Size distribution of individuals in the population of *Asterias amurensis* (Echinodermata: Asteroidea) and its reproductive cycle in China

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Abstract

To obtain baseline information on the size distribution of individuals in the population and reproductive features of sea star *Asterias amurensis*, monthly surveys of the population were carried out from May to December 2010 and March to May 2015 in coastal waters off Yantai, China. Spawning period was predicted by gonad and pyloric caeca indices as well as anatomical and histological methods. In the *A. amurensis* population, both large individuals (>143 mm) and small ones (<42 mm) were present in all sampling months. The population size structure was driven by the appearance of big cohorts of individuals less than 55 mm from May to August. The appearance of small individuals in all months suggested a prolonged spawning period at other sites in this bay or sea stars growing slowly because of food shortage. An arm length is a good predictor to wet body weight for *A. amurensis*. The development of gonad was relative slow from May to September but rapidly reached a peak of 20.95 in October 2010, and then dropped remarkably, indicating its spawning lasted from October to November. The same phenomenon was found from March to May 2015, suggesting another spawning during March to May, which was also verified by the results of histologic analysis on ovary. The gonad index (GI) and pyloric caeca index (PCI) tended to show a negative relationship. Due to the poor food availability, the reproductive characteristics of sea star were most likely affected by the shellfish mariculture in Yantai coastal waters.

Key words: sea star, gonad index, pyloric caeca index, shellfish mariculture, Yantai

1 Introduction

Sea star *Asterias* spp. widely distributes in the oceans of the northern hemisphere (Byrne et al., 1997). The specie *Asterias amurensis* is commonly found in the northwest and northeast Pacific, especially Russia (Kashenko, 2005), Japan (Nojima et al., 1986), Korea (Paik et al., 2005), China (Liao and You, 2002), Norton Sound Alaska (Oliver et al., 1983), and Tasmania (Morrice, 1995; Byrne et al., 1997; Ross et al. 2004, 2006). In China, *A. amurensis* distributes in the Bohai Bay and Yellow Sea, especially in the Yanwei fishing ground, Bohai Sea, and coastal waters of Changshan Island (Zhou et al., 1996). The outbreak of *A. amurensis* happened several times and caused huge damages on mollusca mariculture in China and Japan since 1953 (Nojima et al., 1986; Zhou and Wang, 2008). The normal density of sea star in some bays of the Far East was between 0.12 to 0.7 ind./m² (Galysheva and Pustovalova, 2009), whereas it was up to 6.1 ind./m² during outbreak (Nojima et al., 1986). The recorded outbreaks in China's seas began in the 1960s and became more frequent and serious in recent years (Zhou and Wang, 2008). In 2006 and 2007, the outbreak occurred in coastal waters of Qingdao with an aggregated density of 300 ind./m², and caused economic losses up to 1.5 million US dollars in mariculture of scallop, abalone, and clams (Zhou and Wang, 2008). In 2008 and 2009, similar outbreaks happened in coastal waters of Yantai and Weihai.

Asterinid species have different reproductive patterns, including seasonal or continuous breeding periodicity (Carvalho and Ventura, 2002; Barker and Xu, 1991b; Byrne, 1992; Paik et al., 2005; Pastor-de-Ward et al., 2007; Mariante et al., 2010; Micael et al., 2011; Benítez-villalobos and Martínez-garcía, 2012). The differences are related to many environmental factors, including temperature, hydrodynamics, the quantity and quality of available food, and photoperiod. The seasonal changes of sea temperature affected both larval developmental duration and growth rate (Paik et al., 2005) with the tendency of quicker development in warmer water (Strathmann, 1978; Barker and Nichols, 1983). The size-age composition and reproduction cycle for *A. amurensis* were different from north to south by latitude, e.g., from Russi-

an, Japan, Korea and China to Tasmania (Hatanaka and Kosaka, 1958; Morrice, 1995; Kashenko, 2005; Paik et al., 2005).

