# Ichthyoplankton assemblage structure of springs in the Yangtze Estuary revealed by biological and environmental visions

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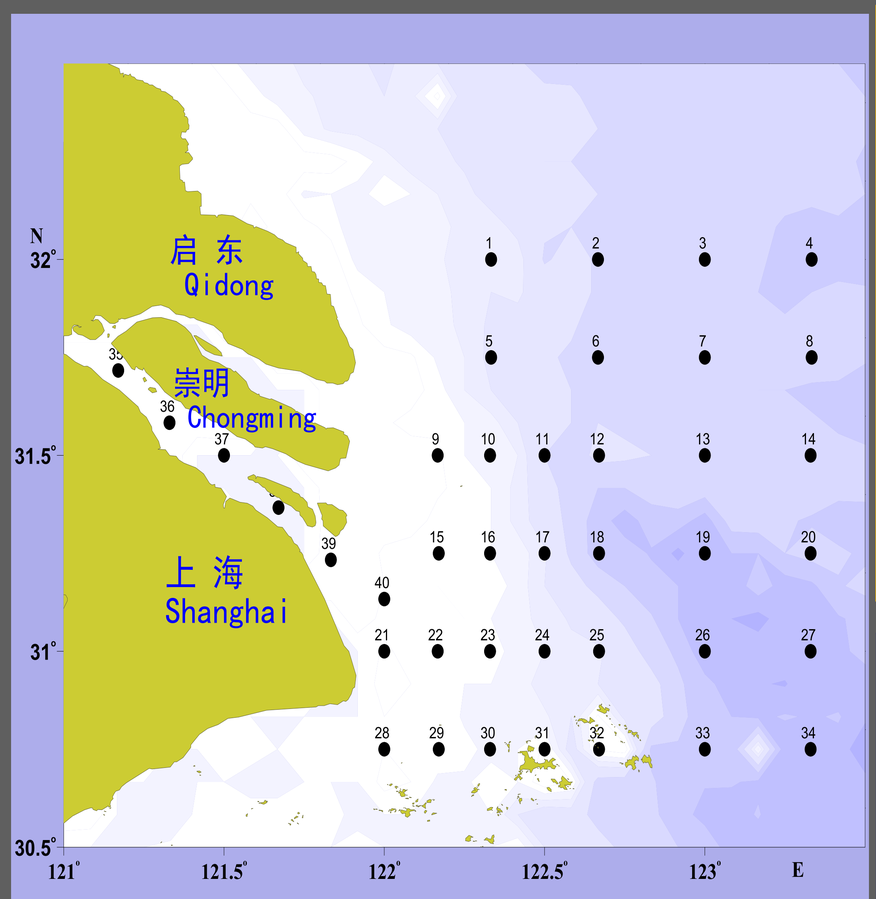


**Study area and sampling stations**

**Data analysis**

## Introduction

The Yangtze Estuary has been extensively modified and threatened during the last decades. The projects have considerably reduced rivers flowing to the Estuary, brought heavy contamination to estuarine aquaculture and habitation, and deteriorated water quality. This degradation has in turn led to a need for multi-year comprehensive surveys. The present study was based on surveys at four springs in 1999, 2001, 2004 and 2007. Our aims are to provide detailed characterizations of the ichthyoplankton assemblage in springs, examine the long-term dynamics of spring ichthyoplankton assemblages, and evaluate the influence of environmental factors on the spatial distribution and inter-annual variations of ichthyoplankton assemblages associated with the Yangtze Estuary.

## Materials and Methods

Biological and oceanographic data were collected during four fishery evaluation cruises in four springs (05/1999, 05/2001, 05/2004, 05/2007) at 40 stations. This study encompasses 160 ichthyoplankton collections from four springs. Ichthyoplankton samples were collected by surface tows of a larva net (0.8m mouth diameter, 2.8 m long, 0.505mm mesh at the body, and 0.505mm mesh at the cod end) equipped with a flow meter. At each station, the net was towed at a depth of about 0.5m from the surface for 10 min against tidal flow. Towing speed was 2-3 knots. The samples were preserved in 5% buffered formaldehyde–seawater solution.

