Original Research

Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Journal of Environmental Biology

JEB™ p-ISSN: 0254-8704
e-ISSN: 2394-0379
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/40/1/MRN-788

Physical factors affecting oyster diversity and distribution in Southern Thailand

Paper received: 17.11.2017 *Revised received*: 26.02.2018 *Re-revised received*: 10.07.2018 *Accepted*: 03.09.2018

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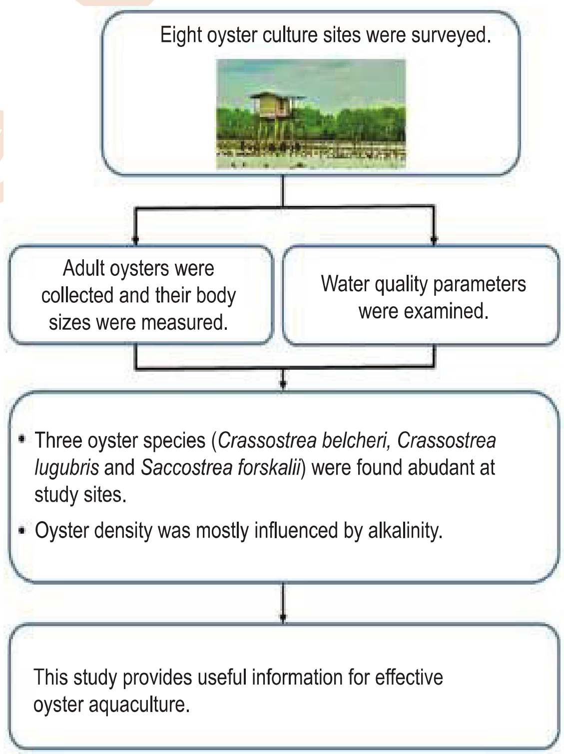
Abstract

Aim : Studies on oyster population dynamic is essential for effective oyster aquaculture.Bandon Bay in Southern Thailand is a major shellfish aquaculture site of high commercial value. The aim of this study was to evaluate the influence of environmental factors on oyster diversity and their distribution in Bandon Bay.

Methodology : Adult oysters were collected from eight aquaculture sites during low tide and their body sizes were measured. Monthly, transparency, salinity, pH, dissolved oxygen, biochemical oxygen demand, alkalinity, ammonium (NH_4-N), nitrite, nitrate and phosphate were recorded from Surat Thani Coastal Fisheries Research and Development Centre, Department of Fisheries.

Results : Three oyster species were observed: *Crassostrea belcheri*, *Crassostrea lugubris* and *Saccostrea forskalii,* however, *C. belcheri* was most abundant at most locations. Oyster density in Bandon Bay was mostly influenced by alkalinity, followed by salinity, pH, NO_3 and NH_4-N.

Interpretation : Since oyster reproduction, survival and shell development depend on environmental factors, thus studies on relationships between environmental factors and oyster occurrence/density may provide a better understanding about the community structures and spatial dynamics of oysters, as well as how oysters respond to environmental changes.



Key words: Bandon Bay, *Crassostrea belcheri*, *Crassostrea lugubris*, oyster, *Saccostrea forskalii*, Water quality

How to cite : Chumkiew, S., M. Jaroensutasinee, F.W. Tina, K. Jaroensutasinee and P. Koad : Physical factors affecting oyster diversity and distribution in Southern Thailand. *J. Environ. Biol.*, **40**, 3-8 (2019).

