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ORIGINAL ARTICLE

Effect of mariculture on sediment grain size and its potential environmental significance in Sishili Bay, Yellow Sea, China

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Abstract The grain-size distribution of sediment is associated with series of environment problems in mariculture area; however, there is still disparity in the effect of marine culture on grain size partly because it is hard to exclude the contribution of other factors such as sources, hydrodynamic. Sediment grain size of two cores (C3 in culture area and A5 in control area) was compared. The results show that the particle sizes of the two cores have the same compositions and variation laws at the bottom sections (during non-culture period), while sand grain-size contents increases from several to 25 % in C3 core than that in A5 core at the surface section (during the culture period), with an average of 15 %. It suggests the grain sizes are coarsened due to marine culture. Moreover, the deviation values of sand grain-size contents, calculated by subtracting grain-size contents of A5 core from those of C3 core at the surface section, were used to quantificationally estimate the variation of grain-size components. It is found that the deviation values of grain size increase with the intensifying of marine culture outputs. Marine culture outputs result in the coarsening of grain sizes; thus, the variation of grain size should be considered when the environmental problems in culture areas are explained, such as heavy metal pollutants, nutrient elements and benthic community structure and so on.

Keywords Grain size · Marine culture · Core sediment · Culture history · Sishili Bay

Introduction

Marine culture is developing all over the world, which has developed rapidly in China over the last 20 years. It is estimated that culture in China supplies 70 % of marine products and has a total output of 1307.34 × 10^4 tons (Editorial Board 2007). The development of marine culture has caused environmental problems such as pollution, biodiversity, genetic impacts of escapees and so on (Pearson and Black 2001; Brown et al. 1987; Díaz López et al. 2005; Cancemi et al. 2003; Santulli et al. 2003). More attention has been paid to eco-environment in marine culture areas recently.

The sediment provides a substrate for water–sediment interaction; thus, it affects the physiochemical components (polluted zones, organic nitrogen, organic carbon and phosphorus) and causes a series of associated factors (Brown et al. 1987). There has been much research into the impacts of marine culture on sediment properties, including bacteria and meiofauna (Mazzola et al. 1999, 2000; Mitro et al. 2000, 2002; La Rosa et al. 2001, 2004), chemical parameters (Santulli et al. 2003; La Rosa et al. 2004; Porrello et al. 2005), and stable indicators such as carbon and nitrogen isotopes (Sarà et al. 2004).

Grain size, an important characteristic of sediments, is related to a variety of eco-environments. For example, fine-grained sediments tend to have relatively higher metal contents, partly due to the higher specific surface of smaller particles, surface adsorption and ionic attraction (McCave 1984; Horowitz and Elrick 1987). Also, organic matters (carbon, nitrogen and sulfur) are enriched in fine-grained

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sediments (Wangersky 1986), and the distribution of some nutrient element is strongly influenced by sediment texture (Lv et al. 2005a, b). Similarly, marine biologists have found that benthos have selective growth according to sediment grain size (Wang and Ma 2009). Besides, other materials, such as pesticide, often are correlated with sediment grain size (Chen et al. 2000; Rockne et al. 2002). Generally, grain-size distribution of sediment, to some extent, is related with material cycle and environmental evolution. Therefore, it is necessary to determine grain-size variation when discussing the forming factors of eco-environment problems in marine culture area.

Sediment grain size is influenced by multiple factors, including source area, climate change, sediment transport and depositional environments; however, there are still hardly any reports detailing the factor of marine culture, and grain-size variation is almost neglected during the investigation of problems deriving from culture activities. Occasionally, surface sediment grain size was compared between culture and control areas (Huang et al. 2005, 2008), but the disparity occurs partly because it is hard to exclude the contribution of other factors except culture activities. That is, the analysis of mariculture effect on grain size requires that the sediments have the same background in culture and control areas besides culture activities.