A conductivity, temperature, and depth device was used to measure environmental variables including depth (D), salinity (S), temperature (T), transparency (Trans), dissolved oxygen (DO), pH, total phosphorus (TP), total nitrogen (TN), suspended particulate matter (SPM), chemical oxygen demand (COD), chlorophyll a (Chla) and primary productivity (PP).

## Results

**Table 1** Ichthyoplankton species information.

| Family | Species | EG | Percentage | 1999 | | 2001 | | 2004 | | 2007 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F% | A% | F% | A% | F% | A% | F% | A% |
| Engraulidae | *Engraulis japonicus* | MED | 20.15 | 34.38 | **51.10** | 32.35 | **10.60** | 16.67 | **11.66** | 26.32 | **6.70** |
| | *Coilia mystus* | AN | 46.30 | 31.25 | **21.02** | 23.53 | **58.47** | 19.44 | **30.06** | 21.05 | **32.46** |
| | *Thrissa kammalensis* | MED | 1.06 | | | 2.94 | 1.63 | | | 2.63 | 0.15 |
| | *Setipinna taty* | MED | 0.01 | | | 2.94 | 0.02 | | | | |
| | *Anchoviella commersoni* | ER | 0.33 | | | 8.82 | 0.27 | 13.89 | 3.07 | 5.26 | 0.58 |
| | *Anchoviella zollingeri* | ER | 0.07 | | | 2.94 | 0.11 | | | | |
| Gobiidae | *Chaeturichthys hexanema* | ER | 2.86 | 12.50 | **10.98** | 5.88 | 0.28 | | | 2.63 | 0.15 |
| | *Chaeturichthys stigmatias* | ER | 2.88 | | | 14.71 | 4.48 | | | | |
| | *Synechogobius hasta* | ER | 0.67 | | | 11.76 | 1.05 | | | | |
| | *Gobiidae* sp. | ER | 0.28 | | | 5.88 | 0.43 | | | 2.63 | 0.15 |
| Sciaenidae | *Pseudosciaena polyactis* | MED | 0.18 | 6.25 | 0.28 | 20.59 | 0.12 | | | 5.26 | 0.44 |
| | *Larimichthys crocea* | MED | 0.01 | | | | | 2.78 | 0.31 | | |
| | *Collichthys lucidus* | MED | 0.28 | | | 2.94 | 0.43 | 2.78 | 0.31 | | |
| | *Johnius belengeri* | MED | 0.02 | | | 0.00 | 0.04 | | | | |
| | *Sciaenidae* sp. | MED | 0.01 | | | 2.94 | 0.02 | | | | |
| Cynoglossidae | *Cynoglossus abbreviatus* | ER | 0.05 | | | 2.94 | 0.07 | | | | |
| | *Cynoglossus joyneri* | ER | 0.14 | | | 2.94 | 0.21 | | | | |
| | *Cynoglossus* spp. | ER | 0.02 | | | 5.88 | 0.04 | | | | |
| Cyprinidae | *Pseudolaubuca engraulis* | FS | 0.01 | | | | | 2.78 | 0.31 | | |
| | *Pseudolaubuca sinensis* | FS | 0.03 | | | 2.94 | 0.04 | 2.78 | 0.31 | | |
| Salangidae | *Hemisalanx prognathus* | AN | 0.47 | 3.13 | 1.83 | | | 5.56 | 0.61 | | |
| | *Salanx ariskensis* | AN | 0.02 | | | | | | | 5.26 | 0.29 |
| Atherinidae | *Allanetta bleekeri* | MED | 8.61 | 40.63 | **7.93** | 41.18 | 3.92 | 25.00 | **30.37** | 26.32 | **39.01** |
| Cottidae | *Trachidermis fasciatus* | CA | 13.64 | 12.50 | 2.77 | 20.59 | **16.69** | 11.11 | **22.39** | 13.16 | **18.20** |
| Stromateidae | *Pampus argenteus* | MED | 0.13 | 3.13 | 0.23 | 2.94 | 0.07 | | | 5.26 | 0.29 |
| Myctophidae | *Benthosema pterotum* | MS | 0.85 | 15.63 | 3.24 | 2.94 | 0.09 | | | 2.63 | 0.15 |
| Apogonidae | *Apogonichthys lineatus* | MS | 0.01 | | | | | | | 2.63 | 0.15 |
| Mugilidae | *Liza carinatus* | ER | 0.06 | | | | | | | 2.63 | 0.73 |
| Scombridae | *Pneumatophorus japonicus* | MS | 0.08 | 6.25 | 0.09 | 14.71 | 0.09 | | | | |
| Carangidae | *Trachurus japonicus* | MS | 0.01 | | | | | | | 2.63 | 0.15 |
| Platycephalidae | *Platycepalus indicus* | MS | 0.19 | 3.13 | 0.05 | 8.82 | 0.28 | | | | |
| Scorpaenidae | *Sebastiscus marmoratus* | MS | 0.20 | | | 8.82 | 0.32 | | | | |
| Hemiramphidae | *Hemirhamphus sajori* | MS | 0.01 | | | | | | | 2.63 | 0.15 |
| Zoarcidae | *Enedrias nebulosus* | MS | 0.01 | | | | | 2.78 | 0.31 | | |
| Taeniodididae | *Odontamblyopus rubicundus* | ER | 0.01 | | | 2.94 | 0.02 | | | | |
| Fistulariidae | *Fistularia petimba* | MS | 0.01 | | | 2.94 | 0.02 | | | | |
| Sparidae | *Sparidae* sp. | MED | 0.09 | 6.25 | 0.38 | | | | | | |
| Tetraodontidae | *Taki fugu* sp. | AN | 0.08 | 3.13 | 0.09 | 2.94 | 0.05 | | | 5.26 | 0.29 |
| Anguillidae | *Anguillidae* sp. | CA | 0.03 | | | 0.00 | 0.05 | | | | |
| n.id.1 | | / | 0.08 | | | 2.94 | 0.11 | 2.78 | 0.31 | | |
| n.id.2 | | / | 0.01 | | | 2.94 | 0.02 | | | | |
| n.id.3 | | / | 0.01 | | | | | | | | |