Introduction

Knowledge on the status and distribution of oyster population is necessary for effective estuarine management, due to their large influence on ecosystem functions (Ruesink *et al.,* 2005; Walles *et al.,* 2015). Oysters provide bio-filter feeding and bio-deposition, improving water quality (Newell, 2004), enhancing biodiversity through structural complexity, and modifying abiotic processes (Gutiérrez *et al.,* 2003; Herbert *et al*., 2016). Diseases, climate change and human activities (e.g., harvesting, aquaculture, industrial pollution, and habitat destruction) have altered the species composition and abundance of oyster population (Summerhayes *et al.,* 2009; Collin *et al.,* 2010; Tomanek *et al.,* 2011). Bandon Bay, a well-developed mangrove forest, formerly served as a nursery ground and feeding area for juvenile shellfish of great economic importance (Jarernpornnipat *et al.,* 2004). Regardless of its long association with a full range of human activities and with huge environmental problems (Chumkiew *et al.,* 2015), Bandon Bay serves as an excellent area for shellfish aquaculture of high commercial value. One species of particular importance in Bandon Bay is the White-Scar oyster, *Crassostrea belcheri* (G.B. Sowerby II, 1871) (Bussarawit and Simonsen, 2006; Kaewnern and Yakupitiyage, 2008; Songsaeng *et al.,* 2010; Thupila *et al.,* 2011). This species is in high demand and commands the highest price due to its premium quality. However, most oyster farms in Bandon Bay are small-scale using natural spat collection (Kaewnern and Yakupitiyage, 2008).

Settlement and metamorphosis of marine bivalves are complex processes and are influenced by physical and chemical characteristics of available substrates and environmental factors, such as water temperature, light intensity and current (Saucedo *et al.,* 2005; Fuchs *et al.,* 2015). Moreover environmental factors influence the survival, shell growth and oyster population dynamics (Angell, 1986). Information on salinity and temperature tolerance, growth, spawning, larval development, genetics and distribution of oysters is available throughout Thailand (Bussarawit and Cedhagen, 2012). However, studies on the relationship between oysters and environmental conditions in Bandon Bay is scarce. Therefore, conducting research on this issue is very important to understand how oyster population respond to changes inenvironmental factors. Additionally, during 1996 and 2010, flash flooding killed up to 90% of all *Crassostrea belcheri* and *Crassostrea lugubris* (Sowerby, 1871) oysters in Bandon Bay, Southern Thailand (DOF, 2000;Wilaipun, 2014). In light of the above this study was carried out to investigate the distribution and abundance of oyster population in Bandon Bay, Southern Thailand, and the relationship between environmental factors and the density of the oysters were also evaluated.

Materials and Methods

Study area: This study was conducted at eight aquaculture sites located in Bandon Bay (Latitude 9.21-9.27 ºN and Longitude 99.40-99.50 ºE), Surat Thani, Southern Thailand. Bandon Bay is adjacent to an open coastal site with gradual slopes and shallow water, covering approximately 1,215 km^2 area. A large mudflat extends about 2 km along the coast from the shoreline and is associated with a high sedimentation rate within the bay. The system has mixed tidal type with semidiurnal tides.The volume of the inner bay is estimated to be $1{,}392 \times 10^6\ m^3$ (Wattayakorn *et al.,* 2001). The major part of the freshwater in Bandon Bay is discharged from the Tapi-Phum Duang river watershed (Muttitanon and Tripathi, 2005). During rainy season, a decrease in salinity level is asignificant problem for oyster population due to the influx of freshwater from these rivers (NACA, 1988).

Water quality data collection: Monthly water quality data (water depth, temperature, transparency, salinity, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), alkalinity, ammonium (NH_4-N), nitrite (NO_2), nitrate (NO_3) and phosphate (PO_4)) at eight oyster culture sites in Bandon Bay were recorded from Surat Thani Coastal Fisheries Research and Development Center (SCFRDC), Department of Fisheries (DoF). There were 120 water samples collected at each site with a total of 960 samples from eight locations.

Oyster sample collection: Oysters were collected from eight oyster culture sites those were near or far from the shore (Thathongmai (1), Thakienthong (2, 3), Kradae (4), Plaiwas (5, 6, 7) and Thathong (8)). The oysters were collected during low tide. At these sites, oysters were cultured on cement tubes. A typical cement tube is comprised of a bamboo pole, 120 cm long and 3.2 cm diameter, which was inserted into a cylindrical cement tube of 44 cm and 15 cm diameter. Ten cement tubes were randomly selected per study site to collect oysters; in total there were 80 cement poles. The collected oysters were counted to estimate the population density. Approximately, 800 oysters were collected, identified up to species level, and their shell height, width and thickness were measured (Harding, 2007) using digital Vernier caliper.

