertical phytoplankton structures during summer stratification. Given the significance of the SCM for food webs, biogeochemical fluxes, and the accuracy of remote sensing estimates of primary production, the behavior and dynamics of the SCM should be studied in detail. Fu et al. (2016) present the first in-depth analysis of the spatial distribution and intrinsic characteristics of the SCM in the YSCWM, based on two comprehensive cruises conducted in the central Yellow Sea during August 2011 and July 2013. This research maps the distribution of the SCM and its correlation with the physical and chemical variables of the

YSCWM; describes the detailed phytoplankton community and maintenance mechanisms of the SCM in the YSCWM.

1.2.2 Hydrographic and chemical conditions

During summer in the central Yellow Sea, the strong solar heating and weak wind forcing result in a mixed surface layer and a cold deep layer separated by a strong thermocline. The mixed layer depth varied between 6 m and 16 m with an average of 11.83 m in the sampling area during summers 2011 and 2013.

The temperature, salinity, light, and nutrient conditions at the SCM depth in the YSCWM area compared with the surface mixed layer. The water column was highly stratified with a strong thermocline between 10m and 30m (Fig.1.2.2.1). In summer 2011, the water temperature decreased from a mean value of 22.48 °C at the surface to 13.97 °C at the SCM depth, and reduced further to < 10 °C at depths greater than 40 m. Despite the steep temperature decline with depth, the vertical salinity variations were small. This means that the stratification was mainly driven by thermal stability.

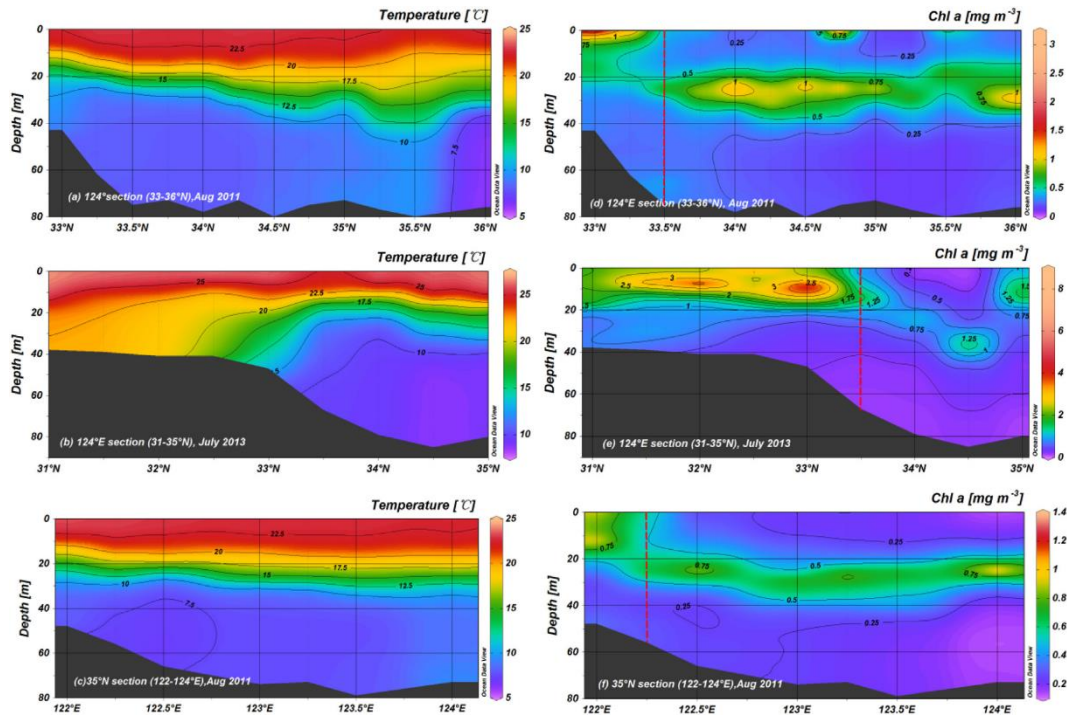


Fig.1.2.2.1 Vertical profiles of temperature (a–c) and Chl a (d–f) concentrations along sections 124°E and 35°N during August 2011 and July 2013 (red dashed lines indicate the approximate southern and western boundaries of the SCM in the YSCWM). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.). (Fu et al., 2016)

The vertical structure of the nutrients followed the typical pattern of a stratified water column (Fig. 1.2.2.2). Nutrients were almost depleted in the surface layer, with NO_3^- and PO_4^{3-} concentrations near the analytical detection limit at many of the sampling stations. The average concentrations of NO_3^- and PO_4^{3-} were below $0.4 \mu\text{mol L}^{-1}$ and $0.3 \mu\text{mol L}^{-1}$, respectively, in the surface waters during the summers of 2011 and 2013. The upper limit of the nitracline varied at around 15 m. At the SCM depth, the nutrient concentrations increased significantly, especially for nitrate ($> 3 \mu\text{mol L}^{-1}$), due to a higher nutrient supply from below the nitracline. In the cold bottom water ($T < 10 \text{ }^\circ\text{C}$), nutrients were replete with mean

concentrations of $8.88 \pm 2.32 \mu\text{mol L}^{-1}$ for nitrate, $1.20 \pm 0.29 \mu\text{mol L}^{-1}$ for phosphate, and $9.24 \pm 2.33 \mu\text{mol L}^{-1}$ for silicate during 2011, which are consistent with previous findings that the YSCWM represents a large nutrient reservoir. The vertical distribution of SiO_3^{2-} was similar to that of NO_3^- and PO_4^{3-} .

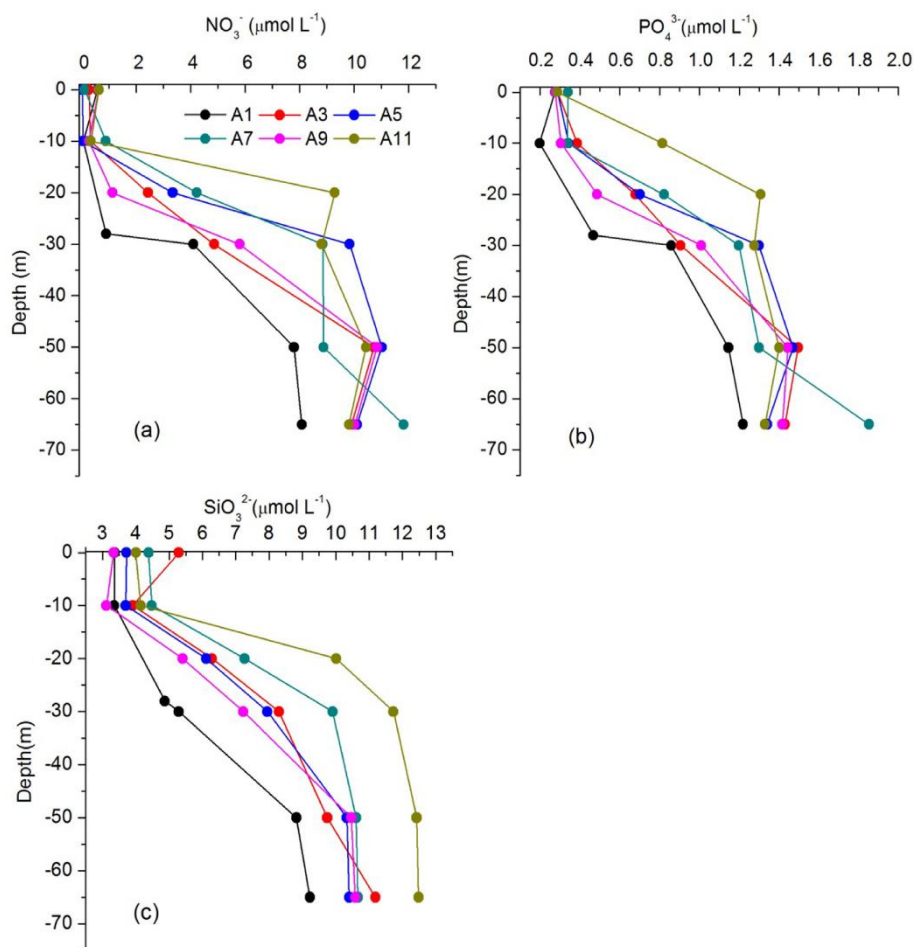


Fig.1.2.2.2 Vertical distribution of (a) NO_3^- , (b) PO_4^{3-} , and (c) SiO_3^{2-} along the 124°E section during August 2011. (Fu et al., 2016)

1.2.3 Occurrence and structures of the SCM in the YSCWM

Subsurface chlorophyll maxima were extensively observed in the central Southern Yellow Sea during the summers of 2011 and 2013. During

August 2011, 15 of the 17 stations displayed a clear SCM and were located within the YSCWM area (Fig.1.2.2.1). During July 2013, the stations located north of 33.5°N (9 out of 18, 50%) also displayed a clear SCM, while the other stations had a surface chlorophyll maximum due to the influence of Changjiang diluted water. This is consistent with previous studies, which found that the SCM was absent near the river mouth or in shallow coastal areas where vertical mixing is significant. In these regions, Chl a was usually highest at the surface.

The SCM varied broadly in vertical positions and thickness in the two summer cruises. During August 2011 and July 2013, the vertical position of the SCM varied between 12 and 29m and 13–25 m, respectively, and occurred most often between 20 and 30 m. The thickness of the SCM varied between 4 and 20m and 6–25 m, respectively. The Chl a concentration in the SCM ranged from 0.83 mg m⁻³ to 1.69 mg m⁻³ with a mean of 1.24 ± 0.27 mg m⁻³, and from 1.14 mg m⁻³ to 3.36 mg m⁻³ with a mean of 1.92 ± 0.65 mg m⁻³ during August 2011 and July 2013, respectively. Chl a decreased to very low levels (< 0.25 mg m⁻³) in the surface layer and below the SCM. Compared with the SCM that occurred in the oceanic area, the SCM in the Southern Yellow Sea was shallower, but with a higher intensity.

