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Transportation of bivalve shells by algae in Sishili Bay, Yantai, China (Yellow Sea)

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ABSTRACT

Empty shells of seven species of bivalve mollusks with attached algae, predominantly *Ulva linza* L., were found intertidally in Sishili Bay, Yantai (Yellow Sea), out of total 17 species collected. Quantitative characteristics of shells and algae, including weight, size and shell/algae weight ratio are provided. Observations show that mass algal attachment may facilitate shell dislodgements leading to transportation of selected species and environmental mixing in thanatocoenoses. Molluscan shells serve as an additional substrate for green algae, thus, it may increase their abundance in shallow waters.

Key Words: Bivalves, Shells, Macroalgae, Attachment, Transportation, Taphonomy, Intertidal, Yellow Sea

INTRODUCTION

A phenomenon of bivalve shells and living mollusk dispersal by means of floating and wave-transported seaweed is recorded in many regions of the World Ocean (e.g., Great Britain, Scotland, the Netherlands, Iceland, Belgium, Brazil, New Zealand, White Sea, Caspian Sea, Sea of Japan/East Sea) and has been discussed in a number of papers (Vallentin, 1895; Oliveira *et al*., 1979; Ansell *et al*., 1988; Tarasov and Kazantseva, 1994; Ing?lfsson, 1995; Cadée and Wesselingh, 2005; Khalaman and Berger 2006; Vandendriessche *et al*., 2006; Lutaenko, 1994, 2012; Lutaenko and Levenets, 2015). Distances of dispersal of mollusks and shells by seaweeds may reach up to several hundred kilometers. Macroalgae carrying attached carbonate material (e.g., coralline algae, shells) are very common: up to 85% of holdfasts on a beach may contain up to 116 g $CaCO_3$ each (Garden and Smith, 2015).

In June 2018, we recorded an interesting case of transportation of empty shells of bivalve mollusks by algae and ecological relationships between mollusks and their shells in the intertidal zone of Sishili Bay, Yellow Sea shore. This research note describes the phenomenon, species composition of mollusks and algae, and their quantitative traits, along with discussion on potential ecological and taphonomic importance of this event.

MATERIALS AND METHODS

1. Sampling area

Material for this study was collected on the sand flat of Sishili Bay (37° 27′ 29″ N, 121° 29′ 31″ E) at low tide, in June 2018 (Fig. 1). Sishili Bay is a shallow-water bay surrounded by Zhifu Island and Yangma Island, with extent of about 20 km located in south-eastern part of Yellow Sea and a mild-temperate monsoon climate. Several small rivers (Guangdang, Xin'an and Yuniao) flow into Sishili Bay. Tidal and wind-induced currents play role in local hydrology; salinity ranges from 29 to 33‰ (Sun *et al*., 1994; Wang *et al*., 2012). Macrobenthic communities in this area

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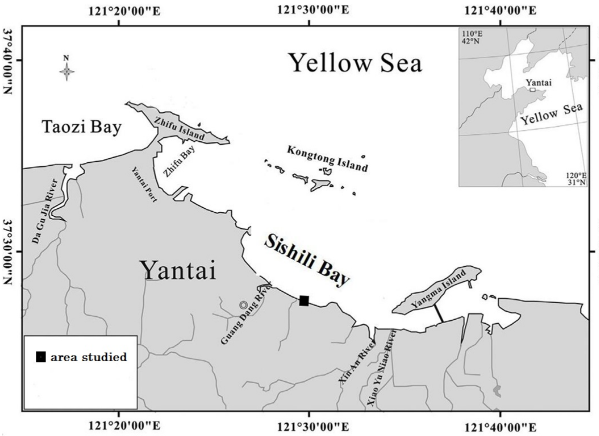

Fig. 1. A map of the area studied.

are slightly stressed due to eutrophication and hypoxia (Zhou *et al*., 2018; Li *et al*., 2013).

