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Zhijun Dong a, Dongyan Liu a, Yujue Wang a, Baoping Di a, Xiukai Song b & Yajun Shi a

a Key Laboratory of Coastal Zone Environmental Processes, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, Shandong, 264003, P.R. China
b Marine Fisheries Research Institute of Shandong Province, Yantai, Shandong, 264006, P.R. China


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A report on a Moon Jellyfish _Aurelia aurita_ bloom in Sishili Bay, Northern Yellow Sea of China in 2009

Zhijun Dong,1 Dongyan Liu,1,* Yujue Wang,1 Baoping Di,1 Xiukai Song,2 and Yajun Shi1

1Key Laboratory of Coastal Zone Environmental Processes, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, Shandong 264003, P.R. China
2Marine Fisheries Research Institute of Shandong Province, Yantai, Shandong 264006, P.R. China
*Corresponding author: dyliu@yic.ac.cn

In recent years, an increasing number of reports on blooms of Moon Jellyfish (Aurelia aurita) have occurred in the northern coast of China. Throughout the summer of 2009, we studied the occurrence of an _A. aurita_ bloom in relation to environmental variables in the Yantai Sishili Bay of the Northern Yellow Sea. The mean abundance of _A. aurita_ was 0.62 no m\(^{-3}\) in summer 2009 with a highest density of 2.28 n m\(^{-3}\), while the mean biomass of _A. aurita_ was 163.7 mg C m\(^{-3}\). Highest biomass peaked at 673.6 mg C m\(^{-3}\). The present study showed that the spatial distribution of _A. aurita_ seemed unrelated to the environmental variables: sea surface temperature, salinity, dissolved oxygen and nutrients. Chlorophyll \(\alpha\) concentration was positively correlated to the occurrence of _A. aurita_ in summer 2009, suggesting a cascading effect resulting from the jellyfish grazing on zooplankton that in turn reduced grazing of zooplankton on phytoplankton. Increased suitable settlement and reduced currents in the Bay by intense building of coastal construction and aquaculture rafts were discussed as possibly being the main drivers for the proliferation of Moon Jellyfish _A. aurita_. Further investigations on _A. aurita_ polyps in situ should be conducted to address this hypothesis and relate these to current management policies.

**Keywords:** Yantai Sishili Bay, chlorophyll \(\alpha\) concentrations, environmental factors

**Introduction**

Increased jellyfish blooms in coastal waters have been highlighted by scientists over the last decade, due to their significant impact on tourism, their ability to clog water intake of coastal power plants and their ability to interfere with fisheries (Purcell et al., 2007; Richardson et al., 2009; Uye, 2010). Over the last decade, Jellyfish blooms caused by _Aurelia aurita_, _Cyanea nozakii_ and _Nemopilema nomurai_ have been frequently observed in the Bohai Sea, Yellow Sea and East China Sea, China (Dong et al., 2010). _A. aurita_ was observed to be the most common scyphozoan jellyfish with a wide range of geographic distribution, from East Asia Margin Sea (e.g. Seto Inland Sea, Tokyo Bay, Korea, Taiwan) up to the northern European waters (e.g. Kertinge Nor, Gullmarfjord and Elefsis Bay) (Lucas, 2001; Uye et al., 2003; Ki et al., 2008; Lo et al., 2008a). Moon Jellyfish _A. aurita_ blooms also occurred in the harbors and coastal waters in the Yellow Sea and Bohai Sea in China where they have been a nuisance for local tourism and coastal power plants (Su, 2007; Liu, 2008; Lu, 2009). Moderate ingress of jellyfish leads to a reduction in the plant efficiency; e.g. 20–50 tons
of *A. aurita* were cleaned up from the clogged intake screens of the coastal power plant in Weihai (the Northern Yellow Sea) in August 2008 (Chinese Huanneng Group, personal communications); over 10 tons of *A. aurita* were cleaned up from the clogged intake screens of coastal power plant in Qingdao (the Southern Yellow Sea) in July 2009 (Lu, 2009). Over 4000 tons of *A. aurita* entered the coastal power plant in Qinhuangdao (the Bohai Sea) from 23 June to 31 July 2008. Despite the continuous cleaning up of the clogged intake screens, one 300-megawatt capacity power generation unit of the Qinhuangdao Power Station had to shut down shortly on 13 July due to the large number of *A. aurita* entering (Liu, 2008).