Asterias amurensis is a "keystone" predator and feeds on a wide variety of prey, including commercially important bivalve species, and it is responsible for huge economic losses in bivalve mariculture. Many studies have investigated its ecology, reproduction, and feeding biology (e.g., Kim, 1968; Sloan, 1980; Nojima et al., 1986; Lockhart, 1995; Ross et al., 2002, 2003; Lawrence et al., 2011). However, there are only a few studies of *A. amurensis* in China and mainly focused on taxonomy, distribution (Liao and You, 2002; Zhou et al., 1996) and nutrition (Hao and Li, 1998). Some studies are gonad development and reproduction, but the results were not consistent, i.e., breeding twice a year in Russia while once a year in Japan and Australia (Byrne et al., 1997; Novikova, 1978; Kim et al., 1968; Hatanaka and Kosaka, 1958). A preliminary study showed the breeding season of *A. amurensis* was from November to next January along the coast water of Qingdao (Zhang et al., 2014). The Bohai Sea and Yellow Sea were once the most important marine fishery grounds in China before the 1980s. However, intensive human activities (mariculture, sewage discharge, and coastal engineering) have significantly affected the coastal water environments and degraded the marine ecosystem (Tang, 2004; Wang et al., 1995; Liu et al., 2009). The Sishili Bay (SB) had a long history of mariculture since the 1950s with different species, from seaweed *Laminaria japonica* and Asian kelp *Undaria pinnatifida* in the 1950s to scallop *Chlamys farreri* and *Argopecten irradians*, and mussel *Mytilus edulis* in the 1990s. The farming area in SB was up to 2 450 hm², of which 800 hm² for scallop, 400 hm² for mussel, and 250 hm² for seaweed respectively (Wan, 2012; Gao et al., 2011). The culture duration for scallop lasted for one to two years, and harvested at the end of October. The shellfish as well as the inorganic carbon from mariculture would provide abundant food supply for *A. amurensis*, which would lead the aggregation and thus provide an ideal area to carry out the present work.

The inconsistent results of reproduction pattern and the lack of information on the size-age composition inspire us to investigate this Chinese sea star population. The aims of the present study were: (1) to obtain basic information on monthly change of sea star population size structure; (2) to speculate the spawning characteristics of *A. amurensis* population in the study area based on the monthly variation of gonad and pyloric caeca indices.

2 Materials and methods

2.1 *Study area and sampling stations*

Individuals of *A. amurensis* were collected at monthly intervals from the Yuren Pier, a scallop mariculture rafts area in SB, during May to December 2010 by SCUBA diving. For getting full yearly data, we extended the investigating period from March to May 2015 again in the same area to fill the time gap in the first stage of samples collection (Fig. 1). In each collection process, we sampled sea star individuals (up to 311 individuals, arm radius (R) being 19 to 155 mm) in same depth about 5 m to minimize the sampling error. Water temperature was measured *in situ* using YSI (Yellow Spring Ohio, USA).

2.2 *Sampling method and treatment*

Individual samples were blotted dry using absorbent paper and was then wet weighed using a 0.001 g precision electric balance. The longest arm length ($R_{\max}$) (from the center of the disc to the arm tip) was also measured using handheld calipers with the accuracy of 0.1 mm. Thirty individuals with intact body, of
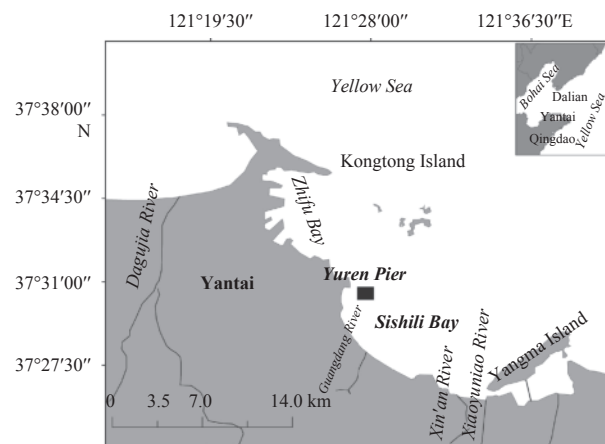

Fig. 1. Study area and locations of sampling site in Yantai.

medium to large size class (R=55.5 to 155 mm), were selected randomly for dissection to calculated the gonad index (GI) and pyloric caeca index (PCI), respectively. Each individual was dissected by cuts extending from the center of the aboral surface towards the apex of each arm, then the gonads and caeca from each arm were removed and weighed separately. GI and PCI were calculated as wet weight of organ/total body wet weight ×100 (Grant and Tyler, 1986; Carvalho and Ventura, 2002). The mean GI and PCI were calculated for each sampling date. Based on the changes of GI against time, the stage of gonad development could be concluded.

The minimum $R_{\max}$ of sea stars presented with gonads was normally *c*. 55 mm (Morrice, 1995; Hatanaka and Kosaka 1958; Kim, 1968). By this, the individuals with $R_{\max}$ shorter than 55 mm were considered as small cohort (one year) and the ones with $R_{\max}$ longer than 55 mm as big size cohorts (two or three years) in the present work.

