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Natural and environmental characteristics of Tra Vinh coastal area, Mekong Delta Vietnam for the development of hard clam culture

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Key words: Tidal flat, Tra Vinh, Coastal area, Depositional environment, Hard clam, Clam farming ground.

Abstract

Tra Vinh is a coastal province in the Mekong River Delta, Vietnam with about 65 km coastline located between the Co Chien and Bassac rivers and bordered to the south east by the East sea. In Tra Vinh coast, tidal flats occupy the widespread area along the coastline to -5 m water depth, consisting of mud and sand flats. On the mud flats, especially around the river mouths, extensive mangroves distribute and provide abundant food for aquatic species. These natural conditions are very favorable for the development of marine brackish water aquaculture especially hard clams *Meretrix lyrata*. Clam farming is considered a potential aquaculture and has contributed considerably to socio-economic development of the locality. However, the cultured area only accounts for about 20% of the total tidal flat area, the development is not commensurate with the potential and available advantages. In order to exploit effectively and reasonably potential of tidal flat and develop sustainably clam farming in Tra Vinh coastal area, it is necessary to study the natural and environmental characteristics for planning suitable culture areas. Combining methods of topography survey, boring cores and analysis of grain size, environmental factors in laboratory, main natural and eco-environmental factors affecting clam culture process are clarified. Morph-sedimentary of tidal flats, meteorological, marine hydrological and environmental characteristics of Tra Vinh coastal area are favorable for hard clam culture. Clam grounds in coastal tidal flat and river mouth bar are characterized by75- 90% fine sand, stable and flat topography slightly sloping towards the sea, mean 4 – 8 h/day exposure time in 2.5- 3m water depth corresponding to topography -1.5 to -2.6 m. Depending on geographical location of tidal flats, adverse factors would affect heavily to the clam grounds also are defined.

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Introduction

Tra Vinh is a coastal province in Mekong Delta region, with about 65 km of coastline. Tra Vinh is surrounded by Co Chien and Bassac Rivers with Cung Hau and Dinh An estuaries and bordered to the southeast by East Sea (Fig. 1). Tra Vinhcoastal area is formed by late Holocene sedimentation with a major component of clay, silty clay, fine sand and organic in mangrove marsh, sand dune and tidal flat sedimentary environments. Together with the unequal semi-diurnal tide regime of the East Sea, an abundant alluvial volume provided from the Mekong river, the tidal flats of this area are typical of deltaic tidal flats (Ta *et al.*, 2012).

Tidal flats are intertidal, non-vegetated, unconsolidated soft sediment habitats, found between mean high-water and mean low-water spring tide datums (Dyer *et al.*,2000) and are generally located in estuaries and other low energy marine environments. They are distributed widely along coastlines world-wide, accumulating fine-grain sediments on gently sloping beds, forming the basic structure upon which coastal wetlands build Tra Vinh has a system of coastal tidal flats that extend from Cung Hau estuary of Co Chien river to Dinh An estuary of Bassac river in Mekong river system (Fig. 1).Coastal tidal flats in TraVinh with well-developed mangrove forests play an important role in providing food source for aquatic species such as crabs, shrimps, fish, oysters and clam. These natural conditions are very favorable for the development of mollusk culture, especially hard clams *Meretrix lyrata*(Nguyen and Nguyen, 1999).Clam is considered a potential aquatic product and has an important role in socio-economic development in Tra Vinh coastal area. The potential area to develop clam culture in Tra Vinh is quite large, but the actual farming area is low, this development is not commensurate with the current potential and advantages (Tran, 2007). In order to develop stably clam culture in the coastal tidal flats of Tra Vinh, it is necessary to assess the natural characteristics for planning suitable aquaculture areas and to study other important factors such as production management, capital investment, ability to approach science, technology and market. This paper presents the results of study on overall assessment of natural and environmental characteristics for culture of hard clam in Tra Vinh coastal area. The study results contribute to orienting effective exploitation of the potential of coastal tidal flats, the development of clam farming contemporaneously rational exploitation and good protection of the Tra Vinh coastal clam juveniles.