2. Sampling technique

In June 2018, empty shells of bivalve mollusks were collected on the sand flat (upper intertidal zone and beach), then washed by fresh water and identified in lab; those shells with attached algae were collected separately from beach area of about 100 m long. Photographic images of the sand flat area and shells with attached algae were made in the field (Fig. 2). Relative abundance of shells were visually estimated by a semi-quantitative approach used in taphonomy (e.g., Carthew and Bosence, 1986): 1-sporadic (1-5 specimens were collected); 2-rare (more than 5 specimens); 3-common (often collected); 4-abundant (visually very common and/or abundant, hundreds of valves/shells). In the lab, shells with epizoic algae were dried on blotting paper for a short time, algae were cut off from shell surface with a maximum effort, and shells and algae were separately weighted with precision of 0.001 g and measured. Photographic images of shells after removal of algae were made in laboratory (Fig. 3).

RESULTS

In total, we collected empty shells of 17 species of bivalve mollusks (Table 1). A majority of species (11) belong to infaunal bivalves, mostly burrowing into

Fig. 2. Views of the sand flat in Sishili Bay and dislodged shells of bivalve mollusks with attached algae: **A-C**: general views of the tidal flat and beach showing clumps of *Ulva* washed ashore; **D**: a *Mactra chinensis* valve with attached *Ulva*; **E**: a *Crassostrea gigas* valve with attached *Ulva*; **F**: a *Nuttallia ezonis* with attached *Ulva*; **G**: an *Argopecten irradians* with attached *Ulva*; **H**: a *Chlamys farreri* valve with attached *Ulva*.

sand (*Mactra chinensis*, *Solen strictus*, *Dosinia japonica*, etc.) or muddy sand (*Anadara broughtonii*, *Macoma tokyoensis*, *Meretrix petechialis*), others are epifaunal cementing to substrates and each other (*Crassostrea gigas*, *Crassostrea nippona*) or attaching to hard substrate by byssus (*Arca boucardi*, *Chlamys farreri*); one species is mobile (*Argopecten irradians*). Wang and Li (2013) collected 31 species of bivalves in coastal waters of Yantai but only 5 species are in common with list from our site.

Relative abundance of shells mostly varied from 1 to 3 but four species were particularly common and abundant (3-4): *A. irradians*, *M. chinensis*, *S. strictus*, and *D. japonica*. Abundance of shells of the Atlantic bay scallop (*A. irradians*) is obviously related to