Here two core sediments from culture and control areas, respectively, were collected in Sishili Bay, Yantai City, China. The similarities and dissimilarities of their sedimentary dynamic were detected by comparing their grain sizes during culture and non-culture periods. A new parameter, the subtracted values of grain-size compositions, is used to determine the effect of marine culture on grain size. The aims are to: (1) compare grain-size characteristics between the two cores and quantificationally clarify the effect of marine culture on sediment grain size, and (2) discuss the potential dynamics of grain-size variation due to marine culture and its potential environmental effects.

Sampling and analyzing methods

Sample collection and treatment

The samples were collected in Sishili Bay, Yantai City. It is a semi-enclosed bay located on the northeast bank of Shandong Peninsula, China, linked with Yellow Sea with a broad entrance (Fig. 1). It belongs to a typical mariculture area in North China, mainly including raft culture of scallop and oyster, and bottom sowing of holothuria. The culture area reaches 10,672 ha with a total output of 59,866 tons in 2005 (Yantai Statistical Bureau 2005).

Two core sediments were collected with a gravity corer in March 2009. C3 core was from culture area, and it is 3 km far away from the offshore with a geographical coordinate of N37°32′52.38″, E121°27′17.32″, with a water depth of 11.2 m. A5 core sediments are 9 km far away from the offshore and located in a clean area with a geographical coordinate of N37°32′24.00″, E121°33′59.00″, which has a water depth of 10.5 m and is hardly affected by human activities (Fig. 1). The sediment cores were sent to the lab and cut into 1 cm segments. Lastly, the core sediments were sealed in plastic caps and frozen for further analysis.

Sample analysis

Before grain-size measurements, chemical pretreatment is essential to isolate discrete particles. The procedure refers to Sun et al. (2001), because the sediment has the levels of 5–10 % carbonate and 0.2–0.8 % organic, which is almost equal to the reported by Sun et al. (2001). 0.001–0.002 g samples were placed in tubes; 2 ml HCl is added to remove carbonate. The sample is pretreated with 10 ml 10 % H_2O_2 and then boiled at 60 °C for 2 h to remove organic matters. Appropriate deionized water is added, and the sample solution was set for 12 h and centrifuged. Eventually, the sample solution was dispersed in 0.05 % $(NaPO_3)_6$ solution for 12 h and ultrasonicated for 10 min before the analysis. The grain-size distribution was determined with a Mastersize 2000 Laser Particle Sizer which has a measurement range of 0.02–2000 um in diameter, with the relative error of less than 1 %. It automatically outputs the medium diameter d(0.5) and mean particle diameter (Mz) of a sample using the statistic moment method (Blott and Pye 2001).

^{210}Pb and ^{137}Cs specific radioactivity was used to determine the sediment age by analyzing γ-ray energy spectrum (Wang et al. 2012).

Result

Sediment grain-size characteristics of two cores

C3 core sediment has average grain-size components of 15.58 % clay, 28.15 % fine silt, 41.78 coarse silt and 14.49 % sand, and A5 has those of 17.83 % clay, 27.03 % fine silt, 43.16 % coarse silt and 11.97 % sand. Silt is the dominant fraction in the two core sediments accounting for almost 70 % of the sediments. The two core sediments should both be clayed silt.

Figure 2 shows the comparison of different grain-size distributions between the two cores. Obviously, coarse silt contents of the two cores almost keep equivalent along the