Materials and methods

Fieldwork survey

We undertook *three* campaigns of *fie*ldwork on the Tra Vinh coast. Two were in November 2014, November 2015covering the transition between rainy and dry seasons; and another in May 2015covering the middle and late dry season. During each of these we carried out topographic surveys of the beach along three approximately shore-normal cross sections (Fig. 1). Weal so collected surface sediment samples along each transect. Most of the surveys were carried out at around the time of low tide. We compiled beach pro*f*iles from ground surface elevations measured at intervals not exceeding 5 m and referenced to a benchmark which was established before the survey and compared with mean low-tide level at the spring tide. Cubic samples (5 cm sides) of surface sediment were collected for grain-size analysis. Boring cores with around 3-4 m depth.

Collecting samples of water, bottom sediment; monitoring salinity, temperature and pH (HORIBA-Japan Field Measurement).

Analysis in the laboratory

Within this study, the depositional environment was determined on the basis of grain size analysis, sedimentary structure of boreholes at depths of 3-4 m. The sediment samples were *f*irst passed through a63-μm sieve; dry weights before and after sieving were compared tocalculate mud content. The grain-size distribution of the sand fraction was analyzed using a 150-cm settling tube.

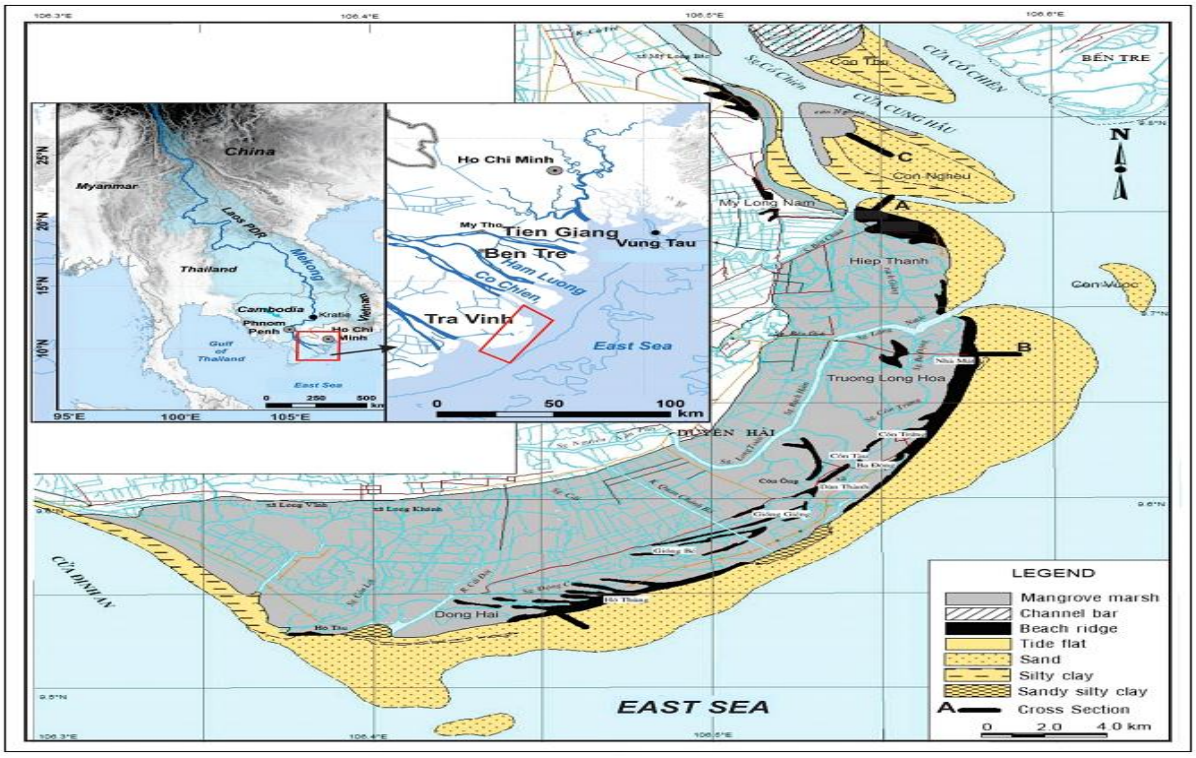

Fig. 1. Morph-sedimentary map of Tra Vinh coastal area.