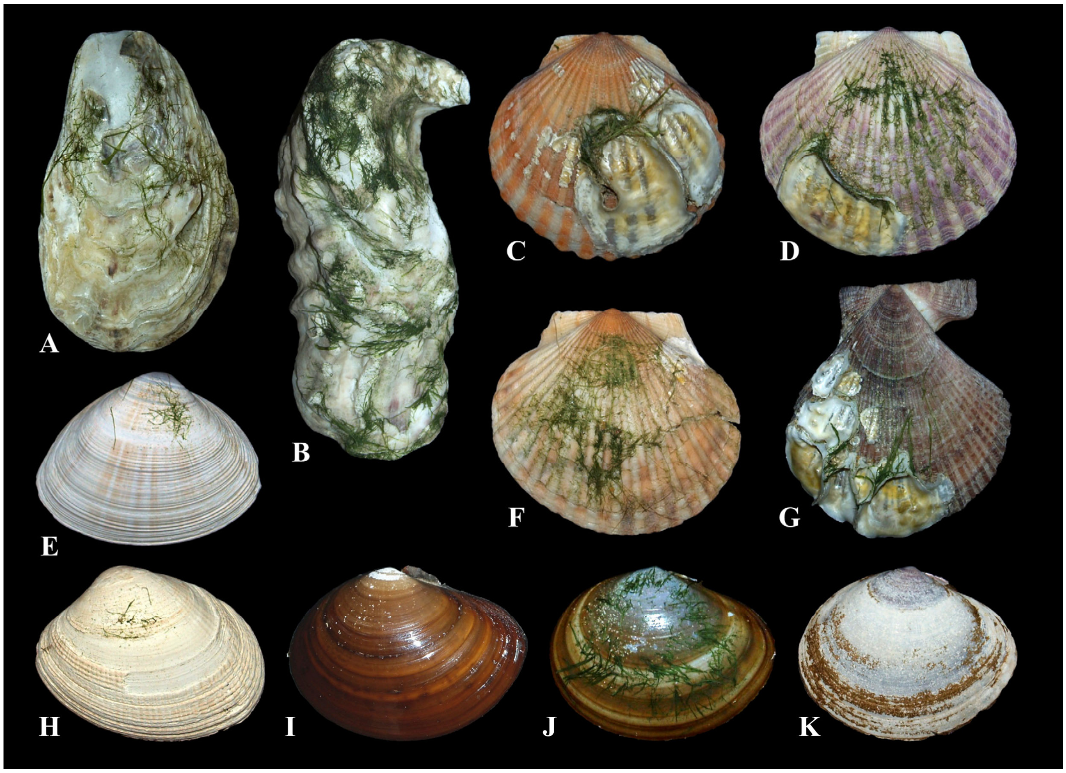

Fig. 3. Empty shells of bivalves after removal of attached algae: **A**, **B**: *Crassostrea gigas* (shell height 65.4 mm (A); 119.1 mm (B)); **C**, **D**, **F**: *Argopecten irradians* (shell height 46.6 mm (C); 46.8 mm (D); 47.4 mm (F)); **E**: *Mactra chinensis* (shell length 45.8 mm); **G**: *Chlamys farreri* (shell height 55.8 mm); **H**: *Ruditapes philippinarum* (shell length 40.5 mm); **I**: *Nuttallia ezonis* (A specimen without attached algae; shell length 55.9 mm); **J**: *Nuttallia* cf. *japonica* (shell length 40.9 mm); **K**: *N*. cf. *japonica* (a specimen without attached algae; shell length 45.2 mm).

Table 1. Species of bivalve mollusks collected in the intertidal zone/beach of Sishili Bay (Yellow Sea) in June 2018

Species	Abundance value	Life mode	Biogeographic characteristics
1. *Arca boucardi* Jousseaume	3	epi1	s-lb
2. *Anadara broughtonii* (Schrenck)	1	in	s
3. *Chlamys farreri* (Jones et Preston)	1	epi1	s
4. *Argopecten irradians* (Lamarck)	4	frl	ct-s
5. *Mytilus galloprovincialis* Lamarck	3	epi1	cb-s
6. *Crassostrea gigas* (Thunberg)	3	epi2	s-lb
7. *C. nippona* (Seki)	1	epi2	s
8. F*elaniella usta* (Gould)	1	in	s-lb
9. *Macoma tokyoensis* Makiyama	1	in	s
10. *Nuttallia ezonis* Kuroda et Habe	4	in	lb
11. *N. japonica* (Reeve)	2	in	s
12. *Mactra chinensis* Philippi	3-4	in	s-lb
13. *Solen strictus* Gould	3-4	in	s
14. *Dosinia japonica* (Reeve)	3-4	in	t-s
15. *Ruditapes philippinarum* (Adams et Reeve)	3	in	s-lb
16. *Gomphina multifaria* (Kong, Matsukuma et Lutaenko)	3	in	s
17. *Meretrix petechialis* (Lamarck)	2	in	s

Notes: *Relative abundance values*: 1: sporadic; 2: rare; 3: common; 4: abundant; *modes of life*: epi1: epifaunal (byssal attachment); epi2: epifaunal (cemented); in: infaunal; frl: free-living; *biogeographic* (*zonal-biogeographic*) *characteristics*: t-s: tropical-subtropical; s: subtropical; ct-s: circumtropical-subtropical; cb-s: circumboreal-subtropical; s-lb: subtropical-lowboreal; lb: lowboreal (Lutaenko and Noseworthy 2012).