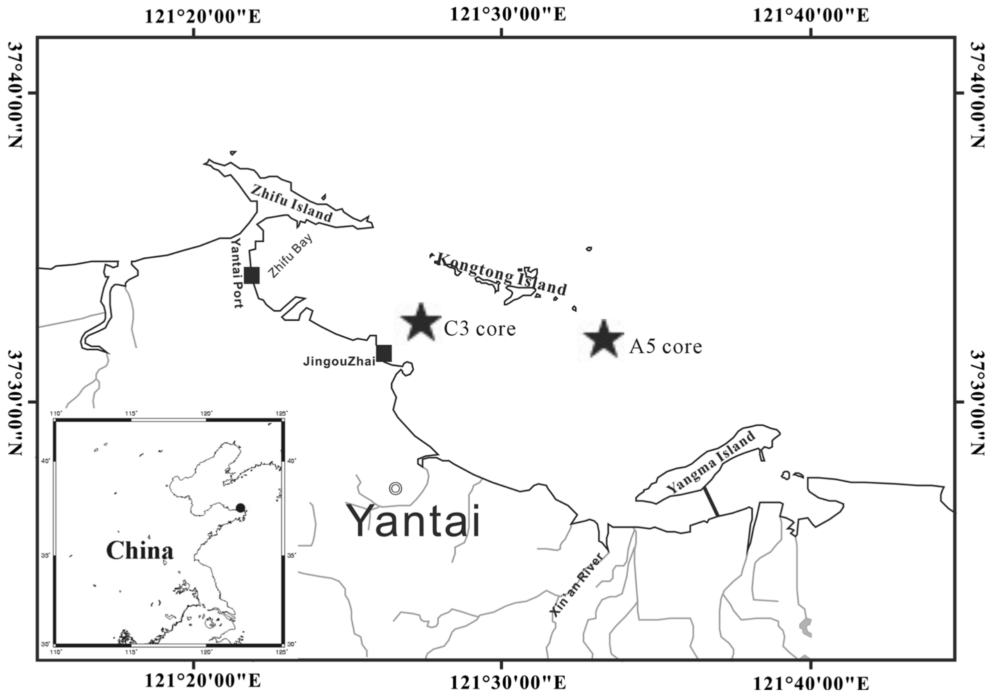


Fig. 1 Schematic map of samples sites in Sishili Bay

whole depth. It seems that there is no clear difference between the coarse silt components in the culture area and control area. However, the difference occurs in the other three grain-size components, and the C3 core has significantly higher contents of sand and lower contents of clay and fine silt than A5 core at the surface section since the 1970s. At the sections from 1940 to 1970, fine silt contents of C3 core are slightly higher than those of A5 core and the variation of clay and sand is fluctuant. However, at the section before 1940, the two cores almost have the same grain-size components and the similar variation tendency. Generally, at the bottom section, the two cores have almost the same components of particle size; however, the grain size of C3 core seems to be coarser than A5 core at the surface sections. Similarly, the medium diameter and mean particle diameter of the two cores also reveal such a result.

Grain-size variation difference at the bottom sections of two cores

Obviously, the sediment at the bottom sections both deposited during the non-culture period, so it is a reliable approach to estimate whether the two cores have the same depositional environments except culture activity by comparing the grain-size characteristics at the bottom sections. Moreover, the percentages of fine and coarse components of core sediment are always negatively correlated, and therefore, only the coarse component (sand) is considered.

As mentioned above, sand, silt and clay ratios of the two cores almost appear to be the same at the same age. The grain-size distribution variations at the bottom section (since the 1970s) along depth are detailed in Fig. 3. The fluctuations of the sand components in the two core sediments show the same variation trend along depth. In particular, a one-to-one correspondence of the peak values appears and they are numbered by the same Arabic numerals, respectively. Besides, the same peak values almost occur at the same time, within more or less than 1–2 year. All these findings indicate that the grain-size distributions of C3 and A5 cores are controlled by the same conditions at the bottom sections.

It is a widely accepted method to compare with control group when the effect of culture on eco-environments is discussed, but numerous researches do not mention the grain sizes are influenced by different factors excluding culture activity, and thus different disparity views occur. As for the two selected cores in this paper, the grain-size distribution at the surface section shows great difference while that at the bottom section does not do. Therefore, it is logical that the grain-size variation at the surface section in C3 core should result from marine culture.