Oyster shell volume was calculated by ellipsoid volume equation :

$$V = \frac{4}{3}\pi\, a\, b\, c$$

where, V = shell volume, $a = \frac{\text{shell height}}{2}$; $b = \frac{\text{shell width}}{2}$

and $c = \frac{\text{shell thickness}}{2}$

Data analyses: One-way analysis of variance (ANOVA) was performed to test whether water quality parameters (i.e., temperature, transparency, salinity, pH, DO, BOD_5, alkalinity, NH_4-N, NO_2, NO_3, and PO_4 levels) differed among the eight oyster culture sampling stations. Pie charts and geo-graphic visualization techniques were used to explore the potential of oyster species distribution. Chi-square test was performed to evaluate the difference between the number of oyster species among sampling sites. Logarithmic transformation was performed on the oyster density and oyster shell volume data to remove the heterogeneous variances. One-way analysis of variance (ANOVA) was used to test the differences between log oyster density and log shell volume among eight sampling sites. Tukey's HSD test was used to compare the parameters among 8 sites. Regression analyses were used to evaluate if oyster density was correlated to oyster shell volume.

Principal component analysis (PCA) was applied to examine the influence of environmental factors in the Bandon Bay. Regression analyses were used to evaluate if oyster density was associated with environmental factors. Multiple regression analysis was performed to explore and identify which water quality variables were strongly correlated with oyster density and oyster body size in the Bandon Bay. In all statistical tests, a significance level of p<0.05 was used.

Results and Discussion

Three oyster species, *Crassostrea belcheri, C. lugubris* and Saccostrea *forskalii* Gmelin, 1791, collected from the study sites represented 92%, 5.8% and 2.2% of the population. The average and standard error of shell width (SW), height (SH) and thickness (ST) of each oyster species were *C. belcheri* : SW- 67.65 ± 1.05, SH- 82.87 ± 1.40, ST- 28.28 ± 0.56), *C. lugubris* (SW- 63.79 ± 2.48, SH- 89.10 ± 4.37, ST- 33.51 ± 1.40) and *S. forskalii* (SW- 46.77 ± 3.80, SH- 54.01 ± 3.17, ST- 22.53 ± 2.09 respectively. *C. belcheri* was found at all sampling sites, exclusively at four sites (1, 2, 6 and 8). More than one oyster species was found at other sites, however *C. belcheri* was the most common (site 3: $\chi^2 1$= 35.10, P< *0.001*; site 4: $\chi^2 2$= 66.46, P< *0.001*; site 5: $\chi^2 1$= 36.75, P< *0.001*; site 7: $\chi^2 1$=

Table 1 : Water quality parameters and oyster volume and density at eight locations of Bandon Bay, Thailand

