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Clam (*Corbula modesta*) as a bio-indicator of environmental condition: the case of Chabahar Bay

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Abstract

Clam shell can be used to reconstruct recent and past environmental variations at high-resolution time scale. During processes of growth increments, carbonate structure can record subdaily (tidally) to seasonal information of environmental variations such as water temperature, salinity and tidal change. This study aims to investigate the potential of clam shells as an environmental recorder, observe the visibility of microgrowth lines in shell cross-sections of *Corbula modesta* from intertidal and subtidal areas and interpret the periodicity of the shell patterns during Pre- and post-monsoon in Chabahar bay. Clams were collected on a fourteen days basis and the shells were sectioned from the umbo to the ventral margin, polishing, etched and observed microgrowth lines and increments under a light microscope. The majority of the clam shells showed that the number of growth lines in shell structures was close to the number of tidal emersions ($P>0.05$) and the growth increments width in intertidal and subtidal areas were significantly different ($P<0.05$). Multiple regression analysis was used to assess independent associations between shell mean increment width and environmental parameters. Study model showed that 60.8% of the variation in shell growth could be explained by temperature, salinity, rainfall and tidal change. Individually, temperature and salinity made the greatest unique contribution to explain shell growth, respectively ($P<0.05$). Increment widths in monsoon season were much narrower and show sudden bunching of growth increments at the onset, with rapid recovery. This study shows monsoon in shell structure are considered markers for identifying the period of seasonal variation. These findings provide a basis for the interpretation of the temporal changes in shell microgrowth patterns in terms of environmental conditions of clam shells.

Keywords: *Corbula modesta*, Intertidal, Subtidal, Monsoon, Shell increment, Micro-growth bands, Chabahar bay.

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1. Introduction

It has been proven that shells of clams consist of microgrowth patterns. The clam shells section contains two parts, specifically called as growth lines and growth increments that are clearly detected in shell cross section. Growth lines are darker, narrower layer, with persistence against etching solution. On the other hand, growth increments are layers between growth lines. The life history of bivalve clam is recorded in the shell structure as a set of time periods in form of microgrowth increments, which varies depending on environmental parameters (Auclair *et al.,* 2003). Clam record environmental parameters (e.g. temperature, salinity) in different type of chemical components or shell structural within inner shell layer during their life span (Arthur *et al.,* 1983); Geary *et al.,* 1992; Schöne *et al.,* 2004). In comparison with many other organisms (e.g. corals and foraminifera), clam have a high growth rate (Mirzaei *et al.,* 2014), high preservation potential as fossils (Scourse *et al.,* 2006) and distributed in a variety of geographical areas (Kim *et al.,* 2002). However, shell growth rate disrupted by various growth breaks that present the environmental conditions such as seawater temperature, shell margin abrasions, tidal changes, storms and temperature shocks (hot or cold) (Goodwin *et al.,* 2001; Schöne *et al.,* 2003; Kirby *et al.,* 1998). In particular, sudden environmental and atmospheric changes are observed in shell structure of clam, and subsequently shell growth stops for a while. The clam *Corbula modesta* is a predominantly intertidal and shallow subtidal filter-feeder known to grow well in relatively warm and saline waters, it is noteworthy that so many individuals arrived in apparently good condition at relatively large sizes. We used this species as a model to current study. Therefore, the major objective of this study was to examine formation of microgrowth bands in clam *Corbula modesta* using to investigate the relationship between shell microgrowth patterns of *Corbula modesta* with environmental variables, oscillating currents and seasonal variation.

2. Materials and methods

Samples of *Corbula modesta* were collected every two weeks from intertidal and subtidal areas of Chabahar bay during the pre-monsoon (April - May), monsoon (June-July) and post-monsoon (August) of 2015 (Figure 1). These periods were classified according to the onset and ending of the southwest monsoon, which is a factor of climate change in the region.

Daily seawater temperature, salinity, rainfall and tidal change were obtained from Chabahar meteorological station during study period. Soft tissues were gently removed from the insides of shells. A single valve of each specimen was rinsed and numbered prior to preparing shell sections. Each valve was cut perpendicularly to the axis of maximum growth using a linear precision saw. One half of the valve is glued on a glass slide with epoxy resin and cut again to obtain shell slices of 300-700 μm thick. Then, thin sections were polished with decreasing size grits from 40 to 5 μm. Slides were observed under an optical microscope (magnification 40-100x) to investigate growth patterns and shell microstructures.