Variation of grain size and its relationship with culture history

The grain contents of the two cores every year are calculated based on the age data, and the deviation value of

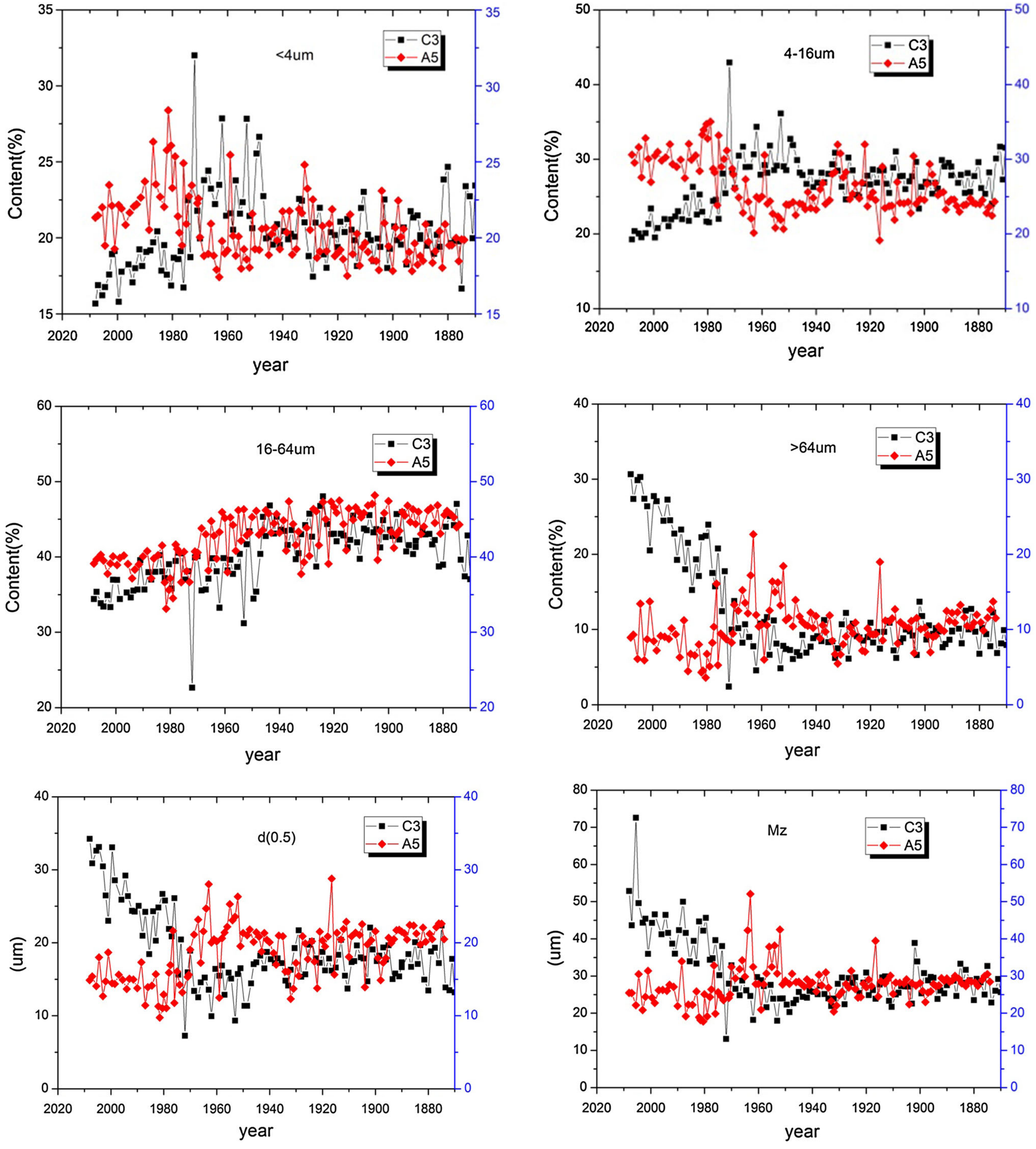


Fig. 2 Comparison of sediment grain-size components between the two cores

grain-size contents is estimated by subtracting grain-size contents of A5 core from those of C3 core at the surface section (since the 1970s). Similarly, only coarse components are considered due to the complementarity of fine and coarse grain, and the result is shown in Fig. 4.