Factors of environmental quality (DO, BOD5, Chlorophyll-a, TSS, TN, TP, TC) in water, sediment samples are analyzed according to current research norm from Oceanography Institute, Vietnam Academy of Science and Technology.

Results and discussion

Depositional environmental characteristics of Tra Vinh coastal area

On the base of litho-sedimentary analysis from cores bored in Tra Vinh coastal area, the depositional environments of Tra Vinh coastal area are composed of beach ridges, mangrove marsh and tidal flats (Fig.1).

Beach ridges

Beach ridges are formed within or near the beach, and are preserved as relict elongate mounds parallel or subparallel to the shoreline following subsequent beach progradation. In Tra Vinh coastal area, beach ridges are convex seaward, and are associated with branching and recurved shapes, concordant with recent coastal changes. The beach ridges distributed along the beach from Hiep Thanh, Truong Long Hoa, Dan Thanh and Dong Hai have medium elevation about 1.8 - 4.0 m above the present mean sea level. The width of beach ridges is less than a few kilometers and shaped like a bow with high topography forming long, narrow ridges that are easily distinguishable from the low lying mounds or marshes around. This is compatible with data of beach ridges in the lower Mekong delta plain (Gagliano and McIntire, 1968; Ta *et al.*, 2002).

The beach ridges are mainly composed of fine yellowish gray sand with a thickness of about 2.5-5.5 m, covered by sand, silty sand or silty clay tidal flat. Grain size analysis showed that 85-96% fine sand, 7-10% silt and 4-8% shell fragments. Beach ridges are the most evident marker of past sandy shorelines during the Holocene, their geometry and depositional age generally indicate past shoreline position and shape (Mason, 1993). In Duyen Hai district there are three sets of beach ridges from the coast to inland, beach ridge located near the recent shoreline is younger than inland.