Reports on *A. aurita* blooms in China Seas contain data on the abundances and distribution too limited to understand their basic lifecycle characteristics and ecological importance in the coastal ecosystem. Previous case studies on coasts elsewhere indicated coastal eutrophication and increased substrate suitable for jellyfish larval settlement to be an important contributor to the *A. aurita* blooms (Arai, 2001; Mills, 2001; Lo et al., 2008b). However, there is little knowledge of the environmental factors favoring suggested population increases of *A. aurita* in China.

Yantai Sishili Bay (YSB), located in the Northern Yellow Sea, China, is an important harbor in Shandong province. The bay also supports marine aquaculture for state seafood market (Figure 1). The seasonal occurrence of adult Moon Jellyfish *A. aurita* was thought to be a common phenomenon in this region. However, a poll survey of local fishermen showed that most of them considered an increase in *A. aurita* numbers in recent years. A Moon Jellyfish bloom event was recorded in Yantai harbor in summer 2007, which was thought to be infrequent in this region (Su, 2007). In summer 2009, a three-month (July–September) survey was conducted in YSB to understand the formation of an *A. aurita* bloom. To further explore the cause and sequence of *A. aurita* bloom in YSB, *A. aurita*’s distribution patterns were studied in relation to key environmental factors.

**Materials and Methods**

YSB is an ear-shaped semi-closed bay located in the Northern Yellow Sea, China, with a total surface area of about 130 km$^2$, and with a water depth of generally less than 15 m (Figure 1). Aquaculture and shipment have been greatly developed by Yantai City around YSB over the last decades. Seven stations were designed for *A. aurita* collections; stations J2, J3 and J4 were located in the aquaculture area; stations J5, J6 and J7 were nearshore stations; J1 is outside the bay as contrast (Figure 1; J1–J7).

Three cruises were carried out in YSB on 24 July, 7 August and 3 September 2009, respectively. Surface trawl tows (the net mouth with a length of 1.5 m and a width of 0.5 m; the net body with a
At each station, medusae were collected by towing for ten minutes in surface waters. All medusae were counted and weighted immediately after capture. Catch data were standardized to density (number m\(^{-2}\)) were length of 4.5 m long; trawl mesh size ranges from 2.0 cm at the mouth to 0.7 cm at the end) were used to quantify A. aurita biomass. At each station, medusae were collected by towing for ten minutes in surface waters. All medusae were counted and weighted immediately after capture. Catch data were standardized to density (number m\(^{-3}\)) for statistical comparisons. Volume swept by each tow was calculated by multiplying the mouth area of the net by the distance towed. The distance towed was determined using start and end latitude and longitude corrected for the curvature of the earth. Carbon biomass (mg C m\(^{-3}\)) for A. aurita at each station was determined by multiplying abundance by weight conservation (from count and wet weight measurement at sea). Jellyfish carbon content was assumed to be 0.163% wet weight (Larson, 1986).

Temperature, salinity, dissolved oxygen (DO), chlorophyll \(a\) (chl \(a\)) concentrations and nutrients were determined during the summer field surveys in YSB (Figure 1; E1–E7). The sea surface temperature, salinity and dissolved oxygen were measured in situ using an YSI 6920 multi-parameter water quality monitor. Nutrients concentrations, including \(\text{NO}_3^-, \text{NO}_2^-, \text{NH}_4^+, \text{PO}_4^{3-}\), and \(\text{SiO}_4^{3-}\), were analyzed using Flow Injection Analysis (AA3, Bran+Luebbe, German). Chl \(a\) concentrations were determined using UV-VIS spectrophotometer (TU 1810, Beijing Purkinje General Instrument Co., Ltd., China) after filtration on GF/F membranes (Whatman) (Lorenzen, 1967).

