Characteristics of jellyfish community and their relationships to environmental factors in the Yangtze estuary and the adjacent areas after the third stage impoundment of the Three Gorges Dam

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Abstract

Over the last decade, a significant increase in jellyfish blooms has been observed worldwide in marine ecosystems and is becoming seen as an indicator of a state shift in pelagic ecosystems. As large jellyfish blooms may have detrimental effects on fishery resources and ecosystem functioning. It is scenically valuable to understand the factors leading to jellyfish assemblage. Based on the survey of hydro-environmental parameters and jellyfish information in the Yangtze River Estuary in 2010-2011, spatial distribution of jellyfish was characterized, and then its relationships with environmental factors were analysed by employing Biota-Environment matching (BIOENV). There were totally 17 species, including 10 species of Hydrozoa, 4 species of Siphonophora and 3 species of Ctenophore, respectively. \textit{Muggiaea atlantica} in spring, \textit{Diphyes chamissonis} in summer and autumn were absolutely dominant species. Seasonal change of averaged abundance of jellyfish was in following order: summer (24 ind. \textcdot m\textsuperscript{-3}) > spring (20.8 ind. \textcdot m\textsuperscript{-3}) > autumn (7.6 ind. \textcdot m\textsuperscript{-3}); and it is summer (0.86) > spring (0.8) > autumn (0.52) for their diversity. The primarily important environmental factor impacting on jellyfish assemblage was temperature, silicate and dissolved inorganic nitrogen for the whole year.

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1 Introduction

Jellyfish abundance is increasing in numerous marine ecosystems worldwide\textsuperscript{[1]}. Examples include the Gulf of Mexico \textsuperscript{[2]}, Japan Sea \textsuperscript{[3]}, North Sea \textsuperscript{[4]}, German Bight\textsuperscript{[5]} and also the East China Sea (ECS)\textsuperscript{[6-7]}. Distinguished from the natural phenomena of jellyfish aggregation, jellyfish blooms in pelagic ecosystems are regarded as a response to anthropogenic disturbance and climate change and could cause numerous deleterious consequences \textsuperscript{[8]}, such as high mortality of fish in fish farms, the depletion of commercial fishery resources because of the competition and predation, blockage of cooling intakes at coastal power plants, losses in tourist revenue during beach closures, and even the death of swimmers, marine ecosystem degradation, and regime shift\textsuperscript{[9-10]}. Thus, bloom of jellyfish reflects a significant ecological threat. More attention has been paid to jellyfish in recent years because of their interference in human enterprises, their ecological importance, and their benefits to humans\textsuperscript{[11-12]}.

The Yangtze River Estuary (YRE) and adjacent area are located in the centre of the Chinese eastern coast\textsuperscript{[13]} and are fishing ground of the diversiform economic fish species\textsuperscript{[14]}. The Yangtze River basin, especially the lower reaches and the estuarine area, is characterized by high industrialization and urbanization\textsuperscript{[15]}. Jellyfish blooms have outbreak in the YRE and adjacent area in successive years since the middle and later in the 1990s\textsuperscript{[16]}. In the autumn of 2003, a bloom of the jellyfish *Nemopilema nomurai* occurred in the East China Sea with an average biomass of 1555 kg • ha\textsuperscript{-1} and the maximum biomass of 15,000 kg • ha\textsuperscript{-1}, consequently, the CPUE of the commercial fishery for *Pseudosciaena polyactis* declined 20% during the period of the bloom\textsuperscript{[17]}. Hence, it is desirable to understand the factors leading to jellyfish assemblage in the YRE and adjacent area. The objectives of this study were to understand the composition and structure of jellyfish community in the YRE and to identify the most important hydro-environmental variables affecting the distribution of jellyfish.