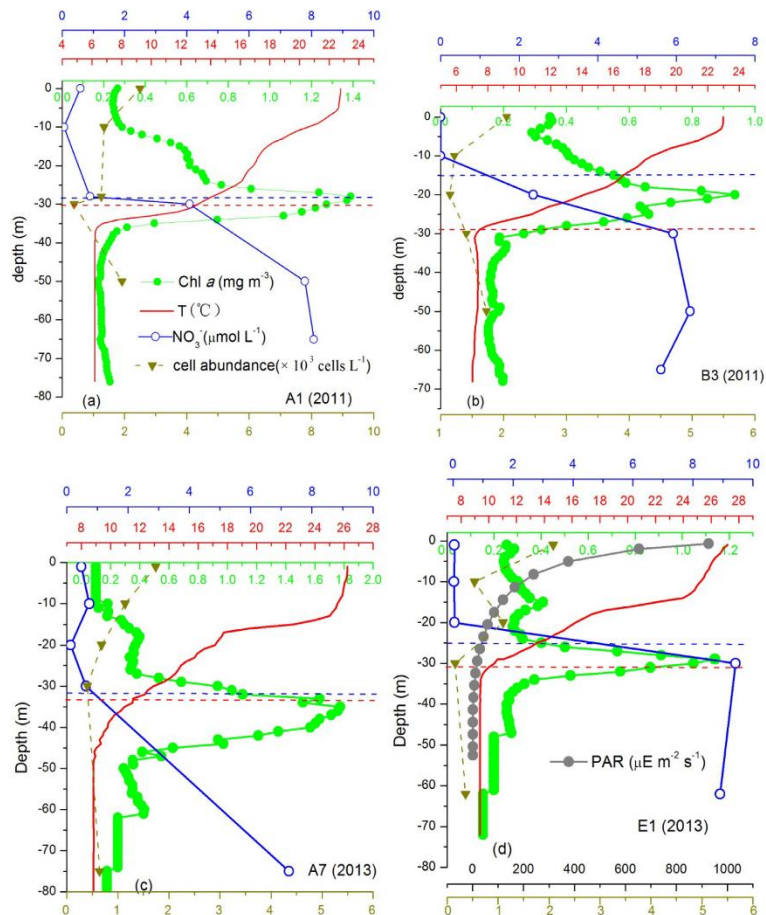


Fig.1.2.3.2 Vertical profiles of Chl a, temperature, NO_3^- concentration, and PAR at typical stations during August 2011 and July 2013. The positions of lower boundary of thermocline (red dashed line) and nitracline (blue dashed line), and the profile of micro+ nano phytoplankton cell abundance were also plotted for reference. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.). (Fu et al., 2018)

The positions of the SCM relative to the vertical profiles of the nutrients, temperature, and PAR in the water column during summers 2011 and 2013 are presented in Fig.1.2.3.2. At most stations, the SCM was located within or at the bottom of the thermocline, and the upper part of the nitracline. Because of limited measurements, detailed PAR profiles were only available at four stations during the July 2013 cruise. The SCM was at, or well above, the 1% surface irradiance in the surface waters.

1.2.4 Phytoplankton community

The Fv/Fm values were generally high in the SCM, implying that the local phytoplankton communities were photosynthetically active. This means that the phytoplankton assemblages were well acclimated to the nutrient and irradiance conditions in the SCM in the summer stratified Yellow Sea.

During the 2011 summer cruise, the phytoplankton size structure was analyzed at the SCM depth which was determined by the fluorescence sensor. At the SCM depth, the average proportions of micro-, nano-, and picophytoplankton were 1.43%, 25.11%, and 73.46%, respectively. This was in accordance with previous studies where picophytoplankton dominated in the summer central Yellow Sea, with a slight increase with water depth (Huang et al., 2006; Fu et al., 2009a, 2010; UNDP/GEF, 2011).

Because of the importance of picophytoplankton in the YSCWM, the vertical distributions of different groups of picophytoplankton were measured with flow cytometry. *Synechococcus* and picoeukaryotes were the main components of the picophytoplankton community in the summer central Yellow Sea during 2011 and 2013, and no *Prochlorococcus* was detected in the seawater samples.

Synechococcus abundance was generally one order of magnitude greater than that of the picoeukaryotes (Fig.1.2.4.1 and Fig.1.2.4.2). The

vertical distribution indicated that high picophytoplankton abundance occurred in the nutrient-depleted upper 30m of the YSCWM area (north of 33°N; Fig. 8), with no clear correlation with the SCM layer. During July 2013, the picophytoplankton displayed a similar vertical distribution, but lower cell abundance (Fig.1.2.4.1 and Fig.1.2.4.2).

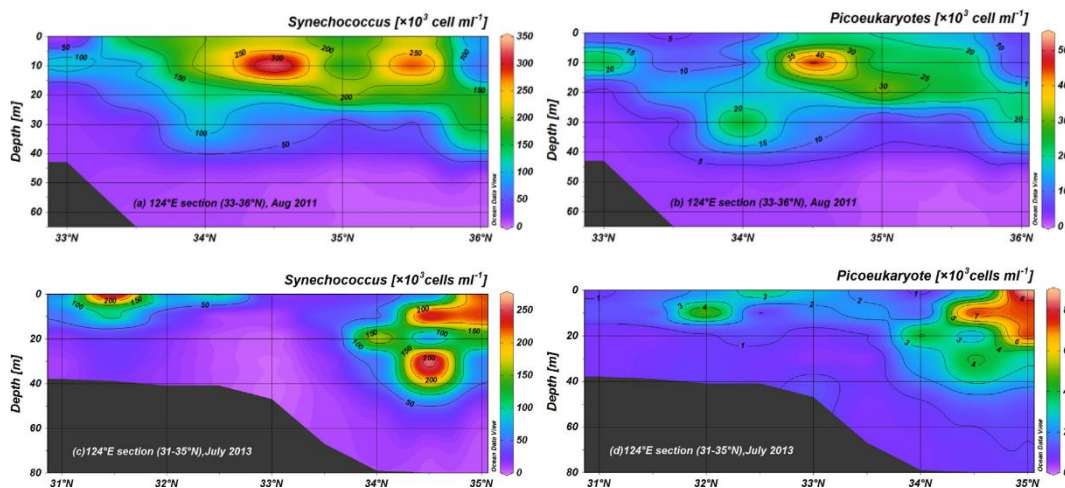


Fig.1.2.4.1 Vertical profiles of *Synechococcus* (left panels) and picoeukaryotes (right panels) cell abundance along section 124°E during August 2011 (top panels) and July 2013 (bottom panels). (Fu et al., 2016)

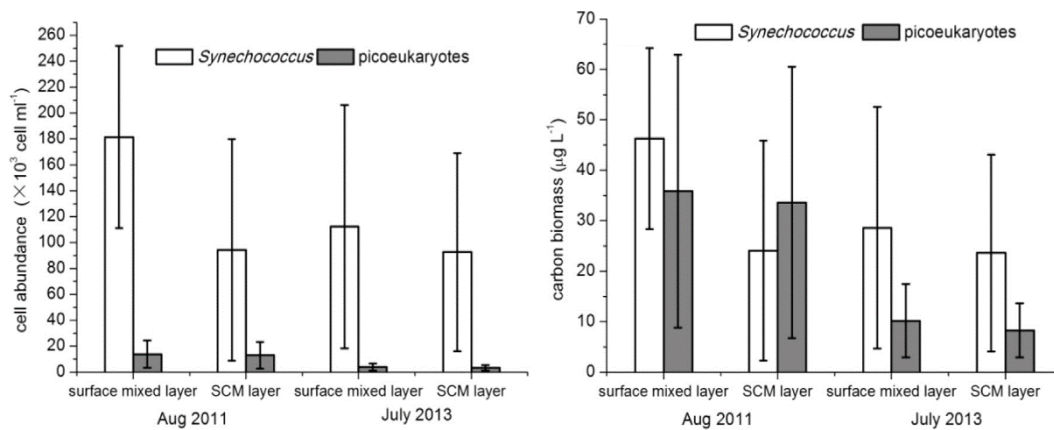


Fig.1.2.4.2 SCM layer vs. surface mixed layer cell abundance and carbon biomass of picophytoplankton groups in the YSCWM. (Fu et al., 2016)

1.2.5 Taxonomic composition of micro- and nanophytoplankton

The cell abundances of micro- and nanophytoplankton were highly variable, but generally low in the study area. Dinoflagellates and diatoms were the predominant phytoplankton groups in summer in the YSCWM area, while other species, e.g., *Dictyocha fibula*, was observed occasionally with cell abundance contributions of less than 5%.

During August 2011, the cell abundance of dinoflagellates dominated both depths, measuring 79.42% and 76.25% at the surface and in the SCM layer, respectively. By contrast, the proportions of diatoms were 16.11% and 21.13% at the surface and in the SCM layer, respectively.

During July 2013, similar to the results of 2011, dinoflagellates dominated in the central Yellow Sea to the north of 33.5°N, representing 67.45% and 64.65% of the total cell abundance at the surface and in the SCM layer, respectively. Influenced by the CDW, the proportion of diatoms was greater than that in 2011, measuring 32.55% and 35.35% at the surface and in the SCM layer, respectively.

The dominant phytoplankton species and their relative contributions are presented in Table 2. Except for the weak dominance of *Thalassiosira* sp. and *Paralia sulcata* at the SCM depth during summer 2011 and 2013, respectively, the other dominant species were all dinoflagellates. *Gyrodinium* spp. and *Gymnodinium* spp. were frequently the main species. The total cell abundance and the composition of the dominant species

were similar between the surface and the SCM depth (Fig.1.2.5). No particular dominant species were detected at the SCM depth. This suggests that the formation of SCM was not primarily caused by the high cell abundance or the difference in the phytoplankton species composition in the layer.