The differences of sea star size, gonad and pyloric caeca indices during eight sampling months were tested by the analysis of variance (ANOVA) and Kruskal-Wallis ANOVA analysis (*Chi* square) in case of heterogeneity of variance. Relationship between gonad and pyloric caeca indices was analyzed using a simple linear regression. Figures were drawn with software Matlab.

To support the GI, histological evalucaiton was performed on the gametogenesis and gonad maturity pattern from March to May (in the mid to late part of every month). Gonad from each individual was fixed in Bouin's solution for at least 24 h and then transferred to 70% ethanol. The middle section of the gonad was dehydrated, embedded in paraffin and sectioned (7 μm thick). The sections were stained with haematoxylin and eosin, and then the maturity stage of gonads were examined based on the gametogenesis state and staining properties of oocytes and spermatocytes (Kim, 1968; Byrne, 1992). Gametogenesis development stages were divided and used as evidence of gonad development, according to the results from two typical previous researches (Byrne et al., 1997, Zhang et al., 2014).

3 Results

3.1 *Population size structure of A. amurensis*

The body size of individuals ranged from 25 mm to 143 mm in $R_{\max}$, and small individuals (<42 mm) presented in all months. The distribution histograms of $R_{\max}$ were characterized by the al-

ternating appearance of the small (<55 mm) and big cohorts (>55 mm) in different months (Table 1, Fig. 2). From May to August, the size structure was dominated by large size cohorts and changed to small size individuals in September. In the following three months, October, November and December, the population were dominanted by big cohorts again. Considering all the individulas collected in same area, the R_{max} of *A. amurensis* in eight sampling months were significantly different (χ^2 =614.04, P=0.001).

Table 1. The R_{max} range charaters of *A. amurensis* collected at Yantai from May to December 2010 and March to May 2015

Month/Year	R_{max} range/mm	n	Mean	SE
05/2010	25–100.6	219	56.8	±1.12
06/2010	41.5–134.5	178	78.2	±1.49
07/2010	38–123	256	78.1	±1.74
08/2010	41–143	245	81.3	±1.74
09/2010	28–119	284	65.7	±1.75
10/2010	33–139	311	79.3	±1.92
11/2010	38.5–126.5	299	75.5	±1.43
12/2010	29–115	286	68.3	±1.54
03/2015	41.5–120.67	67	71.2	±1.64
04/2015	33–95.7	123	59.9	±1.53
05/2015	33–116	47	71.4	±1.90

Note: n means number and SE standard error.

3.2 *Arm length and body wet weight*

There was significant correlation between R_{max} and wet weight of *A. amurensis* (Pearson correlations, r=0.871, P<0.01), which indicates the R_{max} was a good predictor for body wet weight (Fig. 3). The quadratic polynomial formula (y=0.017 9x^2 – 0.870 4x + 14.285) can be adopted to describe the relationship between wet weight (y) and arm length (x)

3.3 *Gonad and pyloric caeca indices*

The presence of gonad varied with body size and months. The smallest body size of sea stars with gonad was 49.5 mm during all the sampling months. The monthly variations of GI were significant different (ANOVA, F=77.81, P<0.001), indicating the obvious seasonal cycles of reproduction (Fig. 4). The GI peaked in October with the value of (20.95±6.52)% (8.28–39.19), then dropped in November ((5.31±5.1)%) and December ((4.96±4.9)%), indicating a spawning event happened from October to November. This

coincided well with the lower bottom water temperature (14.29°C) recorded at October 2010, though there was no significant correlation between seawater temperature and GI (r=–0.29, P>0.01) (Fig. 5).

The PCI varied significantly from 3.2% to 21.7% with the average value of (15.2±4.1)% in sampling months (ANOVA, F=21.6, P<0.001). From May to August 2010, PCI gradually increased, then decrease in September, and dropped markedly to the minimum value in October, and increased again in November 2010, suggesting the seasonal cycles of development. However, the correlation between seawater temperature and PCI was not significant (r=0.15, P>0.01)

GI and PCI presented a significantly negative correlation (r=0.85, P<0.001) (Fig. 3). The lowest PCI value coincided well with the maximum value GI in October, and maintained a high value from May to September, then increased markedly in November and December, which is converse to the GI development.

3.4 *Ovary development from March to May 2015*

Individuals with gonad were mainly collected in late March and April 2015 and only one individual with gonad out of 30 individuals was found in late May. Due to indistinct results of testis histology, only the ovary maturity development was shown here (Fig. 6).