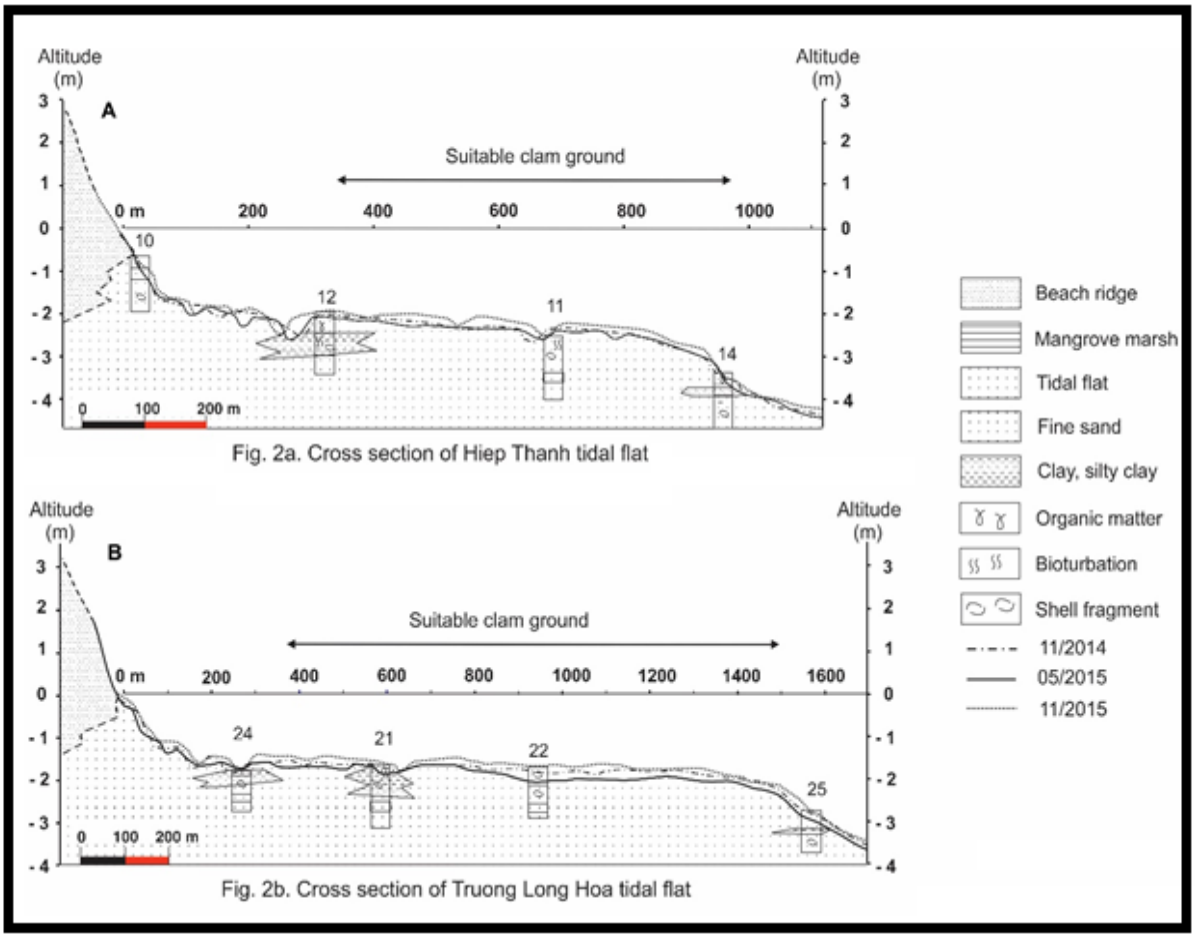

Fig. 2a. Cross section of Hiep Thanh tidal flat

Fig. 2b. Cross section of Truong Long Hoa tidal flat

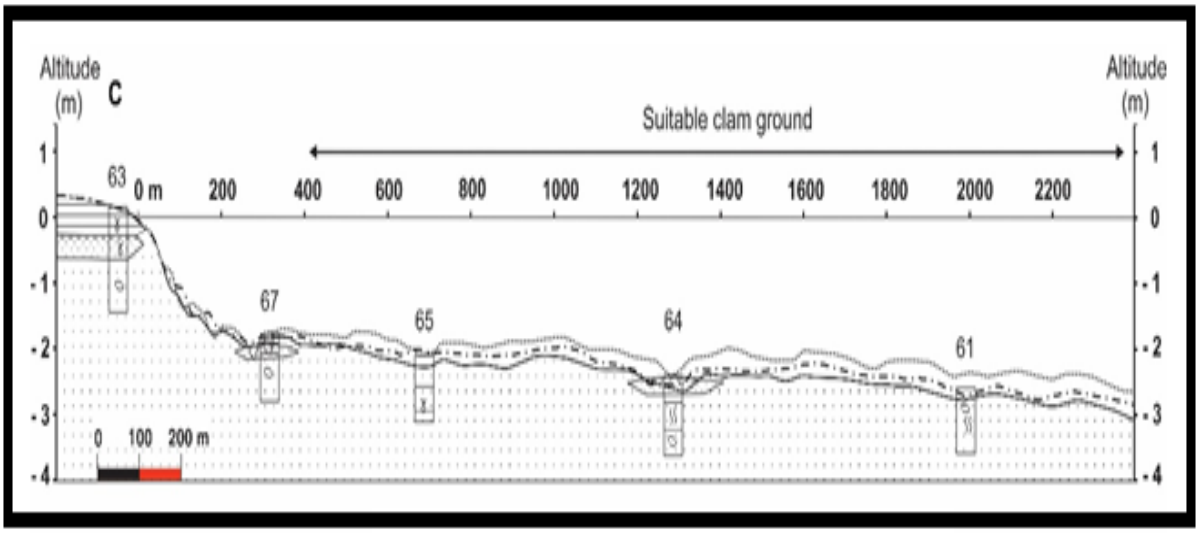

Fig. 2c. Cross section of Con Ngheu river mouth bar.