The relationships between carbon biomass distribution of A. aurita and their environmental variables including temperature, salinity, DO, chl \(a\) concentrations and nutrients were determined using Pearson’s rank correlation. The three cruises were treated as repeated samples because the environmental factors of near-shore aquatic systems often have obvious fluctuations and it maybe unadvisable to draw conclusions on their properties based on data from a single investigation (Song et al., 2009). All statistical analysis was done using SPSS 17.0 software.

### Results

Environmental parameters of water quality in YSB during the summer cruises are shown in Table 1. The mean surface temperature and salinity varied less during the period of survey ranged between 21.7°C and 23.8°C, and 30.1 psu and 31.2 psu respectively. The mean surface DO concentration for all stations ranged between 6.67 mg l\(^{-1}\) and 10.88 mg l\(^{-1}\). Overall, the mean surface temperature, salinity and DO varied slightly among stations. Mean chl \(a\) concentrations ranged between 6.4 mg l\(^{-1}\) to 8.1 mg l\(^{-1}\) during the time of survey. The mean nutrient loadings were higher in September with an average of 17.89 \(\mu\)mol in DIN concentrations, while lower in July and August with an average of 6.70 \(\mu\)mol and 7.08 \(\mu\)mol in DIN concentrations, respectively. The mean DIP concentrations ranged between 0.16 \(\mu\)mol and 0.22 \(\mu\)mol during the time of survey. The DIN: DIP ratio ranged between 17 and 156 during the time of survey with the exception 4 stations that had lower ratios than the Redfield (1958) ratio of 16:1; this includes station E1 (4) in June, station E3 (5) and E5 (6) in July, and station E5 (8) in September. From July to September in 2009, the winds generally came from the east-southeast.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>24th July</th>
<th>7th August</th>
<th>3rd September</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>21.7 ± 0.6</td>
<td>23.8 ± 0.7</td>
<td>22.0 ± 0.1</td>
</tr>
<tr>
<td>Salinity (psu)</td>
<td>30.12 ± 0.51</td>
<td>30.70 ± 0.08</td>
<td>31.23 ± 0.11</td>
</tr>
<tr>
<td>DO (mg l(^{-1}))</td>
<td>10.88 ± 1.23</td>
<td>6.67 ± 1.64</td>
<td>6.94 ± 0.94</td>
</tr>
<tr>
<td>Chl (a) (mg l(^{-1}))</td>
<td>7.11 ± 2.64</td>
<td>6.39 ± 3.01</td>
<td>8.15 ± 6.72</td>
</tr>
<tr>
<td>DIN (µmol)</td>
<td>6.70 ± 5.27</td>
<td>7.08 ± 4.10</td>
<td>17.89 ± 10.57</td>
</tr>
<tr>
<td>DIP (µmol)</td>
<td>0.16 ± 0.06</td>
<td>0.18 ± 0.15</td>
<td>0.22 ± 0.23</td>
</tr>
<tr>
<td>DSI (µmol)</td>
<td>1.19 ± 0.64</td>
<td>2.31 ± 2.83</td>
<td>3.58 ± 2.74</td>
</tr>
<tr>
<td>DIN: DIP ratio</td>
<td>43.04 ± 85.78</td>
<td>39.99 ± 27.92</td>
<td>81.85 ± 45.73</td>
</tr>
<tr>
<td>Abundance (N m(^{-3}))</td>
<td>0.80 ± 1.02</td>
<td>0.79 ± 0.98</td>
<td>0.26 ± 0.51</td>
</tr>
<tr>
<td>Carbon Biomass (mg C m(^{-3}))</td>
<td>165.6 ± 234.6</td>
<td>280.3 ± 283.3</td>
<td>45.1 ± 81.7</td>
</tr>
</tbody>
</table>
abundance of *A. aurita* in the outside station J1 was low with the density below 0.01 N m$^{-3}$ during the whole survey; the abundance of *A. aurita* at the aquaculture stations displayed a decreasing trend during July and September, with an average density of 0.82 N m$^{-3}$ in July, 0.39 N m$^{-3}$ in August, and 0.02 N m$^{-3}$ in September respectively; the abundance of *A. aurita* in the nearshore stations increased from an average density of 1.05 N m$^{-3}$ to 1.46 N m$^{-3}$ from July to August, and decreased to an average density of 0.59 N m$^{-3}$ in September. Overall, the mean abundance of *A. aurita* in YSB was 0.62 N m$^{-3}$ in summer 2009 with a highest density of 2.28 N m$^{-3}$. The relatively high biomass of *A. aurita* occurred at stations J2 and J6 ranging from 252.2 mg C m$^{-3}$ to 661.7 mg C m$^{-3}$ in July; stations J3, J4, J5 and J6 ranging from 287.8 mg C m$^{-3}$ to 673.6 mg C m$^{-3}$ in August. The mean biomass of *A. aurita* in YSB was 163.7 mg C m$^{-3}$ in summer 2009 with a highest biomass of 673.6 mg C m$^{-3}$ (Figure 2d–f).