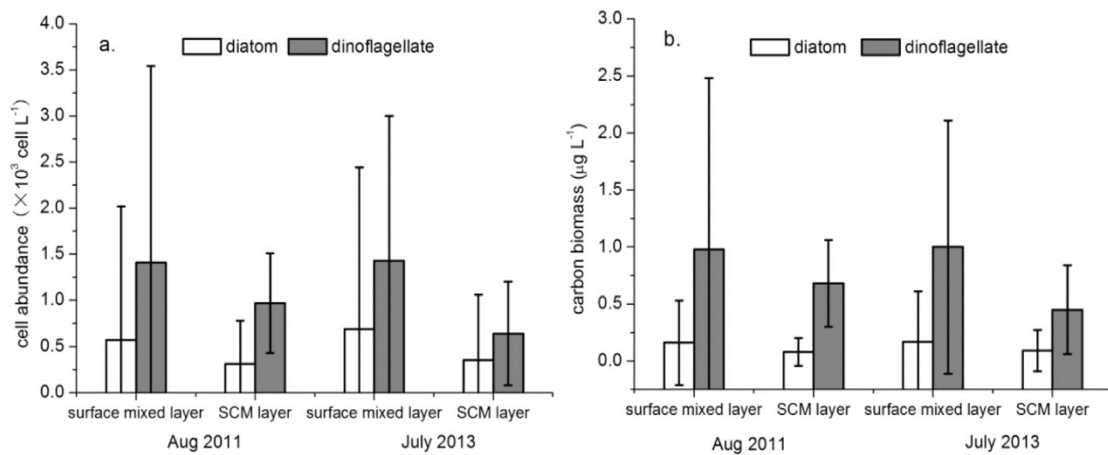


Fig.1.2.5 SCM layer vs. surface mixed layer cell abundance and carbon biomass of major micro-/nanophytoplankton groups in the YSCWM. (Fu et al., 2016)

1.2.6 Phytoplankton carbon biomass

Diatoms and dinoflagellates contributed approximately 95% of the cell abundance and were the major components of the micro- and nanophytoplankton. Their carbon biomass was estimated from the cell volume to carbon relationships described in Menden-Deuer and Lessard (2000), assuming that the cell is spherical and the average diameter is 20 μm in the SCM layer. The dinoflagellate biomass was more than five-fold greater than that of the diatoms (Fig.1.2.5). No significant biomass differences were observed between the surface and SCM layer for diatoms

or dinoflagellates. Overall, diatoms and dinoflagellates were a minor part of the total phytoplankton carbon pool.

The biomass of both *Synechococcus* and picoeukaryotes was slightly higher in the surface mixed layer than in the SCM layer. During July 2013, the picophytoplankton carbon biomass was less than that in August 2011 (Fig.1.2.5), in particular, for the picoeukaryotes. The picophytoplankton biomass was also slightly lower in the SCM layer than in the surface waters. Picoeukaryotes contributed about 50% and 30% of the picophytoplankton carbon biomass during August 2011 and July 2013, respectively, which was considerably higher than its corresponding contribution to cell abundance (10.17% and 4.24%. respectively).

1.2.7 Summary

(1) Relatively stable feature of the SCM in the YSCWM area

In general, the spatial distribution of the SCM coincides approximately with the YSCWM area during stratified seasons, forming a southern boundary around 33.5°N and a western boundary around 122.5°E. The vertical position of the SCM is mainly determined by the interactions of the nutrient flux from below and irradiance from above. This study shows that the vertical position of the SCM in the YSCWM is mainly located within or at the bottom of the thermocline and the upper part of the nitracline, and is at or well above the 1% surface irradiance in the surface waters.

(2) Phytoplankton community in the SCM

The detailed characteristics of the phytoplankton community structure in the SCM layer of the YSCWM were studied based on size and taxonomic composition. Picophytoplankton dominated the phytoplankton community in the study area in cell abundance and carbon biomass, contributing > 90%.

The results are consistent with the global estimate of picophytoplankton biomass with *Synechococcus* and picoeukaryote contributing 12–15% and 49–69%, respectively

The results are consistent with previous studies regarding the dominance of dinoflagellates in the summer YSCWM area. The vertical migration of dinoflagellates may contribute to the formation of the SCM in the YSCWM.

1.3 Zooplankton abundance/biomass

1.3.1 Significance

Zooplankton occupy a pivotal position in marine food webs, transferring primary production to higher trophic levels. Zooplankton community is the core indicator of biodiversity and biological productivity, and its abundance and biomass are important biological and ecological significant criterion. The YSCWM during summer and the Yellow Sea Warm Current during winter are two prominent features of the Yellow Sea. As the main food source of many fish, zooplankton have been the focus of many studies in the YSCWM (Chen and Liu, 2015); however, there have been relatively few investigations of zooplankton communities during winter, which is a crucial period for parental fish survival. In addition, because the zooplankton community undergoes change in changing ecosystems, it has become necessary to explore zooplankton community structure and spatial distribution in recent years.

Shi et al. (2018) analyzed spatial variations in the zooplankton community (composition, abundance, and diversity) and the way in which the community structure is affected by the prevalent hydrographic conditions in the Yellow Sea during winter (Fig.1.3.1). The results presented herein provide fundamental information that will be useful to future studies of the ecological carrying capacity of fishery resources and long-term monitoring of zooplankton ecology in the YSCWM.

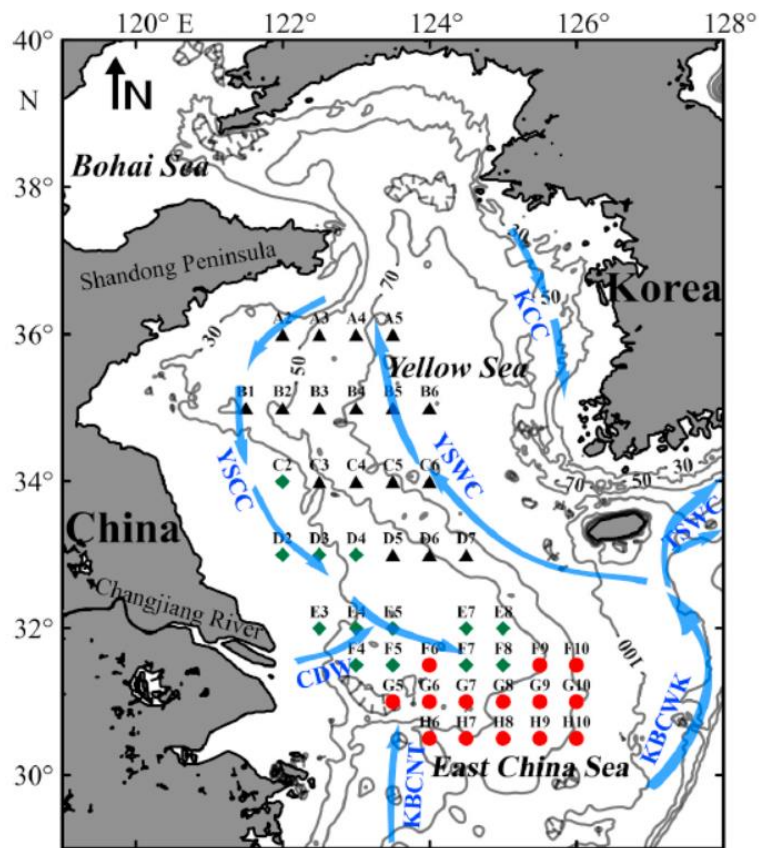


Fig.1.3.1 Map of the sampling stations in the Yellow Sea and East China Sea in January 2016. Contour lines indicate water depth (m), and arrows indicate circulation regimes, including Yellow Sea Warm Current (YSWC), Yellow Sea Coastal Current (YSCC), Korean Coastal Current (KCC), Changjiang Diluted Water (CDW), Kuroshio Branch Current north of Taiwan (KBCNT), Kuroshio Branch Current west of Kyushu (KBCWK), and Tsushima Warm Current (TSWC) after Ichikawa and Beardsley (2002). Symbols represent the different groups identified based on Results 3.2. in the present study: Triangles: Group 1; Diamonds: Group 2; Circles: Group 3. (Shi et al., 2018)

1.3.2 Community structure and assemblages of zooplankton

A total of 68 taxa (mostly at the species level) were identified. Three zooplankton communities (Groups 1–3) were identified based on cluster analysis of zooplankton abundance at a level of 61% station similarity (Fig. 1.3.2a). Stations of the same cluster group assembled closely in the 2-

dimensional representation of the NMDS plot with a stress value of 0.13 (Fig.1.3.2b), suggesting that the cluster results were reliable.