**Notes.**
EG, Ecological guilds; F%, Frequency percentage; A%, Abundance percentage; MS, Marine species; MED, Marine-estuarine-dependents; ER, Estuarine residents; FS, Freshwater species; CA, Catadromous fishes; AN, Anadromous fishes.

**Table 2** Dominant species determined by the IRI.

| 1999 | | 2001 | | 2004 | | 2007 | |
|---|---|---|---|---|---|---|---|
| Species | IRI | Species | IRI | Species | IRI | Species | IRI |
| *E. japonicus* | 5,915 | *C. mystus* | 5,624 | *A. bleekeri* | 4,131 | *A. bleekeri* | 4,800 |
| *C. mystus* | 2,212 | *E. japonicus* | 1,783 | *C. mystus* | 3,180 | *C. mystus* | 3,200 |
| *A. bleekeri* | 1,085 | *T. fasciatus* | 1,405 | *T. fasciatus* | 1,354 | *T. fasciatus* | 1,100 |
| *C. hexanema* | 462 | *A. bleekeri* | 753 | *E. japonicus* | 1,057 | *E. japonicus* | 800 |

**Table 3** Inter-annual comparison of the assemblage structure according to one-way ANOSIM (*R* value and significance level).

| Years | ANOSIM | | SIMPER |
|---|---|---|---|
| | *R* | *P* | Average similarity (%) |
| Global | 0.002 | 0.443 | |
| 1999 vs. 2001 | 0.014 | 0.235 | 78.19 |
| 1999 vs. 2004 | 0.007 | 0.325 | 75.05 |
| 1999 vs. 2007 | 0.023 | 0.868 | 75.12 |
| 2001 vs. 2004 | 0.024 | 0.193 | 79.28 |
| 2001 vs. 2007 | 0.006 | 0.296 | 79.69 |
| 2004 vs. 2007 | 0.026 | 0.818 | 76.05 |