Temperature, salinity, DO and nutrient values didn’t correlate with *A. aurita* (Table 2). However, the carbon biomass of *A. aurita* correlated positively with chlorophyll $a$ concentrations as a measure of phytoplankton biomass (Pearson correlation coefficients = 0.726; $P = 0.032$). An exponential model was fitted to the plots of carbon biomass of...
Table 2. Correlation coefficients (Pearson correlation) of carbon biomass of *Aurelia aurita* with environmental variables. *Correlation is significant at the 0.05 level.

<table>
<thead>
<tr>
<th></th>
<th>Chl a</th>
<th>Temperature</th>
<th>Salinity</th>
<th>DO</th>
<th>DIN</th>
<th>DIP</th>
<th>DSi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pearson</strong></td>
<td>0.726*</td>
<td>0.450</td>
<td>-0.391</td>
<td>0.555</td>
<td>-0.220</td>
<td>-0.340</td>
<td>0.232</td>
</tr>
<tr>
<td><strong>Sig.</strong></td>
<td>0.032</td>
<td>0.156</td>
<td>0.193</td>
<td>0.098</td>
<td>0.318</td>
<td>0.228</td>
<td>0.309</td>
</tr>
</tbody>
</table>

the Moon Jellyfish to chlorophyll *a* concentrations in YSB (Figure 3).

**Discussion**

Moon Jellyfish blooms and related nuisances seem to be a common feature of the coastal waters of East Asia. For example, in the Honjo District of Japan, *A. aurita* peaked on August with 1.33 N m⁻³ with a total mean abundance of 0.55 N m⁻³ during the time of survey from June 2005 to August 2006 (Han et al., 2009). The abundance of *A. aurita* reached a maximum of 14.5 N m⁻³ in April 2002 in Tapong Bay (Lo et al., 2008a), while *Aurelia* sp. also formed dense blooms in the Korean coastal waters and led to the shut down of the Ulchin power plant in September 1996 and August 2001 (Ki et al., 2008; Korean Nuclear Power Plant Operational Performance Information System, 2011). However, quantifying Moon Jellyfish *A. aurita* in total numbers and densities is not straightforward. Previous studies showed the different methods used to determine densities of *A. aurita* to have various efficacy (Suchman and Brodeur, 2005; Purcell, 2009): e.g. *A. aurita* densities at finer scale observed by vertical hauls or Remote Observation Video were higher than sampled using trawl tows. This was probably caused by the often patchy distribution of scyphomedusae.