Five maturity stages of ovary development were observed during our sampling months:

Stage I: recovery stage

The gonad wall is thick with evident two-sac structure (Fig. 6a). The gonad lumen is filled with amorphous materials and may also contain some eosinophilic cell debris and phagocytes (Fig. 6a). Nests of oogonia and many small oocytes are present in the germinal epithelium. Ovaries in this stage were mainly found in samples collected in late April and May.

Stage II: growing stage

The germinal layer is lined up with primary oocytes at various development stages (Figs 6b–c). The germinal epithelium has a tortous outline, and extensions of the haemal layer occupy the center of the germinal folds. The haemal sinus expands to form a conspicuous layer of eosinophilic haemal fluid underlying the germinal layer. Vitellogenic oocytes are present by characteristically pear-shape. Fully grown oocytes are beginning to fill the lumen, being round and eosinophilic. Ovaries in this stage were mainly found in samples collected in mid-March.
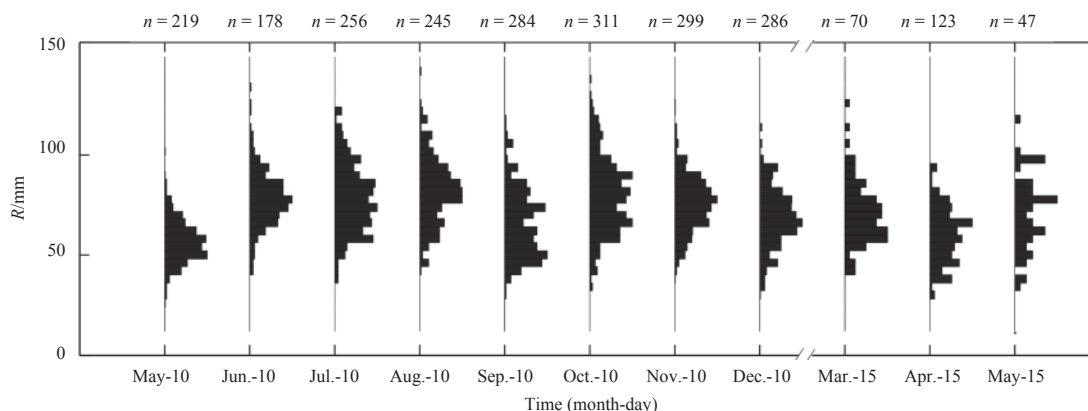

Fig. 2. Size frequency distribution of *A. amurensis* collected in Yantai during May 2010 to December 2010 and March 2015 to May 2015. Size classes in 4 mm intervals.
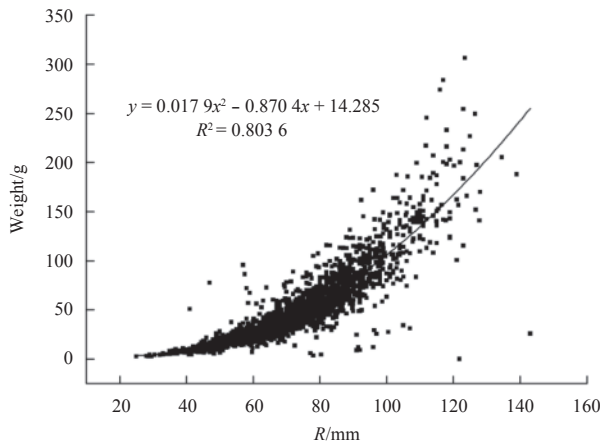
Fig. 3. Arm length and wet weight of *Asterias amurensis* in Yantai from May 2010 to December 2010 and March 2015 to May 2015. Solid line is quadratic polynomial trend line and the equation is the relationship between wet weight (*y*) and arm length (*x*).

Stage III: mature stage

The fully grown oocytes are becoming large and densely-packed in the lumen (Fig. 6d). Pre- and mid-vitellogenic oocytes present in the germinal layer continuing their development. The oocytes occlude the lumen and the ovary wall becomes thin. Ovaries in this stage were mainly found in samples collected in mid-March.

Stage IV: spawning stage

The ovary wall is thin (Figs 6e–f). Fully grown oocytes are loosely packed in the lumen with more spaces due to gamete releasing. The size of these spaces and the number of large oocytes depend on the stage of spawning (early-spawning Fig. 6e, late-spawning Fig. 6f). A few pre- and mid-vitellogenic oocytes still remain in the germinal layer (Fig. 6f). Some relict oocyte debris and phagocytic tissue may be present in the lumen. Ovaries in this stage were mainly found in samples collected in mid-March.