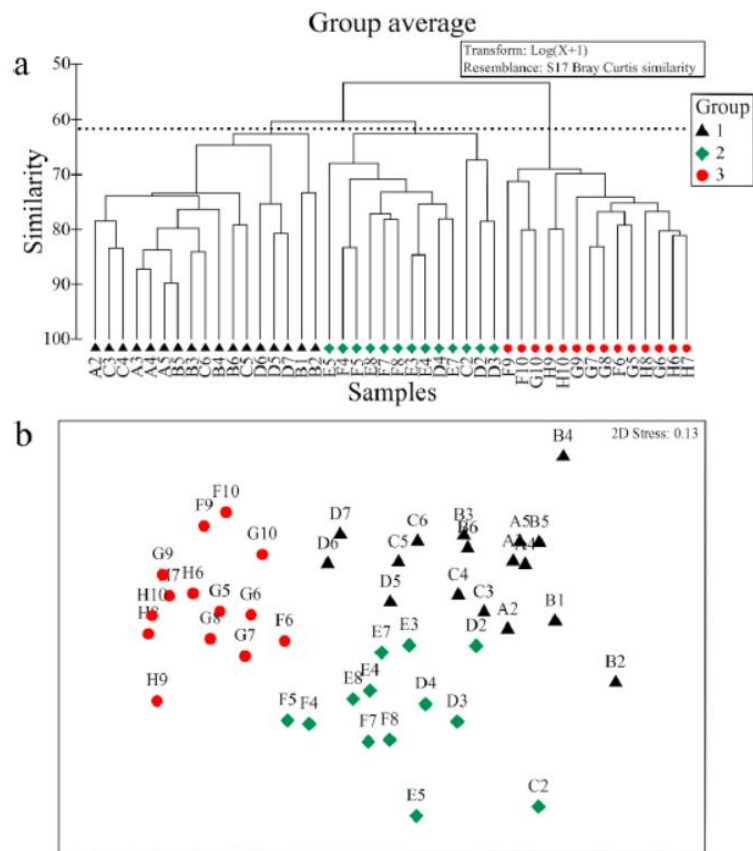


Fig.1.3.2.1 (a) Dendrogram of station similarity based on cluster analysis on zooplankton abundance. (b) Ordination plot based on non-metric multidimensional scaling method. Symbol-code is shared. (Shi et al., 2018)

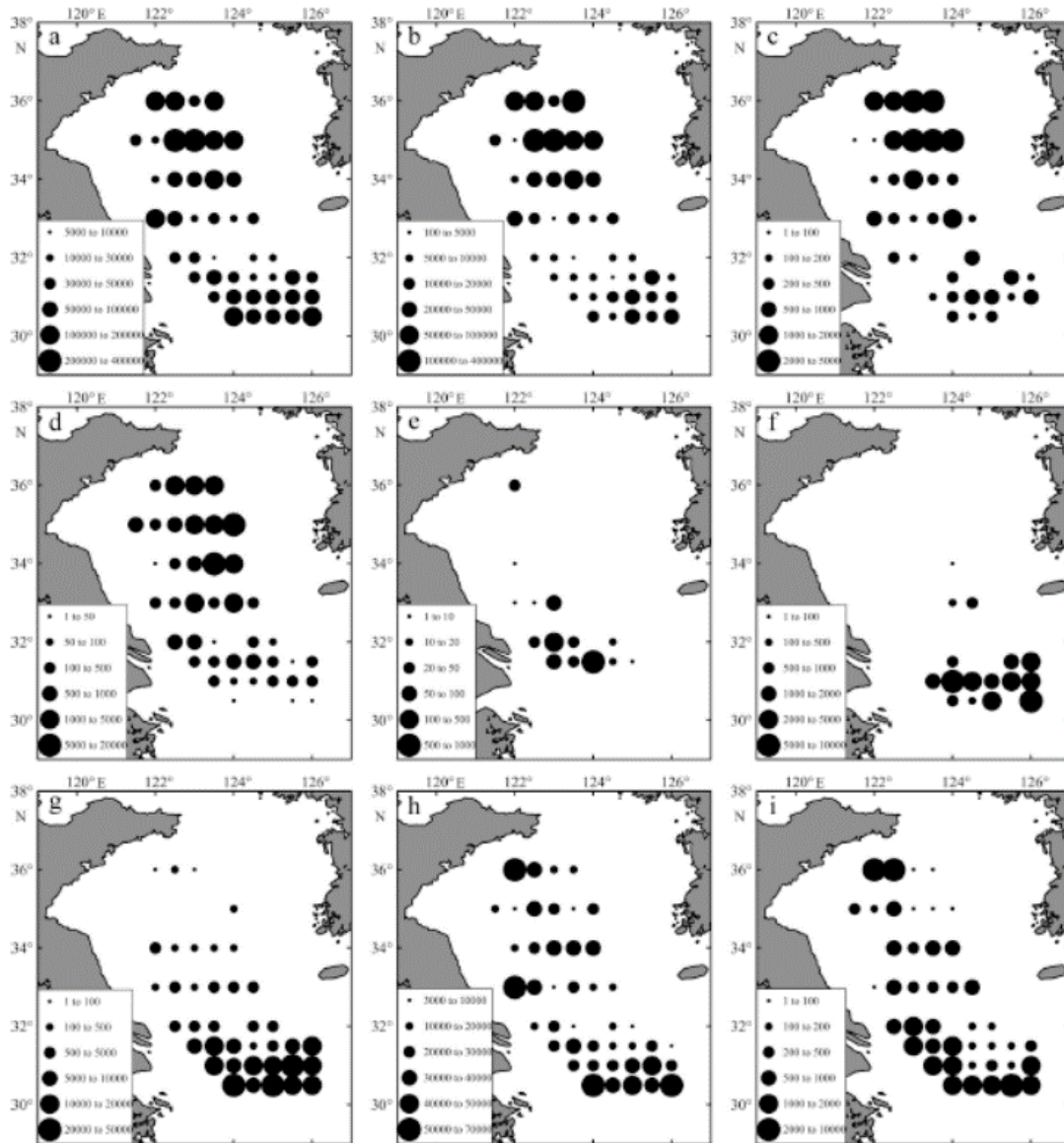


Fig.1.3.2.2 Spatial distributions of abundances (ind/m²) of total zooplankton (a) and representative species (b. *Oithona similis*; c. *Aidanosagitta crassa*; d. *Calanus sinicus*; e. *Labidocera euchaeta*; f. *Oncaea mediterranea*; g. *Microsetella norvegica*; h. *Paracalanus parvus*; i. *Oikopleura dioica*). (Shi et al., 2018)

1.3.3 Zooplankton community structure

Copepods were the most abundant taxonomic group of zooplankton in the Yellow Sea during winter. The mesh size (160 μm) of net used in the present study was lower than that (500 μm) (Chen and Liu, 2015); therefore, more small copepods (Wang and Wang, 2003), such as *O. similis*,

P. parvus, and *M. norvegica*, were resulting in higher calculated zooplankton abundances (Wang et al., 2013). Although the important roles of small copepods in pelagic marine food webs have been confirmed (Turner, 2004), they have always been underestimated in the Yellow Sea as few studies used nets with meshes < 200 μm . Zooplankton can serve as a food source for wintering planktivorous fish. Small yellow croaker and Japanese anchovy overwinter in the southeast region of the present study area, and individuals with a body length of < 10 cm mainly feed on copepods and other crustaceans.

Spatial patterns of zooplankton communities were clearly shaped by hydrological features (Domínguez et al., 2017). In the Yellow Sea, *P. parvus* and *O. similis* were the most abundant species, but their distributions were different. *P. parvus* was more likely distributed in the Yellow Sea in autumn (Chen and Liu, 2015), while it had high mean abundance in all three station groups and was found at all stations.

1.4 Variation in the macrofaunal community

1.4.1 Significance

Macrofaunal community is the core indicator of biodiversity and biological productivity for biological and ecological significant criterion. Researchers analyzed the original survey data during 1958–2014 in a comparative way by means of a variety of statistical methods (Xu et al., 2017). The present study detected the temporal and spatial variation in the macrofaunal species composition, diversity and community structure over the past 56 years; identified the species, genera and families that contributed to the macrofaunal temporal and spatial variation; and investigated the influence of environmental factors on the changes in the macrofaunal distribution and diversity.

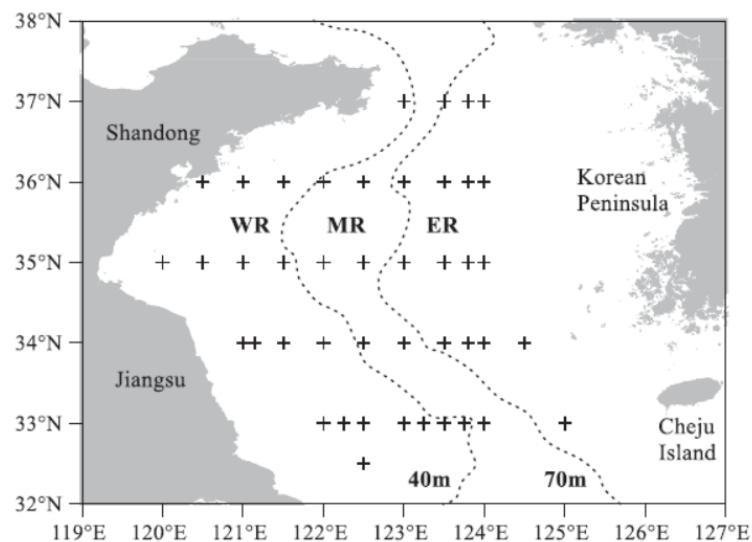


Fig.1.4.1 Macrofauna sampling stations and bathymetric contours in the southern Yellow Sea. WR: western region; MR: middle region; ER: eastern region. (Xu et al., 2017)

1.4.2 Macrofaunal abundance and community structure

In total, 526 species of macrofauna were recorded in the southern Yellow Sea: 369 species from the WR, 199 species from the MR and 207 species from the ER. The total number of macrofauna species decreased from the 1950s to 2014 (222 species in 1958–1959, 195 in 2000–2001, 193 in 2011–2012 and 158 in 2014). Polychaeta and Crustacea accounted for 55% of the total macrofauna species in most surveys (Fig.1.4.2.1). The relative number of Polychaeta species showed a significant increasing trend (chi-square = 10.294, df = 3, $p < 0.05$) from the 1950s to 2014 in the southern Yellow Sea. In the WR, the relative number of Mollusca species decreased (not significantly; chi-square = 3.562, df = 3, $p > 0.05$) from the 1950s to 2014, whereas the relative number of Crustacea species and Echinodermata species changed only a little.