The effects of environmental parameters on the shell growth were investigated in detail using regression analysis on the mean increment widths as a dependent variable and environmental factors such as seawater temperature, salinity, rainfall and tidal change

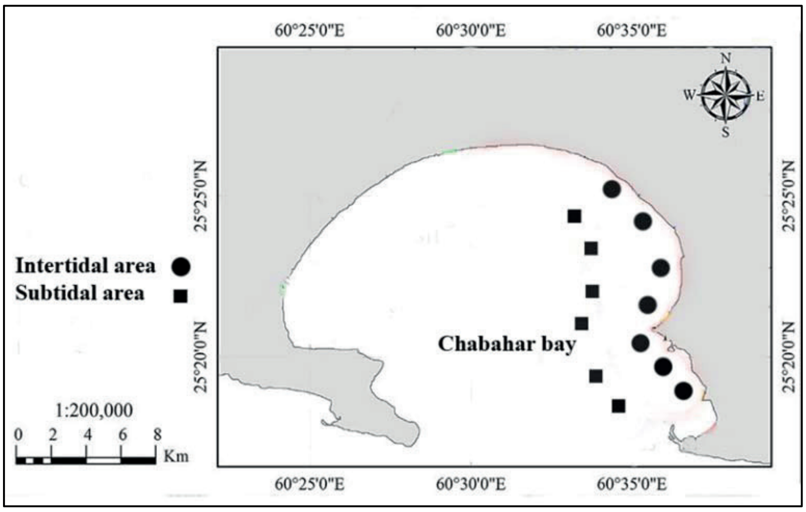

Figure 1. Location map of the study area- Chabahar bay

as independent variables. A paired sample t -test was performed to evaluate whether the observed lines were synchronized daily, tidally or by emersion events.

3. Results

Analysis of the shell section of at different tidal levels showed in intertidal zone strong growth bands successfully run parallel to the growing edge of the shell (Figure 2a). While samples at subtidal area produced weak bands when remained continuously immersed during neap tide. As soon as the shells were emersed, corresponding to each tidal emersion, stronger bands were produced (Figure 2b).On the other hand, mean growth increments were shorter in intertidal area (15 μm) while mean growth increments were wider 28 μm in sub-tidal areas. Increment widths in monsoon season were much narrower and show sudden bunching of growth increments at the onset, with rapid recovery. Mean microgrowth increment widths tightly decreased in beginning of monsoon

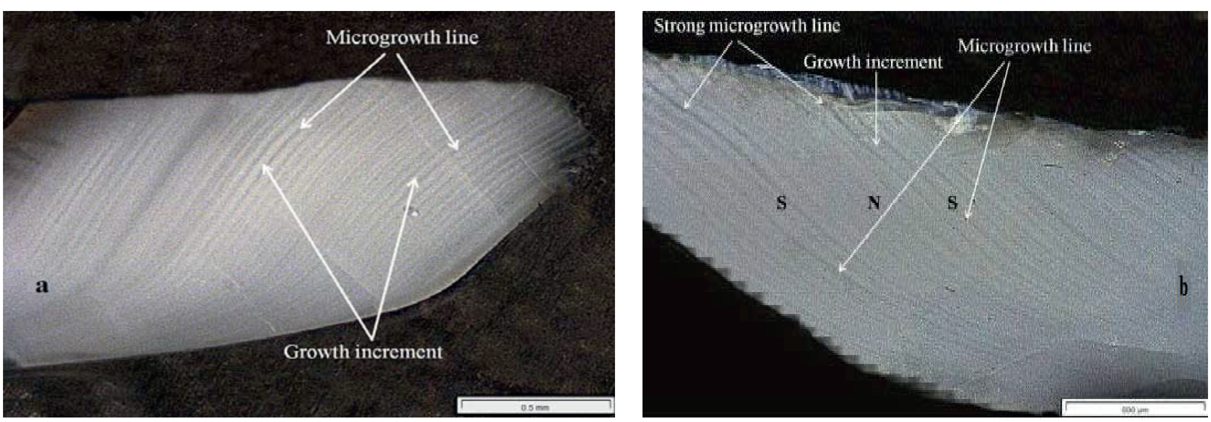

Figure 2. a) Uniform and strong microgrowth lines and increments within a shell layer from intertidal area, b) Weak and strong growth line and increment within a shell layer from subtidal area