Stage V: spent stage

The gonad wall is becoming thick with evident two-sac structure again (Fig. 6g). After the spawning, few oocytes (eggs) still presents in the ovaries, which will be resorbed and disappear later. A few pre-, early- and mid-vitellogenic oocytes remain in the germinal epithelium. Phagocytes and eosinophilic egg debris are also present in the lumen. Ovaries in this stage were mainly found in samples collected in mid-March.

4 Discussion

4.1 *Population size structure*

The high predatory proficiency of *A. amurensis* can cause serious ecological and economic impacts (Byrne et al., 1997), especially on fisheries and aquaculture due to its preference for bivalve mollusks (Sloan, 1980; Morrice, 1995). Because of the more active and stronger feeding strength by larger size individuals, the extent of this influence depend on the features of population size structure, the age composition and growth rate. From May to December 2010, the population size structure was alternatly dominanted by small size cohorts (<55 mm) and large size cohorts (>55 mm) due to the recruitment by more small size individuals and their growth. Normally, the cohorts were mainly composed of individuals with the body size over 19 mm in eight months. However, there were still some small individuals appeared in all months, suggesting some individuals grow more slowly because of food limitation. The changing population size structure will lead to different extent of damage to scallop mariculture during its growing season from May to October in SB. The changing size structure observed in this work could be influenced by the recruitment, growth rate and possible mortality of juveniles, similar to report from Morrice (1995).

Asterias amurensis can reach an arm length of 78 mm in approximate 12 months with an average growth rate of about 6 mm per month in coastal water of Japan (Hatanaka and Kosaka, 1958). In Tasmania, both juvenile and small adult sea stars (*R*=29 to 83 mm) had been growing for a minimum period of nine months with the growth rate of 3.2–9.2 mm per month (Morrice, 1995). Both the quantity and quality of available food are important factors responsible for differences in the size of sea star population (Vevers, 1949; Harrold and Pears, 1980; Lawrence and Lane, 1982; Barker and Xu, 1991a; Morrice, 1995). In the Sishili Bay, water environment and benthic assemblages have been disturbed by human activities, including culture of bivalves which affected the distribution of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) (Wang et al., 2012); ship-
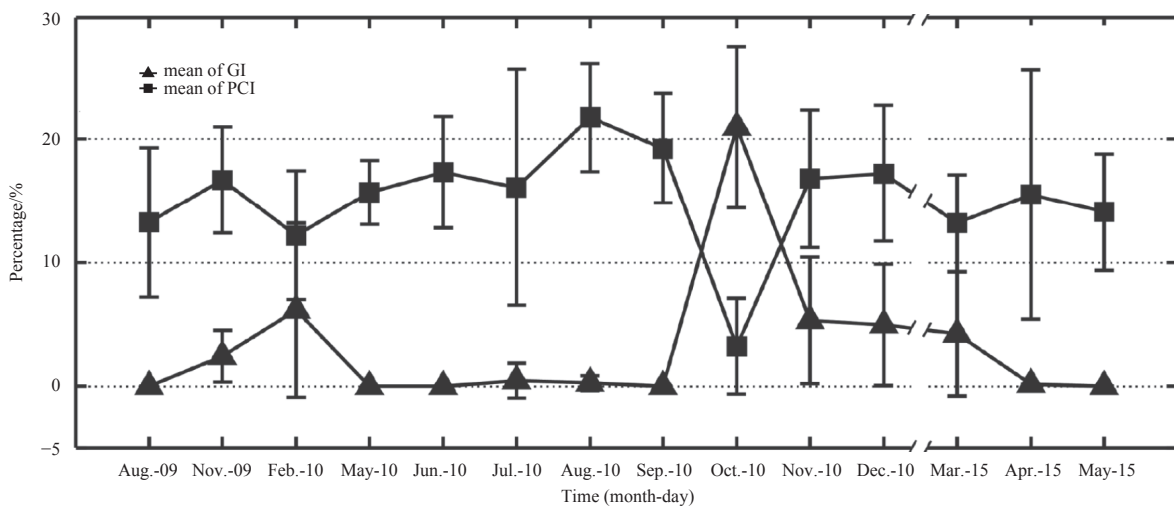

Fig. 4. The mean GI and PCI for *Asterias amurensis* at Yantai coast during sampling period.
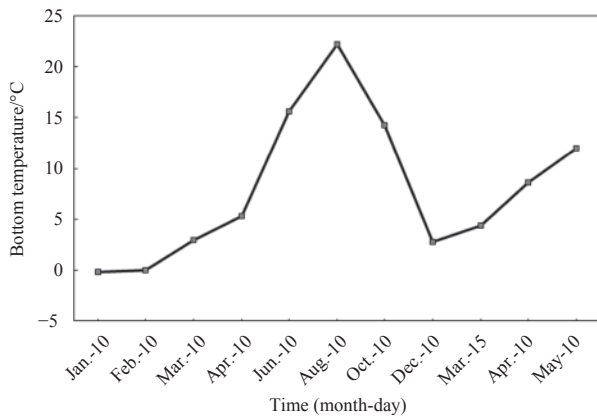
Fig. 5. The seasonal change of bottom water temperatures recorded from December 2008 to December 2010 in sampling area, Yantai.