Generally, the sand content deviation has an increasing tendency with the time. Clearly, the deviation appears the positive values since the 1970s and the values range from several to 25 %, with an average of 15 %. Especially before the 1970s, the deviation shows low values and the sand contents of the two cores are almost equivalent. The

Fig. 3 Sand component variation of the two cores at the bottom sections

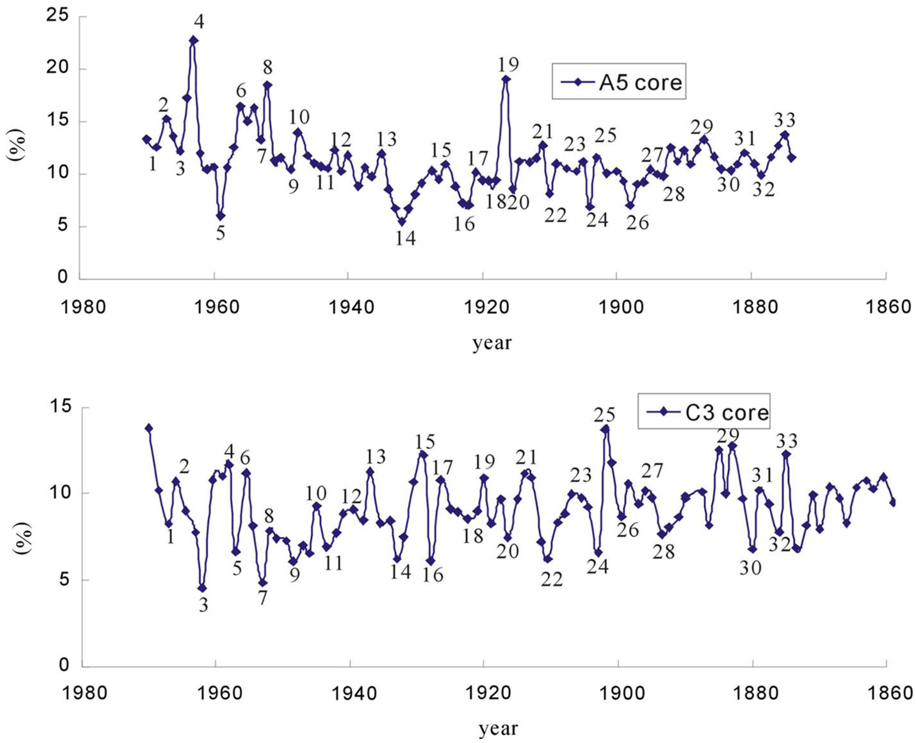
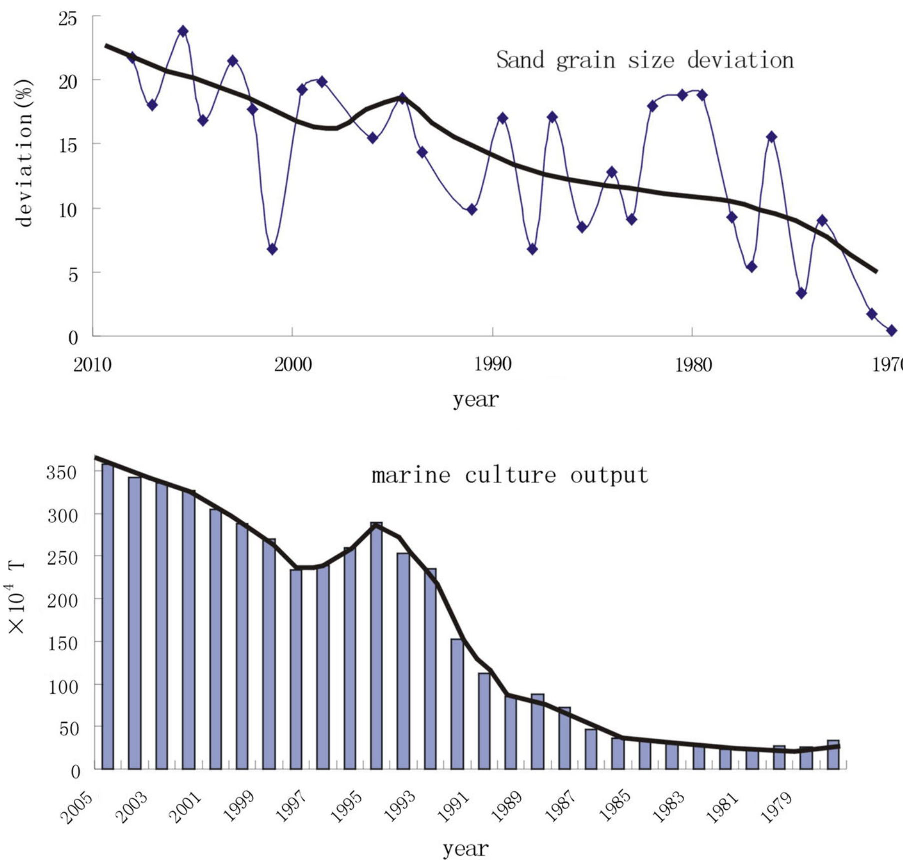