Compiling previous ^{14}C ages and the new OSL ages of beach ridge clarified the formation and development of beach ridges in relationship with late Holocene to recent evolution of the Mekong river delta (Tamura *et al.*, 2012).

Three main sets of beach-ridges in Tra Vinh coastal area were formed by progradation in 500 yr. BP, 300 yr. BP and 100 yr. BP respectively in which the average rate is around 30m/y (Ta *et al.,* 2012).

Mangrove marsh

Mangrove marsh deposits occupy most of coastal land in Tra Vinh province. This is a low-lying terrain with an elevation of about 0.4 to 0.6 m, with an interlacing tidal creek system, flooded during high tide and exposed at low tide. In Tra Vinh coastal area, mangrove marsh is distributed behind the tidal flats and/or present sand dunes, extending west and northwest (Fig. 1). The mangrove marshis composed mainly of dark gray to greenish gray silty clay, sedimentary structures characterized by lenticular and discontinuous laminations. This deposit usually has a thickness of about 0.7 to 1.0 m, containing many plant residues and its lower part is sand, silty sand or silty clay tidal flats. The results of grain size analysis show that about 6- 14% fine sand, 80-85%, silty clay and 10- 22% organic matter. *Rhizophora* sp., *Avicennia* sp., Sonneratia sp., and *Nippa fruticant* are typical of coastal mangroves(Nguyen *et al.*,2000). Mangrove species, especially *Rhizophora* sp. with a particular root system, have an important role in trapping and stabilizing sediments, raising up topography and progradingtidal sediments seawards.

Tidal flats

Tidal flats are new coastal and estuarine areas, where there are frequent changes in topography, geomorphology and sediment. In terms of morphology and formation origin, the tidal flat is divided into intertidal flat (or tidal flat) and sub-tidal flat distributed from the shore to depth of about -5 to -6 m. Intertidal flat which is flooded with high tide and exposed when the lowest tide extends from the shore to a depth of about -2.5 m to -2.8 m and sub-tidal flat zone is always below sea level at low tide. Depending on the distribution locations and formation characteristics, the tidal flats have silty clay, silty sand or sand composition and may change seasonally in a year or several years. Tidal flats are divided into sand flats and mudflats depending on the granular composition of the sediment (Nguyen *et al.*,2000). The sand flats are very popular in Tra Vinh coast (Fig. 1). Grain size analysis showed that 75-87% of sand, 12-20% of silty clay and 8-15% of shell and plant fragments.

The topography is relatively flat with two or three pairs of trough bars parallel to the shoreline and the sandflat extends seawards about 1.5 to 2.5 km (Fig.1). Mudflats often occur at low-energy coasts covered by sand barriers or spits seawards or deep troughs behind sand dunes. The mudflat deposit contains much organic, so the mudflat is one of the most biologically productive wetland ecosystems. The mudflats are found mainly around Cung Hau and Dinh An river mouths. Grain size analysis showed that 55-68% of silty clay, 25-32% of sand and 15- 22% of shell fragments and organic matter.

Tidal flats in Tra Vinh coast are composed of coastal tidal flats and river mouth bars. Coastal tidal flats are distributed mainly from Hiep Thanh, Truong Long Hoa to Dong Hai with the length and width of about 55 km and 1.5 - 3.5 km. River mouth bars are formed in Cung Hau estuary such as Con Ngheu, Con Vuoc with northwest- southeast main direction (Fig. 1).

General characteristics of morphology and sedimentation of these tidal flats indicate that the first part from the shoreline to sea about 350-400 m, topography has significant changes due to accretion-erosion processes occurring in seasons and years. This part has steep slope of about 6 to 11 ‰ and characterized by high topography fine sand bars alternating silty clay, sandy silty clay troughs with a width of about 40 to 80 m. The next part is from 350 m to 900 m or 1,500 m, with a relatively flat topography of about -1.5 m to -2.8 m with a slope of about 0.4 to 0.8 ‰ and slightly inclines towards the sea.