ping which affected the distribution of diatom and silico flagellate fossils (Di et al., 2013); and different pollution sources which affected modern dinoflagellate cysts (Liu et al., 2012). The considerable scale of mariculture in the Sishili Bay and its byproduct will provide abundant food supply for *A. amurensis* population. These complicated factors will also affect the growth rates of sea stars and population size structure, making it hard to calculate the precise growth rate of sea star population.

4.2 *Gonad index*

The maximum value of GI coincided with the lower bottom water temperature (14.29°C) recorded in October 2010, though there was no significant correlation between them. Pastor-de-Ward et al. (2007) investigated the asteroidean species *Cosmasterias lurida* in Argentina, and found the GI was not significantly correlated with seawater temperature, but with photoperiod. The response to photoperiod could ensure the food supply (phytoplankton bloom) for the larvae. However, Bos et al. (2008) found increased gonad weights in the sea star *Protoreaster nodosus* from March to May (spawning period), which coincided with the increasing water temperature. The timing and length of the spawning season correlates with latitude and bottom water temperature (Morrice, 1995). Nojima et al. (1986) also found the seawater temperature of spawning was keeping around 10°C; and the spawning season in the southern part was earlier than in the northern part. . From north to south, the spawning season of the sea stars was different: from June to September in Russian (Kashenko, 2005); from January to May in different latitude of Japan (Hatanaka and Kosaka, 1959; Ino et al., 1955; Kim, 1968); from April to May in Korea (Paik et al., 2005), and from July to October in Tasmania (Morrice, 1995).
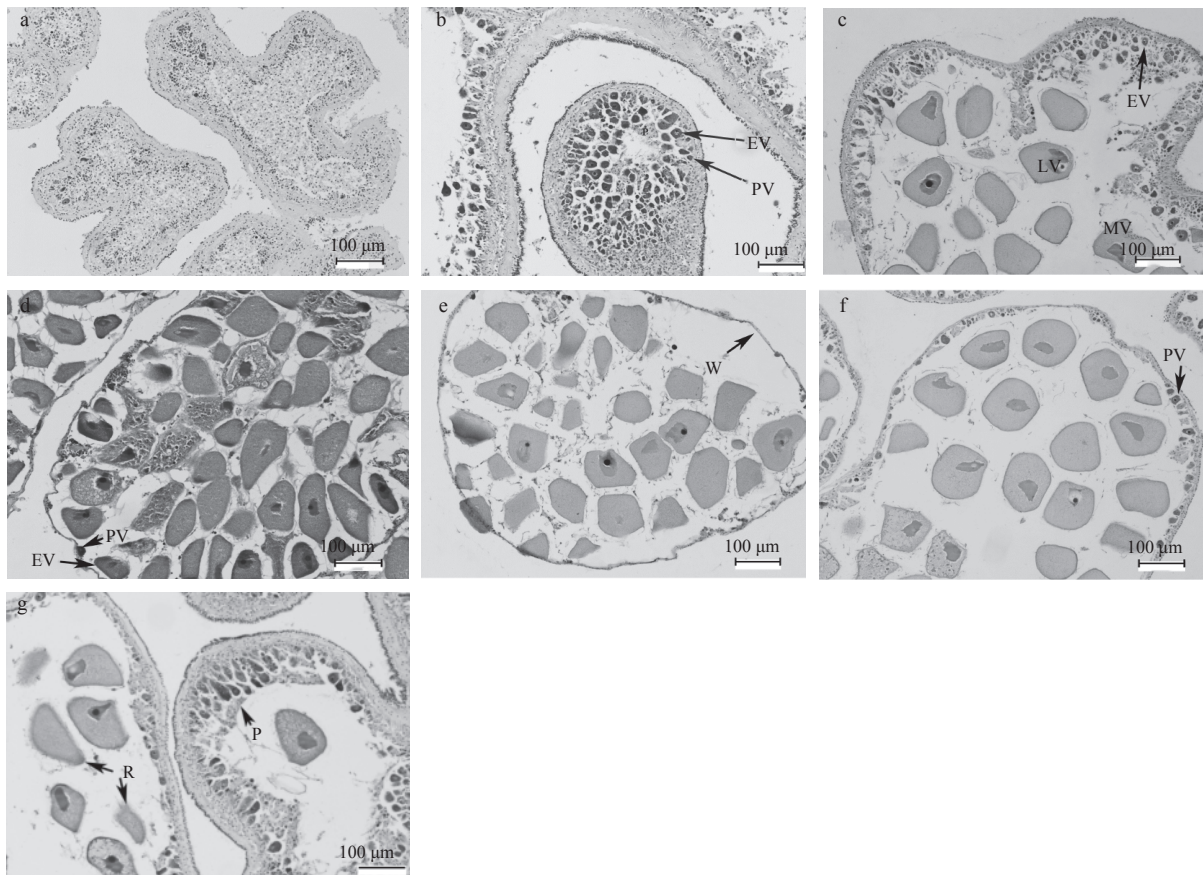