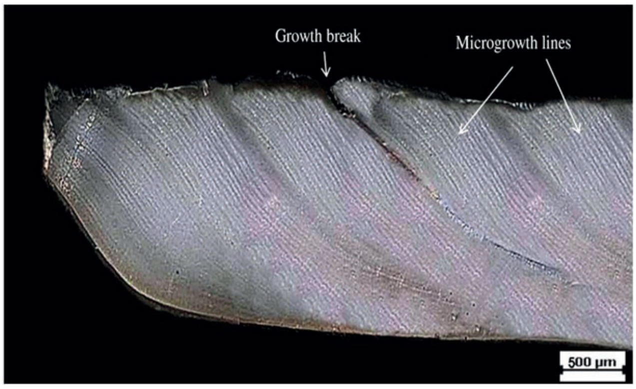

Figure 3. Interior shell section of *Corbula modesta* showing cessation of growth (growth break) during monsoon season

season (8µm) and stopped for a period during the monsoon. Mean microgrowth increment widths rapidly increase during post monsoon (18µm)

Multiple regression analysis was used to predict a continuous dependent variable (increment width) on the basis of several independent variables (environmental factors). Table 1

Table 1. Model summary[b] for environment factors (IVs) and Increment width (DV) in research model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.780[a]	0.608	0.606	4.013

a. Predictors: (Constant), Temperature, Tidal change, Salinity, Rain fall

b. Dependent Variable: Increment width

Table 2. Coefficient table for the variables contributes in research model one

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Tidal change	-0.14	0.25	-0.01	-0.56	0.57
Salinity	0.94	0.11	0.34	8.07	0.00
Rain fall	0.03	0.03	0.04	1.03	0.30
Temperature	2.06	0.08	0.61	24.09	0.00

a.Dependent Variable: Increment width

shows the strength of the relationship between the combination of environmental factors and mean shell increment width. The correlation coefficient between the environmental factors and mean increment width (R-value) was 0.780 which was highly acceptable in the current study.

Temperature was the maximum beta coefficient (0.617) and, as a result, made the greatest unique contribution to shell growth. The lower beta value (0.346) for salinity showed that it was the second factor affecting shell growth (increment width). The results of the Sig. column showed that temperature and salinity were statistically significant in terms of their contribution to shell growth ($P<0.01$), while tidal change and rainfall did not contribute significantly to shell growth ($P>0.01$).

4. Discussion

The most obvious finding to emerge from this study is that microgrowth lines in shell sections of C. modesta in intertidal area consists of strong and uniform microgrowth lines. The number of increments formed was highly correlated to the number of tidal emersion. This indicated that shell growth bands of scallops were formed with a tidal periodicity. The present findings seem to be consistent with other research, which found Shell increments separated by thin growth bands that are laid down at every tidal emersion (Richardson, 1989; Poulain *et al.,* 2011). A possible explanation for microgrowth line formation during the tidal change might be the variation between ratios of organic materials and calcium carbonate in the shell structure. During high tides, the concentration of dissolved oxygen increases in water (Truchot and Duhamel-Jouve, 1980). Therefore, shell valves are opened to facilitate normal aerobic metabolism. As a consequence, the ratio of deposited calcium carbonate increases in the shell structure. However, during low tides, the concentration of dissolved oxygen decreases sharply and shell valves are closed, resulting in anaerobic metabolism and the ratio of deposited organic materials increases relative to calcium carbonate in the shell structure. This cycle is periodically repeated according to the tidal pattern. As a result, variable microgrowth lines are formed sequentially on shells in terms of the ratio of calcium carbonate to organic materials (Vakily, 1992).

Although seawater temperature is the main controlling factor for shell growth, a number of mutually related environmental factors such as salinity also affect shell growth. The maximum increment width (65.08 μm) was at the optimum temperature (30° C), while continuous, and narrow increment widths from 53.23±2.05 to 59.16±3.57 μm were recorded during the lowest seawater temperatures (22–27° C). Therefore, lower shell growth corresponded to lower water temperature. Nevertheless, the distance between growth bands (increment widths) did not increase at temperatures above 30° C and in fact began to decline. A possible reason for the shell growth reduction above the optimum temperature was a decrease in feeding activity, leading to a decline in food availability, thus leading to a breakdown in the mechanism of metabolic activity. Heilmayer et al. (2008) confirmed that high seawater temperatures (30° C) affected respiratory activities such as heartbeat and ciliary movement of marine organisms.

Furthermore, microgrowth increments can be used to recognize the period of monsoon season and the number of seasonal variation occurring throughout the year. During monsoon two narrow bands were deposited very close together (appearing like a double band) and were reflected by the occurrence a cleft on the shell surface. Moreover, by monsoon cleft analysis in shell structure, it is possible to estimate the time of monsoon and life history in fossil of Clams.

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