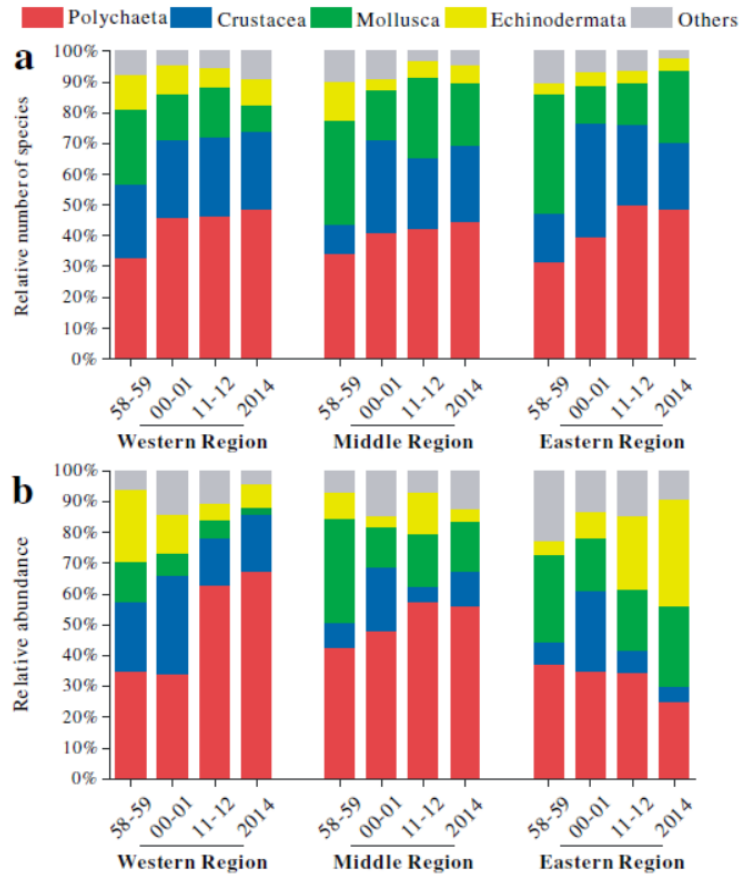


Fig.1.4.2.1 Relative number of species of major taxonomic groups (a) and relative abundance of macrofauna (b) in the southern Yellow Sea. 58–59: 1958–1959 period; 00–01: 2000– 2001 period; 11–12: 2011–2012 period. (Xu et al., 2017)

1.4.3 Variation in the macrofaunal community structure

The cluster analysis and ordination visualized the variation in the macrofaunal community structure at the species, genus and family levels in the southern Yellow Sea (Fig. 1.4.3.1). There were two groups at a 18% similarity level in the cluster analysis and ordination at the species level (Fig. 1.4.3.1). One group was composed of the samples collected during 1958 and 1959, and the other consisted of the samples collected from 2000 to 2014. A regional difference in the community structure was

observed in two groups (1958–1959 and 2000–2014), while a seasonal difference was not obvious.

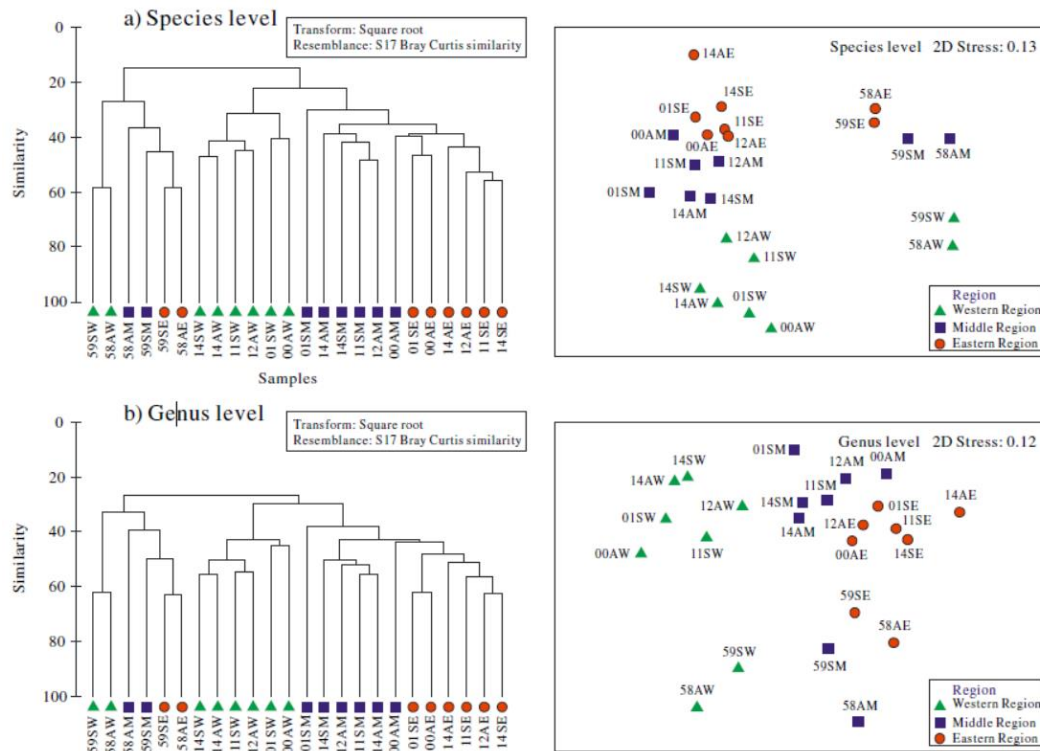


Fig.1.4.3.1 Cluster analysis (left) and nMDS ordination (right) of macrofaunal community structure based on pooled abundance data for each region at the (a) species level and (b) genus level. 58: 1958; 59: 1959; 00: 2000; 01: 2001; 11: 2011; 12: 2012; 14: 2014; S: spring; A: autumn; W: western region; M: middle region; E: eastern region. (Xu et al., 2017)

1.4.4 Species contributing to the observed community variation

From 1958 to 2014, the macrofaunal community structure in the southern Yellow Sea showed significant variation. The macrofauna that cumulatively contributed to 20% of the temporal variation in each region were identified using SIMPER analysis at the species, genus and family levels.

1.4.5 Benthic environment and biological-environmental relationships

The temperature increased in spring but decreased in autumn from 1958 to 2014 in the southern Yellow Sea, while the salinity changed little over time. A decreasing trend was found for temperature from the western region to the eastern region, whereas an increasing trend was observed for depth (Fig.1.4.1) and salinity.

The relationships between the macrofaunal abundance and diversity indices and the environmental variables were revealed using RDA. The first two axes explained 8% of the variation in the species matrix and cumulatively accounted for 92.8% of the species-environment relationship variance. Different indexes were correlated to different environmental variables (Fig. 1.4.5.1). The abundance of mollusks was positively correlated with depth and salinity, while the abundance of Crustaceans was negatively correlated with these variables. H' , J' and d displayed positive correlations with temperature, whereas the total abundance and the abundance of polychaetes and echinoderms showed negative correlations with temperature.

The relationships between the species contributing the most to the temporal variation in the community and environmental variables are illustrated in the CCA ordination diagram (Fig.1.4.5.2). Most mollusks and the echinoderm *Ophiura sarsii vadicola* were placed in the left of the

diagram, which indicates that they were related to higher values of depth and salinity.

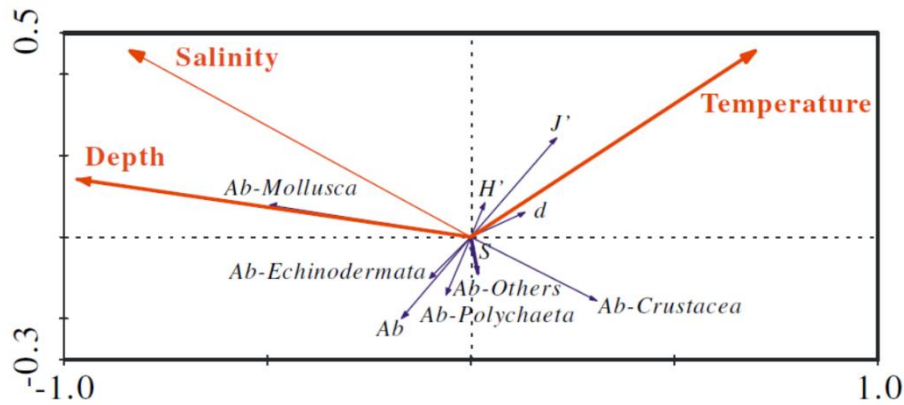


Fig. 14.5.1 RDA ordination with the macrofaunal abundance and diversity indices and the environmental variables in the southern Yellow Sea. Ab: abundance (ind./m²); S: species number; d: Margalef's richness; H': Shannon-Wiener index; J': Pielou's evenness. (Xu et al., 2017)

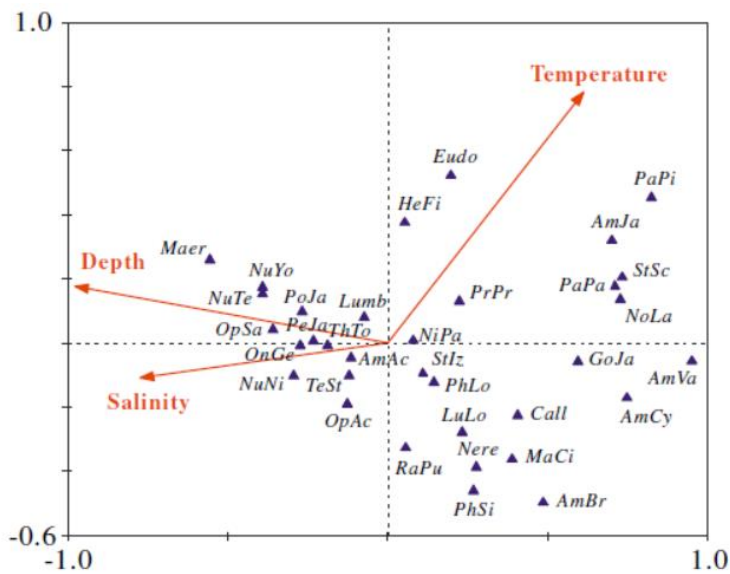


Fig.1.4.5.2 CCA ordination of the species and environmental variables in the southern Yellow Sea.