2 Methods

2.1 Sampling and laboratory analysis

Jellyfish and environmental data were collected from 24 stations in August 2010 (high-flow in summer), November 2010 (low-flow in autumn), and May 2011(normal-flow in spring). The sampling sites were illustrated in Fig. 1.
At each site, three water samples were collected from the surface (0.2 m below water surface), middle and bottom (0.2 m above sea bed) of the water column. Water temperature, salinity and pH were measured in situ with a CTD instrument (CTD90M, Germany). Water samples were collected using 5.0 L Nisk water samplers, and were stored in a portable refrigerator at <4°C. Water samples for DIN (=nitrate (NO3-N) + nitrite (NO2-N) + ammonium (NH4- N)), phosphate (PO4-P), and silicate (SiO3-Si) analyses were filtered through a 0.45μm cellulose acetate filter. Nutrient concentration analysis were performed by a continuous-flow analyzer (Skalar San ++, Netherlands) with colorimetric methods described by Grasshoff et al. (1999)\(^{18}\) and Zhang et al. (1997)\(^{19}\). To determine the total suspended solids (TSS), a known volume of well-mixed sample was filtered through a dried and preweighed membrane filter with a pore size of 0.45 μm. The dry mass of the particulate materials captured in each filter was calculated by subtracting the filter mass from the dried mass.

Field sampling and laboratory analysis of jellyfish were conducted according to the Specifications for Oceanographic Survey (State Oceanic Administration, 1991)\(^{20}\). Jellyfish were collected with a shallow water type I plankton net (mouth size, 0.2 m², mesh size, 505μm) along the vertical direction from the seabed to the surface. The samples were preserved in 5% buffered formalin. In the laboratory.

2.2 Data analysis method

Species dominance: Eq. (1) was used to calculate the species dominance index:

\[
Y = \frac{n_i}{N} f_i
\]  

(1)

Where \(n_i\) is the number of individuals of species \(i\); \(f_i\) is the frequency of species \(i\); \(N\) is the total number of jellyfish individuals. Species with a dominance index more higher than 0.02 were taken as dominant species.

Shannon-Weaver Index:

\[
H' = -\sum_{i=1}^{s} (P_i) \log_2 P_i \quad (i = 1,...,s)
\]

(2)

Where \(H'\) is Shannon-Weaver Index; the \(P_i\) is the proportion of population density of species \(i\) relative to the total number of population density; \(s\) is the total number of species.

Relations between jellyfish population density and hydro-environmental factors: Biota-Environment (BIOENV, Primer 5) was used to investigate the relationship between the jellyfish assemblage and hydro-environmental factors. The Spearman correlation coefficients between the jellyfish assemblage and hydro-environmental factors were calculated. The population density data were transformed through log(x+1) to balance the contributions from the few very abundant species with the many rare species. The Spearman correlation coefficients between the jellyfish assemblage and hydro-environmental factors were calculated.

3 Result

3.1 The community composition and dominant species of jellyfish

A total of 17 species were collected in all three seasons (Table 1). Hydrozoans (10 species) accounted for 58.8% of jellyfish assemblage richness, Siphonophores accounted for 23.5% (4 species), and Ctenophores accounted for 17.7% (3 species). The jellyfish were the most diverse in spring with a total of 13 species, and less diverse in summer with 10 species, and the least diverse in autumn with 9 species. Three dominant species in spring and four dominant species in summer and one dominant species in autumn were identified (Table 2). *Diphyes chamissonis* was the most common dominant species in all seasons. *Muggiaea atlantica* and *Diphyes chamissonis* were the common dominant species in spring and summer.

Table 1. Species list of jellyfish in the Yangtze River Estuary and its adjacent areas
Species Sping Summer Autumn
Aequorea australis +
Phialidium hemisphaericum +
Ablyopsis tetragona +
Beroesp. cucumis + +
Eirenesp. + + +
Solmundella bitentaculata + + +
Phialuciumsp. +
Lensia subtiloides + +
Pleurobrachia globosa Moser + + +
Phialidium chengshanense +
Obiaspp. +
Diphyes chamissonis + +
Liriope tetraphylla + +
Muggiaea atlantica + + +
Eirene ceylonensis + +
Ctenophorasp. + + +
Aequorea conica +