Fig. 6. Histology of *Asterias amurensis* ovaries. a. Stage I, recovering ovary is lined with small oocytes; lumen is filled with flocculent material. b and c. Stage II, growing ovary is lined with pre- (PV) to late- (LV) vitellogenic oocytes. Fully grown oocytes (MV) begin to fill the lumen. d. Stage III, mature ovary with fully grown oocytes and a few pre- (PV) and early- (EV) vitellogenic oocytes. e and f. Stage IV, spawning ovary containing loosely packed oocytes with gonad wall (W) outside in early breeding season and with a few previtellogenic oocytes (PV) in late breeding season. g. Stage V, spent ovary with phagocytes (P) and reclict oocytes (R). Scale =100 μm.

There was no GI increase from May to September 2010, which indicated that gametes did not accumulate in the gonads during this period. The GI peaked to 20.95% in October and markedly dropped in December, although the value of 20.95% is lower than 28.27% and 31.84% in Tasmania (Morrice, 1995). From March to May 2015, the GI also shown a markedly drop from 4.22% in March to 0.18% in April and to 0.0% in May. The development of GI is related to food availability, habitat, and reproductive strategy (Bos et al., 2011; Micael et al., 2011). Considering the changes of GI value, local bottom water temperature (14.29°C) and ovary development from March to May 2015, we confirmed that one spawning happened from October to November, and the second spawning season happened from March to May in spring with a relatively lower fecundity. Spring spawning season of *A. amurensis* was also confirmed by the complete process of ovary maturation displayed in the histologic results of ovary development. During the histologic dissection, only one individual was found with gonad out of 30 individual samples in late May, which also indicates that the spawning season was ended by May. For *A. amurensis*, male and female development is synchronized and no protogynous or protandry phenomenon was found (Vevers, 1949; Byrne et al., 1997; Novikova, 1978; Kim et al., 1968; Hatanaka and Kosaka, 1958; Zhang et al., 2014). Therefore only the ovary development can represent the reproductive pattern of this *A. amurensis* population. The Russian researcher also found two peaks in the maturation of gonads, one in June and the other in September, with the water temperature of 17°C and 23°C, respectively (Novikova, 1978). Nevertheless, only one spawning season was observed in Japan and Korea, e.g., from April to May in Korea (Paik et al., 2005), and from January to May at around 10°C in Japan (Hatanaka and Kosaka, 1958; Ino et al., 1955; Kim, 1968). It is noteworthy that only one spawning season from October to January was observed in *A. amurensis* from Qingdao coast which was not consistent with our results (Zhang et al., 2014). The onset of spawning in *A. amurensis* could be influenced by the combination of several environmental factors, such as food resources, fresh water influx and temperature (Morrice, 1995). The reproductive stages in asteroids should combine several parameters, such as oocyte area and diameter in female, spermatogenic columns and types of germinal cells in the lumens, as well as the presence or absence of sperm in male (Barker and Xu, 1991a, b). Based on the baseline information on monthly variation of gonad and pyloric caeca indices attained in this work, further study will need to determine whether the phenomenon found in *A. amurensis* Chinese population is intrinsic.

The body size of sea star with gonads present was *c.* 55 mm in arm length (Morrice, 1995), which is same to the Japanese populations in the Sendi Bay (Hatanaka and Kosaka, 1958) and the Mutsu Bay (Kim, 1968). However, the smaller size *c.* 46 mm in arm length reaching sexual maturity was reported in the Tokyo Bay (Ino et al., 1955). In the present study, the smallest size of sea star measured with gonad was 49.5 mm in arm length, which is similar to the previous study.