According to the survey results, the topography of the tidal flat is usually lowered by 0.1-0.3 m in the dry season and higher in the rainy season. As compared to November 2014, the topography of tidal flat in November 2015 was about 0.2 to 0.4 m higher, but in May 2015 it was lowered by 0.2 to 0.3 m (Fig 2 a,b,c). This is consistent with the source of sediment brought and deposited in the rainy season and eroded in the dry season due to the northeast monsoon.

In addition, in the northeast monsoon, the tidal flats are covered by a muddy layer with a thickness of about 10-30 cm depending on the wind and wave conditions. The transect of tidal flat in Con Ngheu showed fairly flat topography inclined towards the sea with a slope of about 0.9 - 1.2 ‰ (Fig 2c). Grain size composition of this tidal flat is 73- 79% fine sand, 12-22 % silty clay and 8- 14% organic matter.

On the basis of topography and sedimentary characteristics, it is possible to identify selection sites which is suitable for the clam culture. The intertidal flats located from shoreline to sea around 350 m to 1,500 m with relatively flat topography and slightly inclined towards the sea, fine sand composition, topography around -1.5 to -2.6 m are well selected for clam farming. This is due to the topography is quite stable and the water depth of intertidal flat with mean 4 – 8 h/day exposure time is suitable for clam life. Clam grounds in the area around Cung Hau and Dinh An river mouths have deeper water depth than about 0.5 m as compared to the coastal area. Differences in water depth and geographic location significantly affect the temperature and salinity of clam grounds. Moreover, the intertidal flat in Hiep Thanh with topography is quite flat, convenient for care and nursing clam seed. The indices of water and sediment environment of this ground meet requirements for the growth of clam seed (Ta *et al., 2018).*

Accretion- Erosion process and coastline changes

The coastline of Tra Vinh, about 65 km long is composed of soft sediments so it is easily affected by natural factors and human activities. The accretion–erosion process in Tra Vinh coastline occurred alternately. The erosion process mainly occurred in northeastern coast; the deposition process occurred in southwest coast (Nguyen, 2010; Le *et al.*,2012).

The coastline changes during period 1966 and 2014 was identified with an average deposition rate of about 5 - 10 m/year. Dong Hai is the strongest deposition area with maximum rate of 40 m/year, average 28-30 m/year.

The eroded coastline alternates in Hiep Thanh, Truong Long Hoa, Dan Than tidal flats with an average erosion rate of about 5-8 m/year (Nguyen, 2017).

Climate, marine-hydrology and coastal environment related to clam culture

Climate characteristics

TraVin hcoastal areaas well as the Mekong River delta lies in the tropical monsoon zone where the air temperature and humidity is relatively high during the whole year with two distinct seasons: rainy and dry. The dry season is from November to April with east and northeast wind directions; the rainy season lasts from May to October of the next year with southwest monsoon. Total annual rainfall is about 1,200 - 1,450 mm. The annual average temperature is about 26.6 ^{o}C, the lowest is about 25.0 ^{o}C in January and the highest in April is about 29- 32.0 ^{o}C, which has a significant impact on aquaculture, especially the coastal clam ground.

The average annual humidity is about 77-91%, in which the rainy season is about 83-93% and the dry season is 72-78%, and the lowest is 37% in March-April. The amount of evaporation is quite high, about 1,293 mm/year, which is highest in the dry season 130-150 mm/month causing drought in the coastal area (People's Committee of Tra Vinh Province). Tra Vinh coastal area is generally less affected directly by the storm. Storms and tropical depressions, if present, are usually concentrated in October, November, and December with weak winds do not seriously affect to infrastructure, but significantly impact on clam grounds such as siltation mixing bottom layer to pollute the environment.

Marine-hydrology characteristics

Tidal regime

The tidal regime in this area is a semi-irregular diurnal one of the East Sea with two flood tides and two ebb tides. Tidal amplitude changed from 2.9 to 3.4 m. High tide amplitude is usually in November, December and January in the northeast monsoonal season with strong waves causing salinity intrusion

inland and coastal erosion affect clams. Lower tidal amplitude occurred from April to September every year in the southwest monsoonal season. Calm winds during the rainy season combined with a weak tidal current and low waves facilitate the formation of breeding ground for clams during this period.

