Growth and survival performance of the West African mangrove oyster, *Crassostrea tulipa* cultivated by suspension and bottom culture methods in the Densu Estuary, Ghana

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Abstract

This study compares the efficacy of suspension and bottom culture methods of the West African mangrove oyster, *Crassostrea tulipa*, on recycled oyster shell cultches in connection with some environmental factors in the Densu Estuary, Ghana, from December 2017 to July 2018. Oyster spat grew up to 5.56 ± 0.10 cm SH for suspension and 4.60 ± 0.14 cm SH for bottom culture on the convex surfaces of oyster shell cultches, whereas oysters cultured on the concave surfaces by suspension and bottom cultured measured 5.59 ± 0.14 cm SH and 4.68 ± 0.14 cm SH, respectively. There was a significant difference ($F = 36.26$, $p = 0.001$) between the growth rate of oysters cultured on convex surfaces of cultches by suspension (0.80 ± 0.23 cm/month) and bottom culture (1.02 ± 0.24 cm/month). The growth rate of cultured oysters on concave surfaces of cultches by suspension (1.00 ± 0.24 cm/month) was significantly better ($F = 22.32$, $p < 0.001$) than the bottom approach (0.81 ± 0.23 cm/month). Before the extermination of oysters cultured on the bottom in July 2018, there was no significant difference in the survival of oysters cultured by suspension and bottom methods on the convex ($\chi2 = 0.06$, $p = 0.99$) and concave surfaces ($\chi2 = 0.19$, $p = 0.99$). Of the physico-chemical factors monitored, oyster growth and survival were significantly influenced by DO ($p = 0.004$; 0.039) and salinity ($p = 0.027$; 0.012), respectively. Suspension culture approach should be preferred over the bottom culture, especially for water bodies with low bulk density.

1. Introduction

There is an increasing interest in oyster culture in the tropics and for that matter Ghana because of the awareness of its potential as a renewable resource that provides protein and needed artisanal occupation (Obodai & Yankson, 2002; Yankson, 2004; Asare et al., 2019; Osei et al., 2020). Existing literature on the West African mangrove oyster, *Crassostrea tulipa* (Lamarck, 1819), in Ghana indicate that the species is suitable for mass cultivation (Yankson, 1990; Obodai & Yankson, 2000; Yankson, 2004; Chuku et al., 2020; Osei et al., 2021) and in other West African countries like Nigeria (Ajana, 1979; Ansa & Bashir, 2007), Sierra Leone (Kamara, 1982), Senegal (Diadhiou & Ndour, 2017) and the Gambia (Njie & Drammeh, 2011). Despite the cultural potential of the species, its mass cultivation has not been realised in Ghana and to some extent, Africa.

Quayle (1980) and Obodai and Yankson (2000) indicated that the choice of culture method depends chiefly on the depth of the water at low tide and the nature of bottom sediments. Hence the need to compare the growth and survival of cultured oysters by suspension and bottom culture methods in relation to some environmental factors in the Densu Estuary to inform the right culture technique to employ for its mass cultivation.

The importance of the oyster resource in providing a source of livelihood and protein for communities in Ghana (Asare et al., 2019; Osei et al., 2020) and other coastal communities in West Africa (Njie & Drammeh, 2011; Adite et al., 2013) justifies the culturing of the species to boost production. According to Quayle (1980) and Quayle and Newkirk (1989), there are a few fundamental ways of culturing oysters of which the basic kinds are bottom and suspension types (rack, raft/longline and stake). The suspension and bottom culture techniques have dominated both mass production and experimental culture of oyster species (Quayle, 1988; Cham, 1991; Newkirk, 1995; Obodai & Yankson, 2000; Urban, 2000; Lodeiros et al., 2002). These techniques have been in conjunction with different types of cultches (i.e., substrates used for collecting spat by way of cementation of edible oyster or attachment by byssal threads of pearl oysters) including recycled oyster shells, coconut shells, PVC slats and ceramic tiles. Recycled oyster shells were used in this study because of its efficiency in collecting spat, availability and durability (Obodai, 1997; Obodai & Yankson, 2002). The study was conducted in relation to the growth and survival of cultured oysters on the convex and concave surfaces of oyster shell cultches deployed in suspension and at the bottom to appreciate the performance of cultured oysters on these surfaces.