**Table 4** Environmental factors (means and range) in the Yangtze Estuary.

| Variables | 1999 | 2001 | 2004 | 2007 |
|---|---|---|---|---|
| D (m) | 19.52 (5.00–48.00) | 20.48 (5.00–50.00) | 19.57 (6.00–60.00) | 21.45 (5.00–52.00) |
| S (‰) | 15.79 (2.86–27.56)$^{A}$ | 17.93 (3.00–31.58)$^{A,B}$ | 20.97 (3.00–30.19)$^{B}$ | 21.46 (3.00–31.25)$^{B}$ |
| T (°C) | 19.19 (14.98–20.86)$^{A}$ | 18.14 (16.37–21.17)$^{B}$ | 20.79 (19.15–22.22)$^{C}$ | 18.77 (17.65–20.53)$^{D}$ |
| DO (mg/L) | 9.11 (7.34–13.95)$^{A}$ | 5.99 (5.14–8.73)$^{B,C}$ | 6.27 (4.01–12.03)$^{C}$ | 8.10 (3.90–10.20)$^{D}$ |
| pH | 8.29 (7.82–8.85)$^{A}$ | 8.17 (7.95–8.36)$^{B}$ | 8.13 (7.94–8.47)$^{C}$ | 8.39 (7.95–8.71)$^{C,D}$ |
| COD (mg/L) | 2.19 (0.77–3.47) | 2.06 (0.64–4.32) | 1.92 (0.46–4.22) | 1.72 (0.73–4.24) |
| TN (μmol/L) | 79.37 (35.80–151.30)$^{A,C}$ | 60.89 (13.70–77.70)$^{B}$ | 62.90 (26.30–112.10)$^{A,B}$ | 90.65 (35.71–176.18)$^{C}$ |
| TP (μmol/L) | 1.64 (0.52–6.50) | 1.89 (0.30–7.00) | 1.47 (0.61–3.50) | 1.29 (0.17–4.28) |
| SPM (mg/L) | 24.34 (1.30–95.20) | 186.13 (1.30–1,685.00) | 67.03 (2.30–298.70) | 53.30 (1.20–541.40) |
| Chla (mg/m$^3$) | 1.76 (0.21–5.85) | 1.83 (0.19–7.41) | 2.73 (0.09–17.62) | 0.82 (0.21–2.87) |
| Trans | 1.82 (0.20–6.30) | 1.57 (0.20–8.50) | 1.99 (0.45–6.60) | 1.93 (0.30–6.00) |
| PP (mgC/(m$^2$ ∗ d)) | 536.55 (9.86–2,801.17)$^{A,B}$ | 389.91 (18.84–1,810.45)$^{A}$ | 1048.22 (6.70–8,326.82)$^{A,B}$ | 264.70 (11.84–1,232.01)$^{B}$ |

**Notes.**
Values with different letters ($^{A–D}$) indicate significant difference among years, and values with the same letter indicate that the difference was not significant.

**Table 5** Results of CCA in the present study.

| | CCA axes | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Total inertia |
| Eigenvalues | 0.490 | 0.338 | 0.270 | 0.190 | 8.394 |
| Species-environment correlations | 0.811 | 0.772 | 0.846 | 0.623 | |
| Cumulative percentage variance | | | | | |
| of species data | 5.8 | 9.9 | 13.1 | 15.3 | |
| of species-environment ralation | 25.2 | 42.6 | 56.6 | 66.4 | |
| Sum of all unconstrained eigenvalues | | | | | 8.394 |
| Sum of all canonical eigenvalues | | | | | 1.941 |

**Table 6** Conditional effect of environmental variables, Canonical coefficients and intra-set correlation of environmental variables with the first two axis of CCA.