Current regime

Tra Vinh coastal area is influenced by the hydrographic processes of the East Sea and the Mekong River system that flow into the sea at Cung Hau and Dinh An river mouths. The highest average water discharge through the big floods to the Mekong River is 25,000 m^3/s and the Bassac River about 7,500 m^3/s(People's Committee of Tra Vinh Province). The Co Chien River flows through the river mouths of CungHau and Co Chien with a water discharge of about 12,000-19,000 m^3/s and a sediment load of about 100-500 g/m^3. Bassac river flows to Dinh An estuary with a water discharge of about 2,000-3,000 m^3/s and sediment load from 200 to 600 g/m^3. Current regime varies seasonally and is subject to significant impacts of the marine process and extreme weather, especially in the northeast monsoonal season.

Coastal current is a combination of windy current, tidal current, and density current, in which tidal currents play an important role. Tidal fluctuations control coastal currents and tidal currents having a common tendency from the northeast to southwest which cause coastal erosion and accretion affecting the clam grounds (Nguyen *et al.*, 2010). The current associated with southwest wind has made drift away juvenile clams at south Dong Hai tidal flats to concentrate in the north at Ho Thung ground.

Coastal water environment

Sea water temperature and salinity

Sea water temperature is one of the important factors affecting the life of clams. March to June is the time when the highest water temperature affects the clam ground in the Tra Vinh coastal area. In addition, water temperatures may increase in August but little effect on clams due to short time.

During the annual transition period from dry season to rainy season, in June - July, temperature fluctuation stimulates reproduction and clam seed development. The tidal flats adapting to clams with fine sand composition, shallow water depth, usually have higher day-to-night heat amplitude than deeper water or mudflats.

Water salinity in the estuarine coastal area of Tra Vinh ranges from 1.3 to 30.2 ‰. Salinity in the dry season is much higher than in the rainy season, the highest in April, about 30-32 ‰ and low in the rainy season. Appropriate salinity for larvae and adult clams is 18 - 24 ‰, salinity limit of adult clams is 15 - 33 ‰. However, clam can withstand very low salinity of 1-2 ‰ for a short time of about 2-3 hours in the flood season from September to October at low tide (Nguyen and Nguyen, 1999).

The results show that salinity is within acceptable limits for clam development. However, during the rainy season, salinity decreased dramatically affecting the life of clams in the study area. Survey results show that usually in July - August, the salinity of sea water in some grounds decreased low, resulting in the death of clams. Clam farming grounds in the area of the mouth of Cung Hau, Ben Chua rivers should be influenced significantly by the amount of fresh water brought in during flood season. Clam ground of Truong Long Hoa commune is not affected by the decrease of salinity because it is far from the mouth of the river.

The clam grounds in Dong Hai commune is less affected by the fresh water flowing from Dinh An estuary because the north-south coastal current pushes this freshwater up to the south.

Nutritional salts and total N, P in water environment

The analysis results of inorganic nutrient elements in water environment show that Hiep Thanhclam ground area has significantly affected by river fresh water. Large fluctuations in Nitrogen salinity values such as NH_4 and NO_3show the effects of seasonal

river flow (dry and flood season) to the clam ground. Average NH_4 content is about 80.38- 1576.26 µg/l, and NO_3 is about 204.49-712.50 µg/l in Hiep Thanh ground, while in Truong Long Hoa ground, NH_4 is 53.47 - 73.66 and NO_3 is 162.07 - 224.92 µg/l. Inorganic nutrient salts in water show that the area is quite abundant, which is a good condition for phytoplankton to grow during photosynthesis.

Total Nitrogen (TN) and Total Phosphorus (TP) were 145.48- 449.67 and 16.42-83.50 µg/l, respectively, suggesting that TN is higher than TP and usually reaches maximum in the middle of the dry season (around March). In which the TN and TP in the estuarine area are usually higher than the coastal area, for example in Hiep Than ground, TN and TP levels are about 242.68 - 449.67 µg/l and 18.93 – 83.50 µg/l respectively. Research results show that Total Suspended Solids (TSS) and TN content are quite high in estuarine area and relatively low in coastal area.