Taxa codes: AmBr = *Ampelisca brevicornis*, AmCy = *Ampelisca cyclops*, AmAc = *Ampharete acutifrons*, AmJa = *Amphioplus japonicus*, AmVa = *Amphiura vadicol*a, Call = *Callianassa* sp., Eudo = *Eudorella* sp., GoJa = *Goniada japonica*, HeFi = *Heteromastus filiformis*, LuLo = *Lumbrineris longifolia*, Lumb = *Lumbrineris* sp., Maer = *Maera* sp., MaCi = *Magelona cincta*, Nere = *Nereis* sp., NiPa = *Ninoe palmata*, NoLa = *Notomastus latericeus*, NuNi = *Nucula nipponica*, NuTe = *Nucula tenuis*, NuYo = *Nuculana yokoyamai*, OnGe = *Onuphis geophiliformis*, OpAc = *Ophelina acuminata*, OpSa = *Ophiura sarsii vadicol*a, PaPa = *Paralacydonia paradoxa*, PaPi = *Paraprionospio pinnata*, PeJa = *Periploma japonicum*, PhLo = *Photis longicaudata*, PhSi = *Photis sinensis*, PoJa = *Portlandia*

japonica, *PrPr* = *Praxillella praetermissa*, *RaPu* = *Raetellops pulchella*, *StSc* = *Sternaspis scutata*,
Stlz = *Sthenolepis izuensis hwanghaiensis*, *TeSt* = *Terebellides stroemii*, *ThTo* = *Thyasira tokunagai*.
(Xu et al., 2017)

1.5 Spatial fishery resources density in the Yellow Sea

Fishery resource and its productivity are the core indicators of biological productivity for biological and ecological significant criterion. Based on the analysis, inverse distance weighted interpolation was considered to be a suitable interpolation method for determining fishery resources density in the Yellow Sea (Chen et al., 2016). The spatial distribution of fishery resources density interpolated by inverse distance weighted interpolation during the four survey periods is shown in Fig.1.5.1.

Overall, the results describe the entire trend in the distribution of fishery resources density over the four survey periods. In winter (Fig.1.5.1c), the distribution center of fishery resources was located in the central and southern Yellow Sea, which is an important wintering ground for many migratory marine species, especially in the area (34° - 36° N, 123° - 125° E). There were also some high value scattered stations outside of Shandong Peninsula and the Changjiang Estuary. In spring (Fig.1.5.1d), many species began to move from the deep water to shallow inshore coastal areas as sea temperature increased. These areas, such as waters along Shandong Peninsula and outside Jiangsu Province and the Changjiang Estuary, are vital spawning and nursing grounds for many marine species. In the summer (Fig.1.5.1a), the distribution of fishery resources was more dispersed than that in the spring because many species completed their reproductive activities or, while in their late

reproductive period, began to forage near the spawning grounds. In autumn (Fig.1.5.1b), density decreased in coastal waters and the distribution of fishery resources began to accumulate in offshore areas. Species began feeding migration and began to assemble for the coming wintering migration.

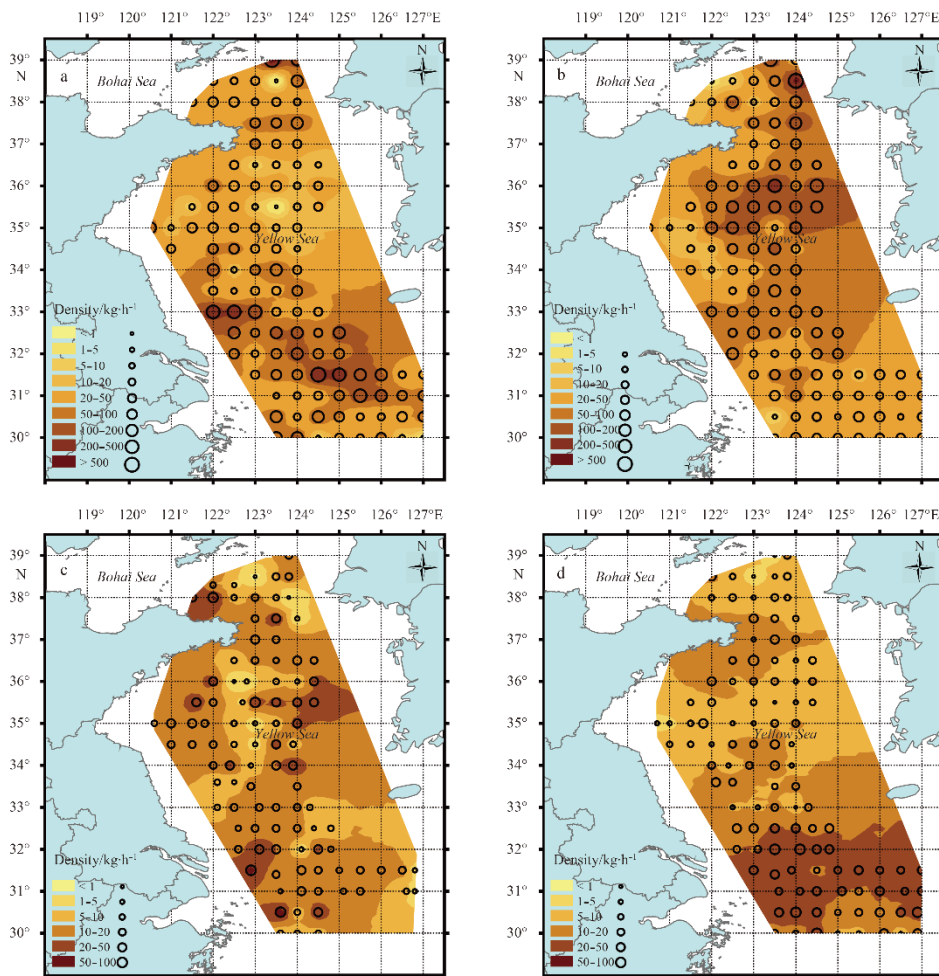


Fig.1.5.1 Spatial distribution of fishery resources density in the Yellow Sea (a. August 2014, b. October 2014, c. January 2015, and d. May 2015.) (Chen et al.,2016)

2. Existing or potential threats to ecological connectivity

2.1 Ecological connectivity

Connectivity in the design of a network allows for linkages whereby protected sites benefit from larval and/or species exchanges, and functional linkages from other network sites. In a connected network individual sites benefit one another. Applicable site-specific considerations refer to currents, gyres, physical bottlenecks, migration routes, species dispersal, detritus, functional linkages. Isolated sites, such as isolated seamount communities, may also be included.

Ecological connectivity is a key concept in landscape and conservation biology. Increasing numbers of international studies are currently showing that coastal ecological connectivity plays an essential role in ecosystem conservation and restoration. Many definitions of ecological connectivity have been proposed, but no unified definition has been recognized. Based on an analysis of existing definitions and principles, Du et al. (2015) propose that ecological connectivity is an integrated relationship of spatial and biological interactions, in which both structural and functional connectivity should be considered.

2.2 Response of phytoplankton community to nutrient enrichment in the subsurface chlorophyll maximum in YSCWM

Studying the role of marine productivity in response to global climate change is one of the major research topics in ecological connectivity. Warm and cold waters exchange at thermocline and boundary of YSCWM, which cause the transmission of nutrient and other kinds of ecological connectivity. The effect of global climate change on the thermocline and boundary of YSCWM may cause a potential threat on the marine primary productivity by disturbing the supporting mechanism of nutrients. The subsurface chlorophyll maximum (SCM) is a prominent biological feature around the thermocline of YSCWM, and may contribute substantial biomass to the water column. Understanding the transient variations of SCM phytoplankton in response to episodic nutrient input is crucial to accurately estimate integrated primary production and to assess the impact of the perturbation to the pelagic ecosystem (Fu et al., 2016, Fig.2.2).

2.2.1 Research purpose

In the summer stratified central Yellow Sea (YSCWM), the SCM is widely observed yet has only been described briefly in previous studies (Fu et al., 2009). Given the importance of SCM to the function of the pelagic ecosystem, the response of the phytoplankton community to environmental disturbance (particularly nutrient entrainment) deserves

further investigation. In the present study, a microcosm nutrient enrichment incubation experiment was conducted at an off-shore station located in the summer stratified central Yellow Sea with aims to assess the responses of the phytoplankton community to the episodic input of nutrients in terms of photosynthetic performance, Chl a concentration, picophytoplankton abundance and shift of microphytoplankton community species composition within the SCM. The results of the study were intended to illustrate the direct biological response in the SCM to pulsed nutrient intrusion induced by episodic events, and help us to better understand and predict the biological response of the SCM to future climate change.

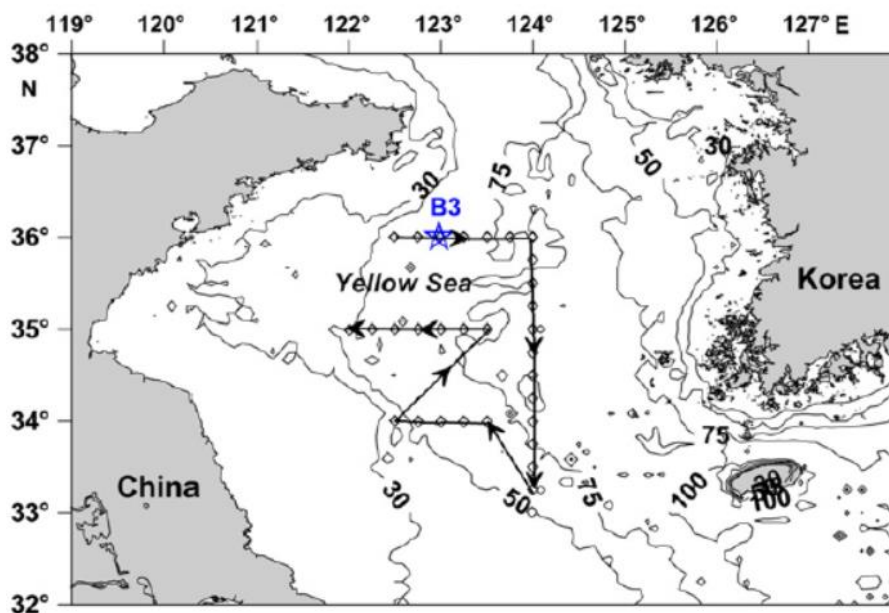


Fig. 2.2.1 Survey stations of summer cruise 2011 and the location of B3 for connectivity disturbing experiment (Fu et al., 2018)

A microcosm experiment designed to investigate the responses of SCM phytoplankton community to pulsed nutrient enrichment was conducted in summer 2011 in the YSCWM area. During the experiment, the incubation cultures sustained a high photosynthetic yield (Fv/Fm) indicating that the phytoplankton was photosynthetically competent and well acclimated to conditions of irradiance and nutrient supply at the SCM. Both Fv/Fm and Chlorophyll a (Chl a) responded significantly in P enriched treatments, but not in the N enriched treatments. The largest increase of Chl a and Fv/Fm occurred when P and N were added simultaneously. *Synechococcus* abundance decreased sharply during the incubation, while picoeukaryote abundance increased in the P and NP addition treatments.