Table 2. Samples of bivalve mollusks with attached algae in the intertidal zone/beach of Sishili Bay (Yellow Sea) in June 2018

Bivalve species	Algae species	Shell length or height, mm	Shell weight (S), g	Wet algae weight (A), g	S/A ratio
1. *Argopecten irradians* (Lamarck)	*Ulva linza* L.	49.2	6.681	16.234	0.41
2. ditto	ditto	46.8	7.054	17.695	0.40
3. ditto	ditto	47.4	5.592	5.288	1.06
4. ditto	ditto	46.6	5.859	6.325	0.93
5. *Chlamys farreri* (Jones et reston)	ditto	55.8	7.140	7.811	0.91
6. *Crassostrea gigas* (Thunberg)	ditto	119.1	53.108	22.684	2.34
7. ditto	ditto	65.4	13.510	8.411	1.61
8. ditto	ditto	51.5	7.706	2.121	3.63
9. ditto	ditto	48.0	5.159	8.848	0.58
10. *Mactra chinensis* Philippi	ditto	45.8	3.883	2.731	1.43
11. ditto	ditto	32.5	1.174	1.733	0.68
12. *Ruditapes philippinarum* (Adams et Reeve)	ditto	40.5	6.635	7.732	0.86
13. *Nuttallia* cf. *japonica* (Reeve)	ditto	40.9	1.848	5.122	0.36
14. *Nuttallia ezonis* Kuroda et Habe	*Ectocarpus* sp.	26.1	0.511	0.254	2.01

Note: For oysters and scallops (*Argopecten irradians*, *Chlamys farreri* and *Crassostrea gigas*), height was measured, for the rest of species-length.

intensive scallop farming in Sishili Bay (Han *et al.*, 2013).

Among 17 species found, only 7 were associated with attached algae (Table 2). Most shells were overgrown or partly covered with green alga *Ulva linza* L. (previously assigned to *Enteromorpha*; see http://www.algaebase.org/search/species/detail/?species_id=12905) whereas some with brown algae *Ectocarpus* sp. (identification by Dr. Liu Zhengyi).

Shell size of studied species varied from 119.1 mm (*C. gigas*) to 26.1 mm (*N. ezonis*); largest and heaviest shells belonged to oysters, with maximum weight 53.108 g (Table 2). Shell material of most species was represented by single valves except for one sample (no. 14 in Table 2: *N. ezonis*) when conjoined valves (complete shell) was found. Maximum weight of algae reached 22.684 g.

DISCUSSION

This molluscan complex is a typical death assemblage of mollusk skeletal remains representing a case of insignificantly transported, sub-autochtonous thanatocoenosis. Biogeographically, it is a warm-water association of bivalves with predominance of subtropical and subtropical species, but some tropical-subtropical (*A. irradians*, *D. japonica*) and lowboreal (temperate) mollusks (*N. ezonis*) are found and in general, all bivalves are typical of shallow waters of Yellow Sea (Zhang *et al.*, 2016). A possible new find for the region is *N.* cf. *japonica* (Fig. 3J, K) but its taxonomy is complicated and it may be conspecific with *Nuttallia obscurata*; however, both are not known from Bohai and Yellow seas (Zhang *et al.*, 2016).

Of 17 found bivalves in this area of Sishili Bay, shells of only 7 (41%) had epizoic algae. It is unclear whether algae have some preference for substrate avoiding some species of mollusks, or it may be related to other factors (e.g., availability of shells or their vertical distribution). There are some literature data of selectivity of algae attachment to shells: at Princess Royal Harbour near Albany, Western Australia, the brown macrophyte *Hormosira banksii* attaches to shells of infaunal bivalves but this alga occupies shells of the bivalve *Katelysia rhytiphora* in preference to *Katelysia scalarina* (Black and Peterson, 1987). *K. rhytiphora* because of its larger size is more difficult to dislodge from the sediments than *K. scalarina*, supporting the hypothesis that *Hormosira* is rare on *K. scalarina* because storm waves selectively dislodge and carry to the beach *Hormosira* attached to *K. scalarina*; this is supported by the fact that another infaunal bivalve, the mussel *Brachidontes erosus*, has a far higher frequency of *Hormosira* occupation than either *Katelysia* species, while providing a much more robust anchor. So, it seems that spore settlement is selective for *K. rhytiphora* in preference to *K. scalarina* (Black and Peterson, 1987). This explanations may be applicable to shells from Sishili Bay. For instance, *D. japonica* and *S. strictus* are among abundant species (Table 1) but no attached algae were found on their shells. It is unclear whether *Ulva* prefers to settle on empty (dead) shells or live mollusks in Sishili Bay as obviously epizoic seaweed do both ways. In the Sea of Japan (East Sea), a similar mass attachment of *Ulva* sp. to shells of the bivalve mollusks *A. broughtonii*, *Spisula sachalinensis* and *Mya japonica* was observed on the beach and in the upper subtidal zone (down to 0.5 m deep) (Lutaenko, 2012). Two species of *Ulva* inhabiting this area vegetate from February to November, *U. linza* mostly in summer, and they were found attached only to empty shells of infaunal species and the algae apparently could not settle on live, burrowing mollusks.