Fig. 4 Sand grain-size deviation, marine culture outputs in Yantai and their relationship



characters may imply that the sand contents at A5 station should be equivalent or even less than those at C3 station if there is no culture activity.

The deviation fluctuates sharply along depth because of the complex factors contributing to grain size. However, there is generally such a tendency, that is, the deviation decreases during 1998–2008 and sharply during 1985–1995 and increases during 1995–1998, and it keeps stable after 1985 (Fig. 4).

Sishili Bay has a long culture history, especially large-scale culture occurs after 1980. The historical marine culture outputs from 1978 to 2005 are also illustrated in Fig. 4. Since 1980, the marine culture outputs have increased several-fold. Correlated with sand content deviation, the marine culture outputs show the same variation tendency as the sand deviation. The more the marine culture output, the more sand content deviation. Obviously, culture has great effect on sediment grain size and makes grain coarser. Moreover, the variation is closely related with culture activities, and naturally it can be predicted that the grain size will be coarser if the culture activities are intensified.

Discussion

Marine culture has boomed in recent decades in coastal areas, and its environmental effects are related to pollutants (Silvert 1992; Calamari and Reyes 1997), biodiversity (Hill 1991; Brake et al. 1999), ecological pattern, etc. Grain size is deeply associated with a series of problems; however, few researches focused on core sediment grain size in detail and there is still disparity of views on the effect of culture on grain size. Huang et al. (2008) surveyed and found four surface sediments in cage culture to be clayed silt, 2 in shellfish culture to be silty sand and 1 in control area to be sandy silt. Huang et al. (2005) reported that there is no obvious difference between grain size in surface sediments in Dapengao cage culture and control area. The disparity may result from the fact that there are some other factors which also influence sediment grain size besides the culture activity, and thus the results are biased by directly comparing the grain sizes between culture area and control area. Obviously, the grain-size variations of the two investigated cores show the same deposit dynamics during non-culture period, and the deviation during culture period can convincingly reveal the effect of culture on grain size.

Particle size of the sediments decreases with declining hydraulic energy. Grenz (1989) demonstrated that ocean current velocity decreases to half in mussel culture area of Thau Bay. Current velocity inside culture area always is less than that outside in Taozhi Bay of Yantai (Li and Gu 1993). The max current velocity decreases to that of 1/8–1/3 in central area in scallop culture of Luzhou Bay, Penglai City, as a result of the increasing in culture area from 2700 Ares in 1975 to 7150 Ares in 1990 (Xiang et al. 2003). These findings indicate that marine culture results in low flow velocity. However, our investigation reveals that the sediment grain size in culture area becomes coarser. Therefore, the current velocity cannot explain why the sediment in culture area contains more coarse particles. The stronger sediment re-suspension caused by marine culture was detected because of destroyed hydrophyte and biomass (Evans 1994), and it may be a main factor controlling grain-size variation due to culture activity. In addition, fishery activities (Han et al. 2007), balder bed (Wen et al. 1997), bait (Walain and Hakason 1991) due to culture activities all can possibly cause coarser sediment.