Parameter	Sampling sites 1	2	3	4	5	6	7	8	test
Temperature (°C)	28.66 ± 1.28^{a}	29.10 ± 1.77^{af}	28.65 ± 1.29^{afg}	29.63 ± 1.84^{b}	30.04± 1.70^{bcf}	29.90 ± 1.48^{bfg}	29.58 ± 1.36^{bfg}	29.72 ± 1.60^{bdf}	$F_{7,461}$= 5.835***
Transparency (cm)	55.89 ± 25.66^{a}	49.89 ± 24.26^{a}	40.56 ± 17.62^{ab}	55.11 ± 20.88^{b}	33.56 ± 28.08^{bc}	39.89 ± 33.49^{a}	67.72 ± 30.22^{ad}	63.40 ± 27.65^{ad}	$F_{7,457}$ = 11.813***
salinity (ppt)	13.91 ± 6.91^{a}	11.72 ± 7.07^{a}	12.59 ± 7.34^{a}	21.54 ± 7.13^{b}	20.04 ± 7.17^{b}	20.54 ± 6.86^{b}	22.82 ± 6.69^{b}	21.78 ± 6.49^{b}	$F_{7,461}$ = 27.553***
pH	7.90 ± 0.27^{a}	0.87 ± 0.33^{a}	7.94 ± 0.25^{a}	8.22 ± 0.27^{b}	8.24 ± 0.26^{b}	8.27 ± 0.23^{bc}	8.21 ± 0.22^{bc}	8.10 ± 0.29^{bc}	$F_{7,481}$ = 21.837***
DO (mg l^{-1})	5.74 ± 0.68^{a}	5.46 ± 0.93^{a}	5.72 ± 0.77^{a}	6.92 ± 0.93^{c}	7.04 ± 1.27^{c}	6.92 ± 0.79^{c}	6.86 ± 0.73^{c}	6.12 ± 1.02^{ab}	$F_{7,461}$ = 28.145***
BOD_5 (mg l^{-1})	1.17 ± 0.64^{ab}	1.00 ± 0.83^{a}	1.35 ± 0.82^{ab}	1.61 ± 0.81^{b}	1.50 ± 0.82^{b}	1.45 ± 0.89^{b}	1.42 ± 0.84^{ab}	1.01 ± 0.74^{a}	$F_{7,401}$ = 4.839***
Chl-a (mg l^{-1})	0.33 ± 0.75^{a}	0.72± 1.23^{a}	0.71 ± 1.15^{a}	0.53 ± 1.04^{a}	0.32 ± 1.00^{a}	0.28 ± 0.81^{ab}	0.29 ± 0.90^{a}	0.92 ± 1.31^{ac}	$F_{7,449}$ = 18.198***
Alkalinity (mg l^{-1})	78.98 ± 13.45^{a}	79.41 ± 15.52^{a}	78.30± 15.60^{a}	91.09 ± 16.13^{b}	89.13 ± 15.24^{b}	90.45 ± 14.95^{b}	94.74 ± 15.12^{b}	97.68 ± 13.31^{c}	$F_{7,497}$ = 3.150**
NH_4-N (mg N l^{-1})	0.04 ± 0.05^{ab}	0.06 ± 0.08^{acd}	0.04 ± 0.04^{a}	0.03 ± 0.05^{b}	0.03 ± 0.05^{bc}	0.03 ± 0.06^{bc}	0.02 ± 0.07^{bd}	0.04± 0.06^{ab}	$F_{7,497}$ = 3.223***
NO_2 (mg N l^{-1})	0.01 ± 0.01^{ab}	0.02 ± 0.01^{a}	0.01 ± 0.01^{ab}	0.01 ± 0.01^{ab}	0.01 ± 0.01^{ab}	0.01 ± 0.01^{b}	0.01 ± 0.01^{b}	0.01 ± 0.01^{b}	F_{7497} = 4.146***
NO_3 (mgN l^{-1})	0.03 ± 0.04^{ab}	0.04 ± 0.03^{ab}	0.02 ± 0.02^{ac}	0.01 ± 0.01^{ac}	0.01 ± 0.01^{c}	0.01 ± 0.01^{c}	0.01 ± 0.01^{c}	0.03 ± 0.03^{a}	$F_{7,497}$ = 12.513***
PO_4 (mg P l^{-1})	0.02 ± 0.02	0.02± 0.03	0.02 ± 0.023	0.03 ± 0.04	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.03	$F_{7,497}$ = 0.795, ns
Oyster body size									
Log Volume (mm^3)	10.80 ± 1.23^{a}	11.59 ± 0.83^{b}	11.72 ± 0.41^{cb}	10.94 ± 1.08^{ab}	11.06 ± 1.01^{abc}	11.25 ± 1.14^{abc}	10.86 ± 0.99^{a}	11.18 ± 0.98^{abc}	$F_{7,366}$= 4.781***
Log density (oysterm^{-2})	4.61± 0.35^{abc}	4.66 ± 0.41^{ab}	4.90 ± 0.26^{a}	4.29 ± 0.20^{bcd}	4.28 ± 0.35^{bcd}	4.04 ± 0.36^{cf}	3.78 ± 0.58^{df}	3.71 ± 0.57^{f}	$F_{7,74}$ = 11.18***

Values are mean ± SE of 10 years, **P< 0.01 and ***P< 0.001

39.23, P<*0.001*). Oyster density was highest at site 3 whereas oysters at sites 2 and 3 had larger shell volumes than those collected from other sites (Table 1).