Table 2 Dominant jellyfish species and their dominance index in the Yangtze River Estuary and its adjacent areas

<table>
<thead>
<tr>
<th>Season</th>
<th>Number</th>
<th>Dominant Species</th>
<th>Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>1</td>
<td>Muggiaea atlantica</td>
<td>0.348</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Diphyes chamissonis</td>
<td>0.089</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Phialidium chengshanense</td>
<td>0.066</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Diphyes chamissonis</td>
<td>0.442</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Pleurobrachia globosa</td>
<td>0.101</td>
</tr>
<tr>
<td>Summer</td>
<td>3</td>
<td>Muggiaea atlantica</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Liriope tetraphylla</td>
<td>0.031</td>
</tr>
<tr>
<td>Autumn</td>
<td>1</td>
<td>Diphyes chamissonis</td>
<td>0.539</td>
</tr>
</tbody>
</table>

3.2 Distribution and seasonality of jellyfish population density and diversity

The average population density of jellyfish in the study area was 20.8 ind. · m⁻³, 24.0 ind. · m⁻³ and 7.6 ind. · m⁻³ in summer, spring and autumn, respectively. There was the same distribution pattern among the three seasons. Three obvious peaks were identified: the first appeared in the outside of the estuary (31.5° N, 122.5° E), the second was in the northeast of the estuary (31.75° N, 122.25° E), and the last appeared in the southeast of Zhoushan Island (Fig. 2A).

The average diversity in the study area varied among seasons, with 0.80, 0.86 and 0.52 in spring, summer and autumn, respectively. In spring, the highest value appeared at the entrance of the estuary and the southeast of Zhoushan Island. The distribution pattern of jellyfish exhibited a trend of decreasing from the southeast to the northwest of the
estuary. High value areas of the jellyfish diversity was located outside of the estuary, and increased from near-shore to offshore in summer and autumn.

Fig.2 Population density and diversity spatial distribution of jellyfish in Yangtze River estuary (A: abundance ind. m\(^{-3}\); D: diversity)

3.3 Relations between jellyfish and hydro-environmental factors

BIOENV (Table 3) showed that the combination of surface layer water temperature, middle layer TSS and surface layer silica could explain the highest percentage (31%) of jellyfish assemblage variation in spring. In summer, jellyfish assemblages were most highly associated with surface layer temperature, bottom layer silica and bottom layer ammonium (NH4-N), with a maximum correlation coefficient of 0.470. In autumn, the combination of surface layer silica, bottom layer water temperature and DIN could explain 55.1% of jellyfish variations.

<table>
<thead>
<tr>
<th>Season</th>
<th>Governing factor</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Temp (s)*, TSS (m), SiO3- Si (s)</td>
<td>0.310</td>
</tr>
<tr>
<td></td>
<td>Temp (s), TSS (s), SiO3- Si (s)</td>
<td>0.304</td>
</tr>
<tr>
<td></td>
<td>Temp (s), SiO3- Si (s)</td>
<td>0.301</td>
</tr>
<tr>
<td></td>
<td>Temp (s), SiO3- Si (b), NH4- N (b)</td>
<td>0.470</td>
</tr>
<tr>
<td>Summer</td>
<td>Temp (s), NH4- N (b), PO4-P (m)</td>
<td>0.446</td>
</tr>
<tr>
<td></td>
<td>Temp (s), SiO3- Si (m), NH4 (b)</td>
<td>0.426</td>
</tr>
<tr>
<td></td>
<td>Temp (b), SiO3- Si (s), DIN (b)</td>
<td>0.551</td>
</tr>
<tr>
<td>Autumn</td>
<td>Temp (b), SiO3- Si (s), DIN (m)</td>
<td>0.549</td>
</tr>
<tr>
<td></td>
<td>Salinity (s), Temp (b), DIN (m)</td>
<td>0.545</td>
</tr>
</tbody>
</table>