Heavy metal pollutants are concerned about in culture areas, and various attempts are made to trace their sources and assess the potential risk to marine products and eco-environments (Dong and Pan 2000; Li and Yuan 2000). Researches on geochemical behavior of sediment heavy metals have concluded that grain size is a main control parameter influencing the heavy metal contents in sediments (Roussiez et al. 2005; Zhang et al. 2002; Chen et al.

Table 1 Sediment heavy metal contents in culture area and control area in Sishili Bay

	Zn	Cr	Cu	Ni	Pb	As	Reference	Notes
Mariculture area	63.6	69.8	18.4	25.2	26.2	8.6	Zhang et al. (2012)	Total metals
Control area	78.1	71	23	30.6	26.9	11.5		
	Cr	Cu	Zn	As	Pb			
Mariculture area	68.84	22.4	72.26	9.94	27.87		Liu et al.(2012)	Total metals
Control area	70.71	22.75	77.32	11.4	26.47			
	Ni	Cu	Zn	Cd	Pb			
Mariculture area	6.02	0.64	1.66	0.009	0.22		Sheng et al.(2013)	HCl-extractable metals
Control area	6.05	0.71	1.73	0.021	0.25			

2004). It is generally believed that finer sediments contain more heavy metals than coarser ones with the same residence time because of a larger surface-to-volume ratio. The relatively lower contents of heavy metals in the culture area than those in the control area in Sishili Bay are also observed (Table 1), and the decreasing of the finer components (clay and silt) by the culture activities may contribute to the lower sediment heavy metal contents. Pollutants transfer at the water–sediment interference (Shu et al. 2002), and naturally the grain-size variation influences the distribution of heavy metal between sediments and water. Although its contribution due to this variation cannot still be quantified, it should be considered whether it is one of the key factors causing the aggravated heavy metal pollutants in marine culture areas or not.

Eutrophication is frequently reported in different culture areas (Brown et al. 1987; Ye et al. 2002; He et al. 1996). Carbon, nitrogen and phosphorus, called bioactive elements, are not only the important nutrient elements for growth of phytoplankton, but also the main factors causing eutrophication (Andridx and Aminot 1997; Wu et al. 1996). Many studies reveal that sediment texture is one of the main factors determining the nutrient elements (Lv et al. 2005a, b). Figure 5 shows the variation of core sediment TOC (total organic carbon) and TN (total Nitrogen) along the depth in the culture area and control area in Sishili Bay. The contents of TOC and TN follow similar trends to the grain size. At the bottom section (during non-culture period), the two cores have almost the equivalent contents of TOC and TN, but the contents at the surface section (culture period) in the culture area are obviously lower than those in the control area because of the coarsening of the grain size. Similar results are experimented in Zhujiang River, Changjiang River and Southern Yellow River. Since these nutrient elements are not permanently fixed in sediments and can be released back into water as a result of environment change as grain size, the distribution of nutrient element contents between sediment and water changes and the changes due to grain-size variation during the culture period should be detected.

Bottom sediment texture has profound impact on benthic community structure (Bremner et al. 2006). A survey of the literature reveals the interrelationships between grain size and benthic community structure. Liu et al. (2007) summarized grain size of 125–250 um is suitable for endopsammon. Zhang et al. (2007) found that meiofauna biomass is significantly positively correlated with sand content and silt content. The comparison of hyperbenthos in culture area and control area of Sishili Bay is shown in Table 2 (Li et al. 2013). The species number, biomass and total abundance in culture area all show lower values than those in control area. Qu et al. (2009) also found species and abundance of community structure show an extra low value with the circumstance of coarse sand. Mariculture has multiple effects on