This study is the first to document the spatial distribution and diversity of oysters at Bandon Bay, Thailand and related to several water quality parameters. Alkalinity was the most influential environmental factor, yet ammonium and nitrates were also important and salinity also played an important role (MacKenzie and Tarnowski, 2018). Three oyster species were found along the Bandon Bay during the investigation. *C. belcheri* was the dominant species, followed by *C. lugubris* and *S. forskalii.* Brohmanonda *et al.* (1998) reported that the large *C. belcheri* and *C. lugubris* were distributed along the estuarine and coastline sites at Kanchanadit district in Surat Thani province, Southern Thailand. The abundance and distribution of these three species have likely changed over time with aquaculture operations and extreme environmental events like low salinity events in 1997 and 2010 (NACA, 1988; DOF, 2000; Wilaipun, 2014). The highest oyster density occurred at site 3, where oysters also had a higher volume. It is possible that this arose because the oyster population at site 3 comprised a narrow size range of individual oysters, suggesting a single cohort, dominated by adult oysters of sufficient size greater than 1 year old; while other sites comprised a wide size range of individual oysters, indicated multiple cohorts, and were dominated by small sizes of less than 1 year (Kaewnernand Yakupitiyage, 2008). This might be related to two oyster spawning seasons, February-April and September-October (Khaonuna *et al*., 1994; Sahavacharin *et al.,* 1988) at Bandon Bay.

The temperature, transparency, salinity, pH, DO, BOD_5, alkalinity, ammonium, nitrate and nitrite levels were significantly different among sampling stations. No evidence of variation was observed in phosphate levels among the sites (Table 1). The first four rotated factors with eigenvalues greater than 1 from PCA were extracted (Table 2) and comprised 58.70% of the total variance. The first factor accounted for 23.67% of the total variance, and showed high positive correlation with salinity, alkalinity and pH levels, and had strong negative loadings of NO_3 and NH_4-N. The second factor accounted for 12.74% of the total variance and was positively correlated with DO and BOD_5. The third factor had a strong positive loading on Chl-a and a negative loading on PO_4 which accounted for 11.43% of the total variance. The last factor accounted for 10.85% of the total variance and had strong negative correlation with water temperature and a positive loading on transparency.

Oyster density was negatively associated with principle component 1 (salinity, alkalinity, pH and NO_3 and NH_4-N; linear regression: $Y = 4.411 – 0.642x$, $R^2 = 0.820$, $P < 0.05$). When the PC1, PC2 and oyster density were considered in three dimensions, three clusters (site 1-3, site 4-7 and site 8) were found. *C. belcheri* density was negatively associated with alkalinity and NH_4-H (stepwise regression model: $Y_B = 9.767- 0.058X_{alk}- 12.351X_{NH4\text{-}N}$, $R^2 = 0.425$, P<0.001). *C. lugubris* density was positively associated with NH_4-H, yet negatively associated with NO_3 ($Y_L = 153.054X_{NH4\text{-}N}- 121.087X_{NO3}- 2.738$, $R^2 = 0.346$, P <0.001). When we pooled these two oyster species, oyster density was negatively associated with alkalinity (stepwise regression model: $Y_T = 8.910 – 0.053X_{alk}$, $R^2 = 0.820$, P <0.001). There was no relationship between oyster density and oyster shell volume ($Y = 0.618x – 2.545$, *ns*).