*s: surface layer; m: middle layer; b: bottom layer.
4 Discussion

4.1 Seasonal variations of jellyfish dominant species

Hydrozoans was the main components of the jellyfish in the study area, which both has benthic and pelagic life-history stages. Siphonophores were pelagic zooplankton taxa, whose life-cycle was entirely pelagic [21]. However, Richardson reported that the increased availability of hard substrate habitats caused by human activities may benefit jellyfish populations, for example, the novel habitats from aquaculture potentially provide more hard substrate for benthic polyp proliferation [10]. The water depth of investigation region was less than 20m and intensive use of coastal areas for aquaculture may have provided a large scale availability of new habitat for the proliferation of Hydrozoans. The result in our study showed that Hydrozoans mostly accounted for the proportion of jellyfish. Diphyes chamissonis and Muggiaea atlantica were the absolute dominant species, which were reported to be the low-salt wide-temperature species in the vicinity of the YRE [22]. Diphyes chamissonis was widespread near shore warm water species. It was distributed from Yellow Sea to the southern region of South China Sea and dominant species of the East China Sea, Taiwan Strait and northern margin of South China Sea [23]. The maximum density area of Diphyes chamissonis appeared in salinity ranging from 28 to 32, and temperature ranging from 14 to 20°C [24]. Muggiaea atlantica was common species appeared in all the sea areas of China, and mainly found in nearshore water of the East China Sea in spring and autumn. It easily aggregated and bloomed in water with temperature ranging from 14 to 20°C, while its dominance was declined in higher temperature water in summer and autumn [25].

4.2 Spatial distribution of jellyfish population density and diversity

The location of three jellyfish population density peaks showed little change in three season. In the area of outside of the estuary, Diphyes chamissonis was the largest contributors to the whole jellyfish population density, accounting for 91%. For the northeast of the estuary(31.75° N, 122.25° E), jellyfish larvae was the main species contributing over 88% to jellyfish population density in spring, and Diphyes chamissonis was the largest contributors in summer and autumn, accounting for 62% and 75% respectively. The southeast of Zhoushan Island was dominated by Muggiaea atlantica. It can could be seen that Diphyes chamissonis and Muggiaea atlantica contributed mostly to the jellyfish population density in the YRE. With respected to Shannon-Weaver index, the average value of jellyfish was all less than 1 in three seasons. According to the definition of Shannon-Weaver index, higher species number and very uneven distribution in different species lead to lower diversity [26]. Due to Diphyes chamissonis and Muggiaea atlantica assembled in the YRE, the distribution of jellyfish in different species varied significantly, which caused low diversity in YRE.

4.3 Relations to hydro-environmental factors

Temperature has a great influence on jellyfish distribution [27]. According to the long-term oceanographic records of Chinese coastal waters (Ocean Environmental Information), it could be found that the surface sea temperature rose gradually, especially in the East China Sea, where the temperature increased most prominently [28]. Firstly, Warmer temperatures would accelerate jellyfish growth and ephyrae production [29]. Secondly, increasing water temperature aggravated water stratification and was conducive to the growth of dinoflagellates. The increased abundance of dinoflagellates as well the hypoxic conditions caused by red tide bloom events could create conditions which favour the growth of jellyfish [30]. In additional, an increase in temperature could enable greater spring survival of young medusa, faster individual growth rates and overall jellyfish biomass [31]. Silicate was significantly associated with the distribution of phytoplankton while its relationship with jellyfish was complex. On the one hand, phytoplankton indirectly controlled population density and distribution of jellyfish by impacting the community composition and biomass of zooplankton [1]. On the other hand, jellyfish would release nutrient in metabolic processes, which stimulated phytoplankton growth [32]. What’s more, jellyfish assembling near the shore resulted in the decline of copepods and other competitors, mitigating the stressors of phytoplankton [33]. From the BIOENV result, there was a high correlation between jellyfish distribution and DIN. The nutrient released by jellyfish in its metabolic processes caused increase of concentration of DIN. Dead jellyfish organization could also release massive material.
Acknowledgements

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References