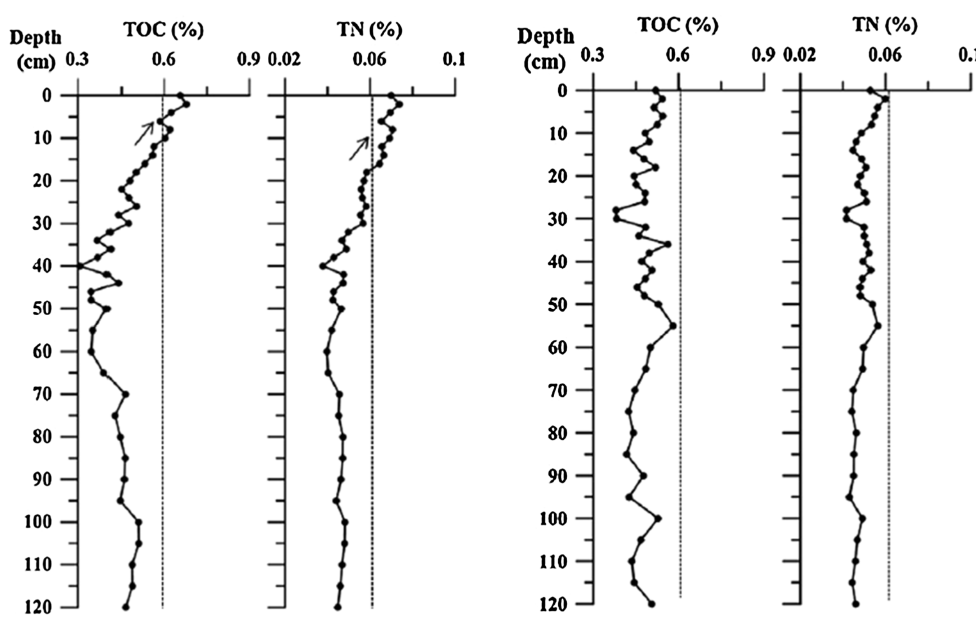


Fig. 5 Variation of TOC and TN along depth in Sishili Bay (from Wang et al. 2012. The *left* core indicates control area, and the *right* indicates the culture area. The two cores are both several meters away from A5 and C3, respectively, of the same year)

Table 2 Comparison of hyperbenthos in culture area and control area of Sishili Bay (from Li et al. 2013)

	Species number	Biomass	Total abundance
Mariculture area	18 Species	3995 g/ha	2697 ind./ha
Control area	19 ± 4.4 Species	7390 ± 5676 g/ha	3707 ± 4993 ind./ha

benthic community structure by altering current and flushing, water quality, and suspended particulate matter depletion. Weston (1990) stressed one of the most obvious effects of mariculture on benthic habitats is organic enrichment, which may be related with the sediment grain size.

Conclusion

The effect of mariculture on sediment grain size was discussed by comparing C3 core in culture area and A5 core in control group, and the followings are gained:

1. The two cores have the equivalent coarse silt contents along depth, and the two cores have almost the same particle sizes at the bottom section, whereas at the surface section, C3 core has an increasing in sand content and a decreasing in clay and silt content comparing with the control group A5. This indicates that culture activity coarsens the sediment grain size in Sishili Bay.
2. At the bottom sections (during the non-culture period), the two cores appear the same variation trend along depth, and the contents of coarse component (sand) fluctuate at almost the same year, which indicates the grain sizes of the two cores are controlled by the same factors, and the coarsening of C3 core sediment should be attributed to the culture activity.
3. It is quantificationally estimated the sand component of C3 core increases from several to 25 % than A5 core during the culture period, with an average of 15 %. Moreover, the deviation values increase with the marine culture outputs. Therefore, marine culture outputs should be responsible for the coarsening of the grain size in C3 core, and the culture history is recorded by grain-size deviation of two cores.
4. The variation of sediment grain size due to culture activity causes a series of eco-environment problems, which can well explain the heavy metal contents, eutrophication and benthic community structure, etc., in sediments.

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