Oyster density was negatively associated with salinity, alkalinity, pH, NO_3 and NH_4-N parameters. Higher shell volumes and high densities of oysters were found in lower salinity waters (sites 1-3) where typically, there is a low oyster larval settlement, however, less competition and suitable condition increased the survival rate of adult oysters which affects the size and population density of oysters in general (Chávez-Villalba *et al.,* 2008; Kimmel *et al.,* 2012; Çelik *et al.,* 2015). Frequent fluctuations in salinity have effects on water quality in a water body (ONEB-MSTE, 1992; Peyre *et al.,* 2016). Hofmann *et al.* (2009) reported that low salinity results in major changes in water chemistry, such as reduced Ca^{2+} concentrations and total inorganic carbon, which associated with changes in alkalinity, buffering capacity and low pH that may affect metabolism and bio-mineralization in marine calcifiers (Ries *et al.,* 2009; Kroeker *et al.,* 2010; Moullac *et al.,* 2016; Lowe *et al*., 2017). The fluctuation and decline of pH levels threaten oyster population, especially during the development of oyster larval shell (Lanning *et al*., 2010; Dineshram *et al.,* 2012; Dickinson *et al.,* 2012; Ginger *et al.,* 2013). However, in this study, pH of water generally ranged from 7.63 to 8.50, appearing within the permissible range for oyster survival and reproduction (Wilson *et al.,* 2005).

The negative relationship between oyster density and nutrient concentration (NH_4-N and NO_3) in this study corroborates

Table 2 : Factors loading of 12 variables from principal components analyses (VARIMAX rotation) of Bandon Bay. Bold values represent high loadings

Variables	Factors			
	1	2	3	4
Salinity (ppt)	**0.82**			
Alkalinity (mg l^{-1})	**0.76**		0.38	
pH	**0.63**	0.43		
NO_3 (mgN l^{-1})	**-0.61**	-0.33		0.36
NH_4-N (mg N l^{-1})	**-0.53**			
BOD_5 (mg l^{-1})		**0.82**		
DO (mg l^{-1})	0.45	**0.66**		
Chlorophyll (mg l^{-1})			**0.81**	
PO_4 (mg P l^{-1})	-0.33		**-0.61**	
Temperature (°C)				**-0.75**
Transparency (cm)	-0.25	0.26		**0.57**
NO_2 (mg N l^{-1})	-0.35			0.48
Eigenvalue	2.84	1.53	1.37	1.30
Variance (%)	23.67	12.74	11.43	10.86
Cumulative (%)	23.67	36.41	47.84	58.70

the previous studies (Kaewnern and Yakupitiyage, 2008), which suggested that culture areas with high densities of mollusc had significantly low concentrations of nutrients and phytoplankton. Kaewnern and Yakupitiyage (2008) reported that the fluctuations in nutrient and phytoplankton concentrations in Bandon Bay were influenced by the Tapi-Phumduang river watershed and by shrimp farm effluents. Shrimp culture effluents can accelerate phytoplankton blooms, while molluscs are efficient filter feeders and are capable of depleting phytoplankton in the water column (Soto and Mena, 1999). Previous studies (Tookwinas and Youngvanitsset, 1998; Jones *et al.,* 2001) have reported that oyster culture may have positively contributed to the Bandon Bay ecosystem by controlling excessive eutrophication.

In this study, it was observed for the first time that oyster populations were affected by various environmental factors in the Bandon Bay, Surat Thani. Therefore, the results of this study provide valuable baseline information on the effects of environmental factors on oyster density in the Bandon Bay. A small change in water quality affect the survival, mortality and oyster population dynamics, so, study on the effects of environmental factors on oyster population dynamics would help to predict how oyster population might respond to future environmental changes. On the other hand, study on environmental factors might help us to predict the probable density and distribution pattern of oyster species in an ecosystem.

Acknowledgments

This work was supported in part by Higher Education Research Promotion, Office of the Higher Education Commission, National Research Universities, Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0307/2550), Center of Excellence for Ecoinformatics, Institute of Research and Innovation, Walailak University, NECTEC and School of Biology, Institute of Science, Suranaree University of Technology, Thailand. We thank R. Kamsen and O. Suthakiet for invaluable field assistance.

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