Dense assemblages of jellyfish in coastal waters can influence phytoplanktonic assemblages through stimulation of production by excretion of nutrients (i.e. bottom-up control) and structuring zooplankton predatory activity (i.e. top-down control), (Schneider and Behrends, 1998; Møller and Rissgård, 2007; Pitt et al., 2007; West et al., 2009). The chlorophyll *a* concentrations, as an indicator of phytoplankton biomass and abundance in coastal waters, are influenced by many environmental and biological factors including water temperature, nutrients and zooplankton grazing pressure. In the present study, the spatial distribution of the chlorophyll *a* concentrations in YSB coastal waters didn’t correlate with water temperature and nutrients. Therefore, correspondence of high chlorophyll *a* concentrations with abundant *A. aurita* suggested possible cascading effect results from the jellyfish grazing on mesozooplankton which in turn reduces grazing of mesozooplankton on phytoplankton in YSB in summer 2009. A significant correlation between satellite derived chlorophyll *a* concentrations and the biomass of the invasive comb jellyfish *Mnemiopsis leidyi* was also observed in the southern Caspian Sea (Kideys et al., 2008).

In addition, the abundance of *A. aurita* in outside stations was consistently low, indicating that *A. aurita* might not come from outside the YSB. Miyake et al. (2002) showed that the polyps of Moon Jellyfish *A. aurita* were observed on the horizontal undersurface of floating piers in Kagoshima Bay and suggested that the polyps of *A. aurita* preferred a low light environment. The intense building of coastal construction and aquaculture rafts might be the potential habitats of the polyps of *A. aurita* in YSB because they could provide shaded surfaces for larval settlement and asexual reproduction (Lo et al., 2008b). The permanent artificial shoreline constructed by concrete accounting for ca. 50% of the total shoreline in the present study area including Yantai Port where 46 berths were built up with a wharf length of 7.3 km, which

![Figure 3. Plots of the carbon biomass of the Moon Jellyfish *Aurelia aurita* to Chlorophyll *a* concentrations in Yantai Sishili Bay during the *A. aurita* bloom.](image-url)
may be favorable for the attachment of benthic polyps. Similarly, the dense aquaculture rafts could also provide additional habitat and surfaces for larval settlement and asexual reproduction and increased retention of the ephyrae and jellyfish in aquaculture area. Lo et al. (2008b) found that increased water exchange could have promoted transport of jellyfish and their planula larvae and ephyrae from Tapong Bay, while restricted water exchange would increase retention of jellyfish and their planula larvae and ephyrae in the bay.

The extensive scallop culture has been placed in suspension in lanternnets underneath longlines and buoys in YSB for over two decades, accounting for ca. 70% area of the entire bay area (Zhou et al., 2006). The movement of water in aquaculture stations is restricted by both the offshore islands and the suspension aquaculture of scallops and oyster, e.g. the surveys conducted by Wu et al. (2001) showed that the actual flow velocity in aquaculture area was only 10 cm.s⁻¹ compared to the inshore flow velocity ranging from 50–90 cm.s⁻¹. Combined with the high standing stocks of A. aurita polyps in aquaculture and nearshore stations might explain the high abundance of A. aurita in this area. Further investigations of A. aurita polyps in situ should be conducted to address this hypothesis.

Conclusions

A Moon Jellyfish A. aurita bloom in Yantai Sishili Bay, of Northern Yellow Sea, in summer 2009 was discussed in the present study. The mean abundance of A. aurita was 0.62 no m⁻³ in summer 2009 with highest density of 2.28 n m⁻³, while the mean biomass was 163.7 mg C m⁻³. Highest biomass peaked at 673.6 mg C m⁻³. In the present study, the spatial distribution of A. aurita seemed unrelated to the environmental variables sea surface temperature, salinity, dissolved oxygen and nutrients. Chlorophyll a concentration was positively correlated to the occurrence of A. aurita in the Bay in summer 2009, suggesting a cascading effect resulting from jellyfish grazing on zooplankton that in turn reduces grazing of zooplankton on phytoplankton.

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