The phytoplankton community shifted from smaller dinoflagellates dominated in the natural environment to larger diatoms dominated under nutrient enrichment conditions. The results indicated that the phytoplankton at the SCM was co-limited by P and N and had a higher requirement for P relative to N. The additional nutrient supply enhanced photosynthetic activity and favored the dominance of larger diatoms which are beneficial to carbon export.

This study suggested that episodic nutrient input induced by various physical processes make a significant impact on the phytoplankton community at the SCM. Using ecological connectivity as key criteria, this

study is important for better understanding and predicting biological responses to the effect of future climate change on YSCWM.

2.2.2 Biological responses after the ecological connectivity disrupted

(1) Photosynthetic quantum efficiency of photosystem II and Chl a

The additions of P resulted in significantly elevated Chl a and Fv/Fm, while additions of N independently did not. The largest increases in Chl a and Fv/Fm occurred when P and N were added simultaneously. The results indicated that phytoplankton at the SCM had a higher requirement for P relative to N. During our experiments, environmental conditions at the SCM caused co-limitation of the phytoplankton community by P and N. This conclusion can be evidenced by the variation in nutrient concentrations at the beginning and end of the experiment among different treatments (Table 3). At the end of the incubation experiment, nitrate concentration remained at a high level in the +N treatment (Table 3), while both N and P concentrations decreased substantially in the +NP treatment. This result also indicated that the growth of phytoplankton was co-limited by P and N.

(2) Picophytoplankton

Synechococcus and picoeukaryotes were the major components of the picophytoplankton community in our study, and *Prochlorococcus* was not detected in the seawater samples. The initial abundance of *Synechococcus* and picoeukaryotes was 118.42×10^3 cells ml⁻¹ and 10.44

$\times 10^3$ cells ml^{-1} , respectively. *Synechococcus* abundance decreased sharply in all treatments to 14- 20% of the initial values. The response of picoeukaryotes was different in different treatments. In the control and +N treatments, picoeukaryotes abundance decreased about 50%. In the +P treatments, the picoeukaryotes abundance increased slightly, while in the +NP treatment the picoeukaryotes abundance increased about 100% (fig. 2.2.2a).

Table 3 Variation of nutrient concentrations at the initial and end of the experiment ($\mu\text{mol L}^{-1}$). (Fu et al., 2018)

	Control		+N		+P		+NP	
	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}
Initial	2.36	0.49	14.86	0.49	2.36	1.24	14.86	1.24
End	0.61	0.17	11.45	0.33	1.09	0.89	7.43	0.61

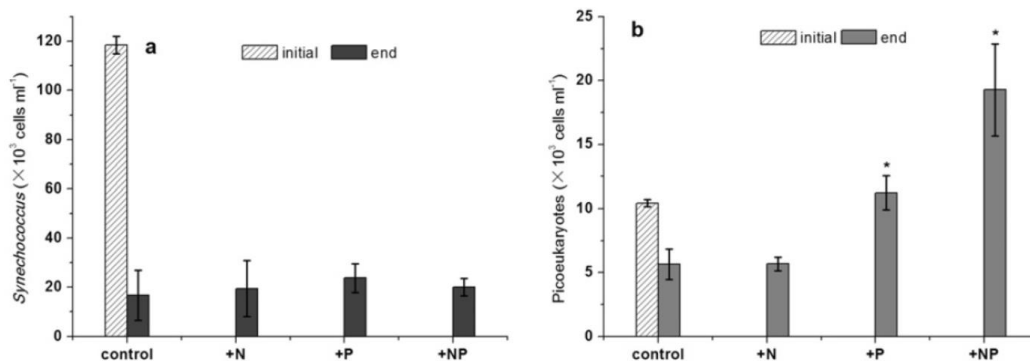


Fig.2.2.2.1 Variation of *Synechococcus* and picoeukaryotes abundance during the experiment. (Fu et al., 2018)

(3) Phytoplankton species composition and community succession

Both cell abundance and species composition of the phytoplankton community changed dramatically during the nutrient enrichment

experiment (Fig.2.2.2b). The average cell abundance in the initial sample was 497.5 cells ml⁻¹, with the relative contribution of diatoms, dinoflagellates and cryptophyta being 48.6%, 44.7% and 6.7%, respectively. The dominant species was *Dinoflagellate* spp. in the initial samples. In the +N treatment, total cell abundance slightly decreased to 366.7 cells ml⁻¹ at the end of the experiment and the dominant species changed to *Skeletonema costatum* and *Nitzschia* spp. In the +P treatment, the total cell abundance increased to 677.2 cells ml⁻¹, and the contribution of diatoms increased to 69.4%. In the +NP treatment, the total cell abundance increased significantly to 1462.4 cells ml⁻¹, and the contribution of diatoms increased to 70.3%. The dominant species changed to *Nitzschia* spp., *Skeletonema costatum* and *Thalassiosira* spp. in the P-containing treatments. The variation in cell abundance was consistent with the similar increasing trend in Chl a concentration. The phytoplankton community structure shifted from being dinoflagellate dominated in the natural environment to being diatom dominated under nutrient enrichment conditions.

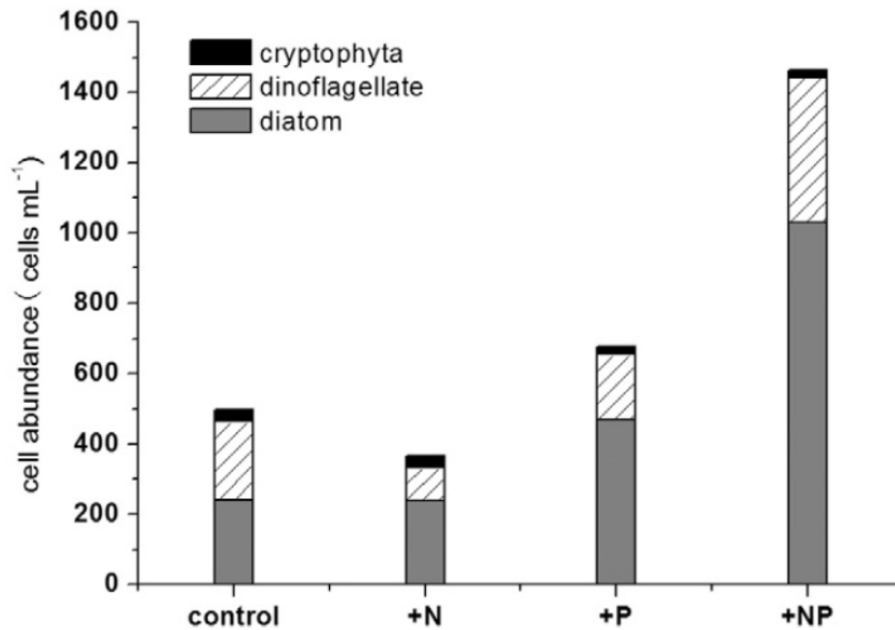


Fig.2.2.2.2 Variation of cell abundance and species composition during the nutrient enrichment experiment (Fu et al., 2018)

2.2.3 Photosynthetic competency and nutrient limitation at SCM

In the summer central Yellow Sea, strong stratification leads to nutrient limitation of phytoplankton growth in the surface waters. Common approaches to determine the limiting nutrient include: absolute nutrient concentrations and their stoichiometric ratios, enrichment experiments with natural assemblages and nutrient uptake kinetics. In a large portion of the oligotrophic oceanic systems, P-limitation/stress or NP co-limitation has been identified through experimental approaches including those in the eastern Mediterranean, the subtropical North Atlantic and the East China Sea. Based on nutrient concentration and element ratios approaches, potential P limitation has been identified in the central Yellow Sea in the surface waters during summer or early

autumn. However, most studies dedicated to the nutrient control of primary productivity and phytoplankton growth have focused so far on the surface layer, and few on the SCM layer, because of the lack of data. In our present enrichment experiment study, the significant increase in Fv/Fm value and Chl a biomass in response to the +P and +NP addition directly confirmed the P-limitation and NP co-limitation in particular at the SCM of the central Yellow Sea.