Bio-chemical characteristics of sea water

The results of DO analysis show that sea water of clam ground area is quite good (average DO> 6 mg/l), However, the level of BOD_5 varies with the time of the crop indicating that the amount of dissolved organic matter in the water also varies differently. Average values of BOD_5 in the cultivating area of Hiep Thanh tidal flat ranged from 1.3 to 4.7 mg/l, and in Truong Long Hoa flat were 1.4 to 2.3 mg/l.Raw biological productivity values show that the coastal waters of Tra Vinhin general and the clam ground in particular are quite high, ranging from 51.7 to 223.6 $mgC/m^3/day$, and often reach high values at the river mouth area such as Hiep Thanh tidal flat because of receiving a large amount of inland inorganic salts fed by the river.

The POC content is about 361.4 to 796.8 µg/l, and the high Chl-a content is about 2.23 to 6.29 µg/l, indicating the abundance of phytoplankton that is an appropriate condition, food sources for many zooplankton, benthic organisms such as clam growing.

The results show that in addition to the presence of carbon content of phytoplankton, there is also a large amount of organic carbon derived primarily from humus residues fed by river water into coastal waters.

Bottom sediment characteristics

The bottom sediment of the tidal flat area varies seasonally. In the rainy season from August to September up to November, the clam ground often is accumulated by a layer of liquid mud brought by the river. This phenomenon depends on the amount of mud and the impact of current from the river mouth as well as topography of the ground. In the northeast windy season, when the weather is bad, the surface of the ground is often covered with a muddy layer. Ecological characteristics and seasonal changes of bottom sediment affect to the density, growth rate and distribution of clam. Clam farming ground is usually covered by mud in a short period of 1 to 2 weeks and during this time, clams were often buried deep themselves in sand safely, however clams will die if the muddy fill time is longer so it is necessary to remove clams to the appropriate location to reduce the damage.

The farming ground bottom is composed mainly of sand, fine sand, silty sand with a little mud and organic matter. The bottom basement is mainly fine sand, silty sand with grain size 0.25 to 0.063 mm in which the fine sand is about 75 - 90%.The bottom sediment usually varies seasonally and by the natural conditions of the ground. Hiep Thanh clam ground has bottom sediment that changes significantly in season. Meanwhile, the bottom sediment of Truong Long Hoa clam ground is mainly fine sand and shell fragments. The content of TOC and TN in the sediment of the clam ground is about 1.28-483 and 0.04-0.60 mg/g dry in Hiep Thanh and 0.18- 0.99 and 0.006- 0.21 mg/g dry in Truong Long Hoa. This shows that organic sludge and humus accumulate quite largely in Hiep Thanh ground where is near the river mouth, which is convenient for food sources for creatures. However, this is disadvantageous for clam farming because of creating hydrogen sulfide gas which is a reducing environment.

Conclusions

Tidal flats of Tra Vinh coast have a rather large area that is favorable for hard clam *Meretrix lyrata*farming. On the base of topography survey, boring cores and analysis of grain size, environmental factors in laboratory, main natural and eco-environmental factors affecting clam culture process are clarified. Morpho-sedimentary of tidal flats, meteorological, marine hydrological and environmental characteristics of Tra Vinh coastal area are favorable for hard clam culture. Clam grounds in coastal tidal flat and river mouth bar are characterized by 75- 90% fine sand, stable and flat topography slightly sloping towards the sea, mean 4 – 8 h/day exposure time in 2.5- 3m water depth corresponding to topography -1.5 to -2.6 m. Depending on geographical location, some factors unfavorably affect to the clam grounds also defined. These results provide scientific base to enlarge clam culture area on potential tidal flats that have not been cultivated. To develop clam farming of Tra Vinh coastal area well and sustainably, it would be necessary to carry out more additional research oneco-environment, hydro-dynamic regimes, and morpho-sedimentary features in relation to hard clam life, protection and development clam seed sources of Tra Vinh. It needs also to assess and predict the human impacts and the effects of climate change son clam culture in the future. Moreover, there is a need to study other important factors such as production co-management, capital investment, ability to approach science, technology and market.

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