Direct observation of the transport behaviour of pebbles with attached algae, purposely laid out in the nearshore zone, showed that they can be easily transported by oscillatory water movements, if the ratio (weight of pebble)/(wet weight of algae) is less than or equal to about 3 (Kudrass, 1974). In our case, the ratio was between 0.36 and 3.63 being on average 1.27 (Table 2) and indicating that epizoic algae should facilitate shell movements under wave action. In case of light shells, e.g., *A. irradians* and *N.* cf. *japonica* (Table 2: 1, 13) weight of algae was up to 2.7-2.8 times higher than those of shells perhaps suggesting that these shells can float with seaweed. Witman and Suchanek (1984) showed that mussels overgrown by the kelp (*Saccharina latissima*), encountered flow-induced forces that were two to six times greater than flow forces on the mussels alone. Flow force data and surveys of dislodged mussels at an exposed beach indicate that epizoans increase the risk of mussel dislodgement. Thus, seaweeds facilitate mollusks dislogement and transportation in the coastal zone, thus influencing bottom communities and leading to death of mollusks (e.g., Ansell *et al*., 1988). These events have important implications for taphonomic processes as well: shells and living mollusks can be transported to a different environment finally leading to environmental mixing in modern death assemblages (Powell *et al*., 1989). On the other hand, presence of many shells available as substrate may increase abundance and local distribution area of algae and facilitate to some degree algal blooms; such blooms became more frequent in Chinese waters in the last two decades (Keesing *et al*., 2011). So, fouling of empty shells may have both ecological and taphonomic consequences but scale and role of algal epizoans on molluscan shells in Yellow Sea should be further studied in more detail. According to Lutaenko and Levenets (2015), observations in Peter the Great Bay (north-western Sea of Japan/East Sea) have shown that attached algae and their debris were found on empty shells of 13 species of bivalves, both epifaunal and infaunal and 13 algae species were identified; more than 50 algae species are known to be epibiotic on living bivalves. The dislodgement of shells with attached algae took place in both semi-enclosed, low-energy and open, surf-influenced areas and it indicates the wide scale of this phenomenon in the Sea of Japan. Further studies in Yellow Sea should contribute to understanding of shell-algae transportation processes in shallow waters and their scale.

CONCLUSIONS

1. Preliminary observations of attachment of seaweeds to empty shells of bivalve mollusks in Sishili Bay (Yellow Sea) show importance of this phenomenon in post-mortem transportation of organic remains (molluscan shells) in shallow-water, intertidal and upper subtidal, environments. About 41% of bivalve species collected as empty shells had epizoic seaweed, predominantly green algae *Ulva*. These green seaweed

periodically develop as massive blooms (green tide) in Yellow Sea providing conditions for large-scale transport of shells.

2. *Ulva* apparently prefers shells of selected bivalves, however, belonging to various mode of life groups: epifauna, infauna and mobile, free-living scallops. It may affect species-selective taphonomic processes (transportation of empty shells to different environments) leading to decrease of fidelity of original alive benthic communities to subrecent death assemblages (thanatocoenoses) and environmental mixing.

3. The biomass of *Ulva* may be much higher than shell weigth (up to 2.8 times) which should facilitate shell movement; in case of heavy shells (e.g., oysters), the biomass of algae is lower than shell weight but shell sail is more important. In any event, epizoans increase the risk of shell dislodgement.

4. Empty shells serve as supplementary substrate for seaweed in sandy or muddy-sand bottoms thus promoting development of algae growth and local distribution.

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