4.3 Pyloric caeca index

The pyloric caeca of sea stars has many nutritional and physiological functions, e.g., digestive enzyme production, digested product assimilation and reserve material storage (Farrand and Williams, 1988). The reserved materials can be utilized later by the gonads in the period of gametogenesis. Thus, the PCI can indicate the nutritional conditions of populations (Barker and Xu, 1991a, b). The PCI of Chinese *A. amurensis* population varied monthly from 3.2% to 21.7%, with the average value of 15.5% and

the changing pattern of PCI was just opposite to GI. Our results are similar to the Japanese population of 4.0 to 23.2 with an average of 15.21±4.10 (Nojima et al., 1986). The changing pattern of PCI, however, was different from other sea star species. Keesing et al. (2011) found the PCI of *Archaster angulatus* ranged from 2.1% to 4.3%, which is much lower than *A. amurenis*. The main reason was possibly resulted from the different feeding biology of two species: *A. angulatus* is a passive deposit feeder with low nutritional diet value while *A. amurensis* is an active carnivorous feeder with high quality and nutritional diet value. The inverse correlation between the GI and PCI of *A. amurensis* could be an energy strategy for the sea star, which enables the species to maintain a high level of potential reproductive output (Scheibling, 1981; Micael et al., 2011). This distinct reciprocal relationship also displays in sea star *Acanthaster plancii* (Bos et al., 2013). Previous study observed that *Sclerasterias mollis* transferred nutrient from the pyloric caeca to the gonad during the period of gametogenesis (Barker and Xu, 1991a, b). Gonadal growth requires nutrients and needs a minimum amount of energy for maintenance (Carvalho and Ventura, 2002). The quantity and quality of food availability may strongly influence the nutrient allocation in body components in asteroid which can alter the reciprocal relationship between GI and PCI (Miller and Lawrence, 1999) as well as the larval development (Basch, 1996). However, many sea stars can change their food requirement and habitat during ontogenetic development (Bos et al., 2011). In our study area, all the samples were collected inside the scallop culture zone where the food supply for *A. amurensis* was available before October each year, i.e., the harvesting season of shellfish culture. However, followed by the scarce food source from November to February next year due to the absence of shellfish culture, *A. amurensis* would have to find new food source and habitat in the study area during their ontogenetic development.

4.4 Suitability of two indices in sea star population characters

GI is an indicator of the development stage of gonads, which reflects the gonad size in relation to the body size (weight) at a particular time point (Barker and Xu, 1991a, b). However, the use of GI was controversial and some researchers considered it as an inapposite indicator to reflect the reproductive feature or it should be used cautiously (Devlaming et al., 1982; Packard and Boardman, 1999). Meanwhile, it was also adopted by many investigations on the reproductive features of sea star (Franz, 1986; McClary and Mladenov, 1989; Ventura et al., 1997; Guzmán and Guevara, 2002; Carvalho and Ventura, 2002; Lawrence et al., 2011). Carvalho and Ventura (2002) found that the spawning started earlier than suggested by the GI according to histological analysis of gonads. However, GIs also documented a massive spawning period. The eggs released earlier were probably not fertilizable due to small egg size (Carvalho and Ventura, 2002), and then would not affect the population fertilization ratio. The aim of this work was primarily to understand the population size structure, monthly variation of gonad and pyloric caeca indices. We adopted the gonad index and physiological evaluation to investigate and predict the massive reproduction features of Chinese sea star population. The most import aspect is to clarify the population dynamics and the mechanism of outbreak of the sea stars (Nojima et al., 1986). Lockhart (1995) reported *A. amurensis* had a natural aggregated behavior, which provides the basic biological theory as the intrinsic factor for outbreak. This study provides important insights about the size structure, gonad and pyloric caeca indices of the sea star *A. amurensis* in China. However, due to the complexity of environmental factors and

food supply in study area, no satisfactory answers have been obtained up to now. Further investigation is needed on long-term and extensive surveys of this species and the changing environmental factors in relation to the global warming.

5 Conclusions

This study provides basic information to understand the life-history and reproductive strategy of *A. amurensis*, with the following conclusions:

(1) The population size structure of the sea star was characterized by the alternating appearance of the small (<55 mm) and big cohorts (>55 mm) in different months. The arm length of *A. amurensis* was a very good predictor to wet body weight.

(2) The reversal correlation between GI and PCI could reflect an energy strategy for the sea stars. Considering histology result of ovary, we speculated that there are two spawning periods occurred from October to November in later autumn and March to May in spring in the coastal waters of Yantai.

(3) Gonad and pyloric caeca indices could be used to reflect the gonad development. However, physiological study should be added for more predictability accuracy.

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