| Variable | Lambda A | *p* | Coefficient | | Correlation | |
|---|---|---|---|---|---|---|
| | | | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| D | 0.31 | **0.002** | 0.20 | 0.68 | **−0.51** | **0.43** |
| S | 0.41 | **0.002** | −0.52 | −0.91 | **−0.69** | −0.22 |
| T | 0.06 | 0.490 | 0.15 | −0.01 | 0.36 | 0.01 |
| DO | 0.15 | 0.052 | 0.03 | −0.09 | −0.05 | 0.37 |
| pH | 0.10 | 0.150 | −0.04 | 0.22 | −0.22 | 0.39 |
| COD | 0.10 | 0.051 | −0.06 | 0.01 | **0.46** | −0.06 |
| TN | 0.10 | 0.096 | 0.36 | −0.06 | **0.69** | −0.03 |
| TP | 0.15 | 0.080 | 0.20 | −0.11 | **0.52** | −0.33 |
| SPM | 0.28 | **0.008** | 0.21 | −0.17 | 0.39 | −0.29 |
| Chla | 0.13 | 0.116 | −0.12 | −0.27 | −0.20 | 0.19 |
| Trans | 0.05 | 0.644 | −0.17 | 0.04 | **−0.46** | 0.39 |
| PP | 0.08 | 0.264 | 0.06 | 0.39 | −0.27 | **0.44** |

**Table 7** *R*-statistic values of species composition of the areas for different years by ANOSIM.

| Area | 1999 | 2001 | 2004 | 2007 |
|---|---|---|---|---|
| Inner vs. central | 0.422** | 0.741*** | 0.471** | 0.354** |
| Inner vs. outer | 0.451** | 0.523*** | 0.016 | 0.155 |
| Central vs. outer | 0.405*** | 0.188** | 0.231* | 0.075 |

**Notes.**
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

**Table 8** Environmental data (means and range) of the areas resultant of CCA.

| Variable | Inner<br>Mean (range) | Central<br>Mean (range) | Outer<br>Mean (range) |
|---|---|---|---|
| D (m) | 8.37 (5.00–10.00)$^{A}$ | 12.20 (5.00–32.00)$^{B}$ | 34.17 (12.00–60.00)$^{C}$ |
| S (‰) | 4.03 (2.86–18.03)$^{A}$ | 19.88 (3.30–28.61)$^{B}$ | 24.50 (6.62–31.58)$^{C}$ |
| T (°C) | 20.10 (18.68–22.22)$^{A}$ | 18.91 (14.98–21.75)$^{B}$ | 18.84 (15.89–21.64)$^{B}$ |
| DO (mg/L) | 7.64 (5.24–12.03) | 6.88 (4.55–10.23) | 7.77 (3.90–13.95) |
| pH | 8.13 (7.90–8.36)$^{A}$ | 8.19 (7.82–8.47)$^{A}$ | 8.35 (8.06–8.85)$^{B}$ |
| COD (mg/L) | 2.80 (1.04–3.52)$^{A}$ | 2.09 (0.77–4.32)$^{B}$ | 1.50 (0.46–4.32)$^{C}$ |
| TN (μmol/L) | 118.08 (45.90–176.18)$^{A}$ | 76.62 (34.80–146.87)$^{B}$ | 49.85 (13.70–86.78)$^{C}$ |
| TP (μmol/L) | 2.83 (1.20–7.00)$^{A}$ | 1.88 (0.55–6.50)$^{B}$ | 0.74 (0.17–1.50)$^{C}$ |
| SPM (mg/L) | 91.75 (28.10–398.00)$^{A}$ | 163.44 (2.50–1,685.00)$^{A,B}$ | 5.11 (1.20–30.40)$^{C}$ |
| Chla (mg/m$^3$) | 0.71 (0.10–2.20)$^{A}$ | 1.64 (0.10–11.70)$^{A,B}$ | 2.32 (0.20–17.6)$^{B}$ |
| Trans | 0.34 (0.20–0.60)$^{A}$ | 0.95 (0.20–4.50)$^{B}$ | 3.37 (0.40–8.50)$^{C}$ |
| PP (mgC/(m$^2$ ∗ d)) | 35.27 (6.70–102.13)$^{A}$ | 265.04 (7.69–3.213.64)$^{B}$ | 1,027.07 (64.39–8,326.82)$^{C}$ |

**Notes.**
Values with different letters ($^{A–C}$) indicate significant difference among years, and values with the same letter indicate that the difference was not significant.