2.2.4 Summary

Previous studies have shown that in the summer central Yellow Sea, picophytoplankton was dominant in the phytoplankton community and played an important role of ecological connectivity in the food web. Although covariance of *Synechococcus* and picoeukaryote abundance has often been found in the field. According to the published studies, the picophytoplankton community did not respond homogeneously to nutrient additions. For example, in the nutrient enrichment experiments conducted in the oligotrophic stratified Gulf of Aqaba, picoeukaryote cell concentrations increased over an order of magnitude regardless of nutrient addition treatment. In contrast, *Synechococcus* declined in abundance for all treatments and in the control. However, in other studies, abrupt decrease in *Synechococcus* and picoeukaryote abundance was observed during the diatom bloom period, both in mesocosm experiments and field observations, including in the Yellow Sea. During

the spring bloom in the Yellow Sea, *Synechococcus* abundance decreased sharply from 10.17×10^3 cells ml⁻¹ to 1.90×10^3 cells ml⁻¹ in 2007 and from 8.04×10^3 cells ml⁻¹ to 4.76×10^3 cells ml⁻¹ in 2009. In our present study, picoeukaryote cell abundance increased in the P containing treatments, while *Synechococcus* abundance decreased substantially in all treatments including the control. The presence of small grazers, (e.g., ciliates and heterotrophic nanoflagellates) was suggested by some researchers to be responsible for the decrease in *Synechococcus* abundance during the blooms. Cells of the cyanobacterium *Synechococcus* are slightly smaller than those of picoeukaryotes, and might be more susceptible to the impact of microzooplankton grazing. In addition, picoeukaryotes are classified on the basis of size and comprise a highly diverse taxon. The multiple taxonomic groups of picoeukaryotes might be another explanation for their different responses to nutrient enrichment.

SCM was widely observed from late spring to early autumn and is a pronounced feature during the stratified period in the central Yellow Sea. In the nutrient-depleted upper layer, biological activity is low and the phytoplankton community is dominated numerically by a few dinoflagellate species and cyanobacteria. However, water column stability is frequently disturbed by physical processes and episodic events (e.g., typhoons, upwellings and internal waves) and all these are associated with nutrient supply. Nutrient enhancement will not only cause increases in

phytoplankton biomass but also changes in cell size and species composition which are closely associated with carbon export. Some in situ studies have reported phytoplankton communities in various surface waters shifting from domination by dinoflagellates or *Trichodesmium* spp. to domination by diatoms such as *Skeletonema* spp., *Chaetoceros* spp. and *Nitzschia* spp. after the passage of a typhoon. Moreover, a recent study conducted in the South China Sea showed that in addition to a Chl a bloom in the surface waters, one was also observed at the subsurface. This resulted from subsurface upwelling induced by a typhoon, and the subsurface Chl a bloom was even stronger and lasted longer than the surface bloom. Yet, so far, very few papers have addressed phytoplankton community changes and their ecological connectivity in the YSCWM. In the experimental study, similar phytoplankton dominance pattern shifts occurred in response to nutrient input, as observed in other surface water studies (Fig. 2.2.2b). This result is not surprising, because dinoflagellates are generally considered to have competitive advantages in low phosphate concentrations and under stratification conditions, while diatoms have a higher growth rate when nutrients are sufficient. This species dominance shift will favor carbon export due to the sinking potential of diatoms. In addition, the increase in picoeukaryotes in response to nutrient enrichment might further enhance carbon export.

This is because, although less abundant, picoeukaryotes are larger in terms of cell size and carbon biomass compared to *Synechococcus*.

This study has suggested that episodic nutrient input induced by disturbing ecological connectivity may have a significant impact on the whole phytoplankton community at the YSCWM. The results provide information on subsurface phytoplankton community dynamics and will help us to better understand and predict biological responses to future climate change at the YSCWM area.

2.3 Environmental factors affecting zooplankton community in the YSCWM

The present studies showed that temperature had a great effect on zooplankton community structure in the Yellow Sea during winter (Chen et al., 2011). Several species (e.g., *O. similis*, *P. parvus*, *C. sinicus*, *A. crassa*, *E. pacifica*, and *T. gracilipes*) affected by the Yellow Sea Cold Water Mass, characterized by low bottom temperature, provides a refuge that allows them to survive through summer (Sun et al., 2011).

Spatial patterns of zooplankton composition and community structure are also closely associated with water currents. The Yellow Sea Warm Current (YSWC) is a prominent feature during winter in the Yellow Sea. The YSWC takes warmer and saltier water with low zooplankton biomass into the southern Yellow Sea (Lü et al., 2013), causing a decrease in total zooplankton biomass and a change in the zooplankton migration patterns in the intrusion area (Lü et al., 2013), and leads the connectivity between southern Yellow Sea and East China Sea. Meanwhile, it brings tropical zooplankton species, even species typical of Kuroshio water, into the southern Yellow Sea (Wang et al., 2013). Some tropical species (*Candacia bradyi*, *G. rostratus*, *O. mediterranea*, and *F. enflata*) were identified, which were likely transported by the YSWC with low abundance.

The Yellow Sea Coastal Current (YSCC) together with the YSWC composed the general circulation of the Yellow Sea. The warm-temperate

zooplankton species could be carried southward by the coastal current from the center of the population in the Yellow Sea (Hwang and Wong, 2005), which may have affected the zooplankton composition and community structure.

Some warm-temperate zooplankton species (like *T. gracilipes*) originated from the Yellow Sea and some tropical or subtropical species (such as *Nannocalanus minor*, *O. venusta* and *U. vulgaris*) transported by Kuroshio Branch Currents, which results in the most diverse zooplankton community.

2.4 Variation of the macrofaunal community in YSCWM

The southern Yellow Sea ecosystem has been experiencing enormous variation both in terms of its natural environmental and biological characteristics. For the natural environmental variables, Lin et al. (2005) found that the values of both temperature and salinity in the southern Yellow Sea exhibited ascending trends from 1976 to 2000. The variation in temperature was closely related to climate change, while the slight variation of salinity was not (Lin et al., 2005). Xu et al. (2017) also revealed an increasing trend in the bottom temperature in spring but not in autumn. Variation in nutrient levels has been documented in the southern Yellow Sea, with the concentration of inorganic nitrogen increasing steadily (especially for nitrate) from the 1980s to 2008, while the concentrations of silicate and phosphates decreased (Li et al., 2015). The imbalance in the variation in nutrient levels induced changes in the N/P ratio. A high N/P ratio was commonly observed in 2008 and 2012, which far exceeded Redfield's ratio and might be related to the recent occurrence of macroalgal blooms (Li et al., 2015). The Yellow Sea has changed from being nitrogen limited to phosphorus limited, which also occurred in the adjacent Bohai Sea because of the huge amount of terrestrial pollutants carried by river runoff and the organic discharge caused by aquaculture.

From 1958 to 2014, significant temporal variation in the macrofaunal community structure in the southern Yellow Sea was identified, and

changes in the species composition, abundance and diversity indexes were also observed (Figs.2.4.1).

Ophiuroids can reshape the sediment surface and influence the distribution of other benthic species and are therefore important ecosystem engineers (Harris et al., 2009). Ophiuroids are also considered to be important food sources for demersal fish (Harris et al., 2009).

2.4.1 Temporal variation and the increase in ophiuroid abundance

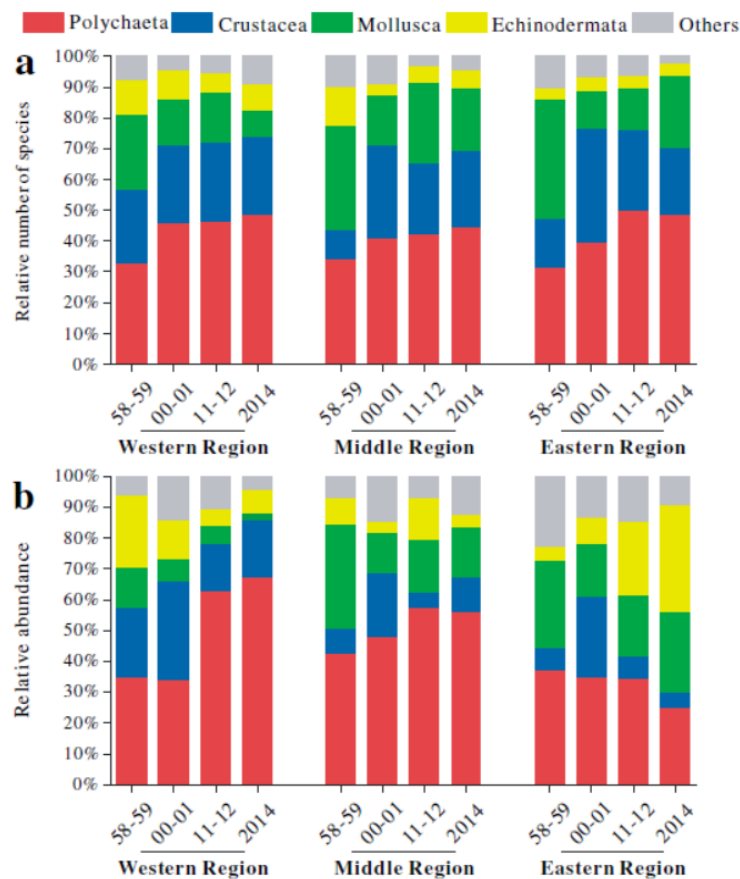


Fig.2.4.1 Relative number of species of major taxonomic groups (a) and relative abundance of macrofauna (b) in the southern Yellow Sea. 58–59: 1958–1959 period; 00–01: 2000–2001 period; 11–12: 2011–2012 period. (Xu et al., 2017)

Ophiura sarsii vadicola, a subspecies of the carnivorous *Ophiura sarsii*, was one of the dominant cold-water species in the Yellow Sea (Liu,

2013), mostly living in areas with low temperature and high salinity (Fig.2.4.1), such as the Yellow Sea Cold Water Mass.

2.4.2 Biological-environmental relationships

The distribution patterns of macrofauna seem to largely rely on the hydrobiological and physicochemical characteristics of the environment (Peng et al., 2014). Environmental parameters such as depth, temperature, salinity, sediment type and median grain size have been considered to be important factors influencing the macrofaunal community in the southern Yellow Sea (Zhang et al., 2016). In the YSCWM, depth was the most important factor affecting the distribution of macrofauna in the southern Yellow Sea, as temperature, salinity and sediment type were found to be closely related to depth (Zhang et al., 2016).

However, more environmental parameters need to be included in future investigations to understand the biological environmental relationships, and the fishing effort needs to be estimated to evaluate the extent of the impact of anthropogenic activities on the macrofaunal community in the southern Yellow Sea, especially in terms of its temporal variation.

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