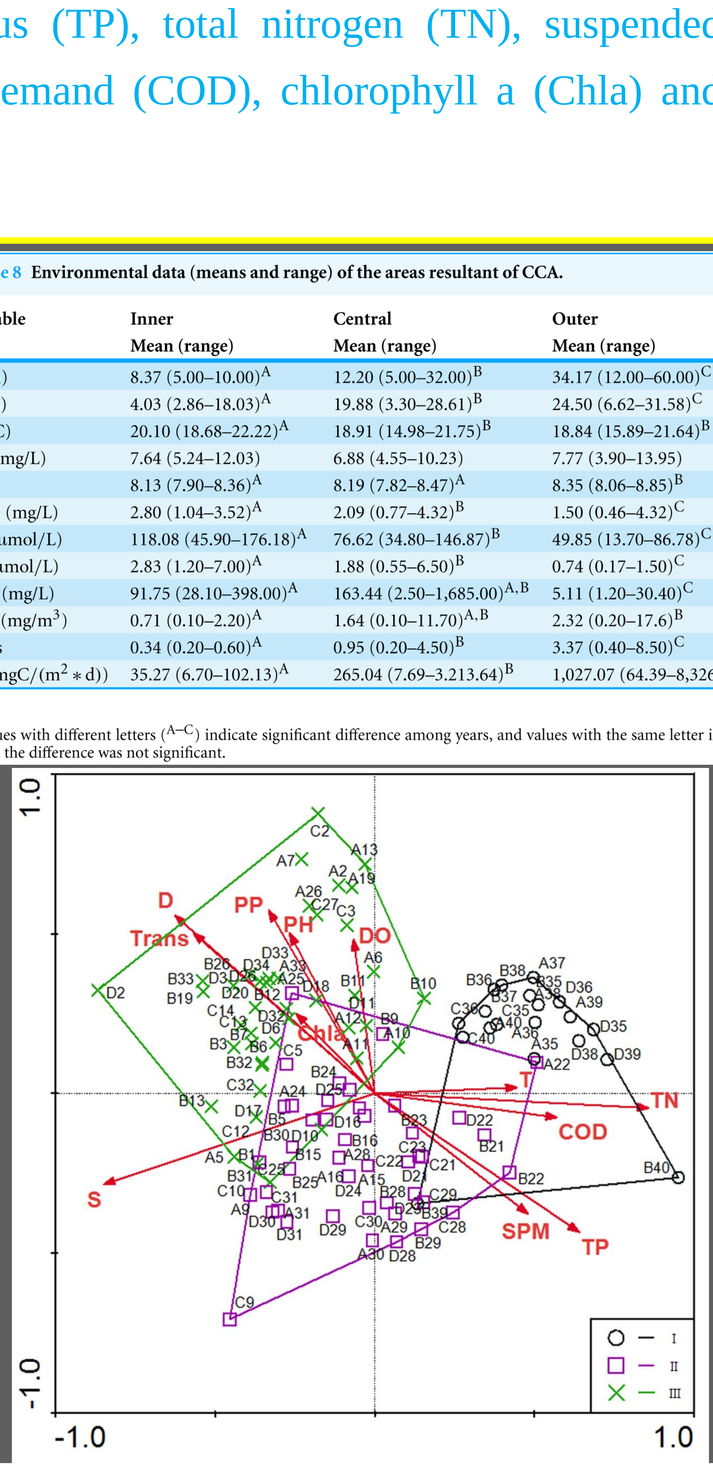


**Figure 3** Plot of scores on the first two axes from CCA for sampling stations in the Yangtze Estuary (A, spring in 1999; B, spring in 2001; C, spring in 2004; D, spring in 2007; the numbers following A–D indicate the station numbers)

## Disscussion

- Forty-two ichthyoplankton species belonging to 23 families were collected. Engraulidae was the most abundant family, including six species and comprising 67.91% of the total catch. Only four species (*Coilia mystus*, *Engraulis japonicus*, *Trachidermis fasciatus* and *Allanetta bleekeri*) could be considered dominant, accounting for 88.70% of total abundance.
- The structure of the ichthyoplankton spring assemblage persisted on an annual basis, with the dominant species reappearing consistently even though their abundance fluctuated from year to year.
- CCA indicated a spatial structure of the ichthyoplankton assemblage in three areas.
- The observed ichthyoplankton assemblage structure appears to be strongly influenced by depth, salinity and suspended particulate matter gradients.

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