The objective of the study was to compare the growth and survival of *C. tulipa* cultured by the suspension and bottom methods in the Densu Estuary, Ghana in connection with some environmental parameters.

2. Materials And Methods

2.1. Study area

The Densu Estuary is located between longitudes 0° 16' W - 0° 21' W and latitudes 5° 30' N - 5° 33' N. River Densu, which feeds the esturine, has been dammed at Weija for potable water treatment purposes (Fig. 1). The distance between the culture station and the mouth was estimated as 1,030 m and the depth at the culture station was 0.92 m at high tide. The only kind of culture that is done in the Estuary is brush parks (acadja). The water body also supports other marine, brackish, and at times freshwater fish species especially during high influx of freshwater.

2.2. Data collection and analyses

The experiment was conducted over a period of eight months from December 2017 to July 2018 at the estuarine portion of the Densu Estuary, Greater Accra Region, Ghana. Measurements of physico-chemical parameters as well as oyster growth and survival were carried out on monthly basis.

2.2.1. Physico-chemical parameters

A multi-parametric water quality checker (HORIBA, Model U-5000) was used to measure temperature (°C), dissolved oxygen (DO) concentration (mg/l) and pH. Salinity (ppt) and turbidity (NTU) were measured with a handheld refractometer (Eclipse 45 - 65) and turbidimeter, respectively. Nitrate and phosphate concentrations (mg/l) were determined in the laboratory by colourimetric procedures (Hach DR 900 Colourimeter, and reagents of NITRAVER 5 and PHOSVER 3, respectively) upon fixing water samples on ice in the field and later referigerated to maintain its integrity. Physico-chemical parameters were analysed by the second day after sampling. Sediment bulk density was determined once by the use of a soil corer of known volume. The sediment samples were transferred to the laboratory and oven dried at a temperature of 105 ºC until a constant weight was achieved. Non-linear variables are log-transformed prior to the regression analysis. The bulk density of the sediment was calculated according to Allen et al. (1974) as follows:

Bulk Density = Weight of oven-dry sediment / Bulk volume of sediment (Volume of corer)

2.2.2. Culture setup

Strung oyster shells were used as cultches both for oyster spat collection and for grow-out purposes. Five oyster shells were strung with a 4-mm diameter nylon rope to make up a cultch [Fig. 2, using Chuku and Osei (2020)'s approach of mass cultch construction to minimize wastage]. The surface area of oyster shell cultches ranged from 56.70 to 168.00 cm^2 (Osei et al., 2021). Eight suspended and eight bottom tied cultches were tied to bamboo racks of dimensions 1.5 m length x 1.0 m height x 1.0 m width (Fig. 3). Each cultch for both treatments was identified by a number of knots ranging from 1 to 8 after the last unit shell. The treatments were cleaned of fouling organisms, debris and soil particles on monthly basis. Each cultch was allowed to carry 5 spat on the convex and 5 on the concave surfaces (i.e., a strung cultch had 50 spat for a 5-unit cultch) by thinning out unwanted spat (Fig. 4a & 4b). The experiment was conducted with an initial number of 400 spat for each treatment.

2.2.3. Growth

The growth of oysters was monthly recorded by the measurement of shell height (in cm as defined by Gosling (2015) - the distance between the hinge line to the opposite shell margin). Shell height was used because it has a better correlation with meat production than the other shell dimensions (Osei, 2020). Thirty (30) cultured oysters on both the convex and concave surfaces of oyster shell cultches of both treatments were measured randomly from January to July 2018 in situ. The monthly growth rate was calculated by the equation: Monthly growth rate = $(H_2 - H_1)/t$, where H_1 is initial shell height (cm), H_2 is final shell height (cm) and t is the days between sampling periods. Comparison of growth between oysters cultured by the suspension and bottom methods was done statistically by Repeated measures ANOVA.

2.2.4. Survival

The survival of cultured oysters was determined by counting the number of live oysters on a monthly basis and expressing it as a percentage of the initial number stocked. The percentage survival rate was calculated as follows: Survival rate = (Number of survivors/Number of spat stocked) x 100. The significance of survival of oysters cultured by suspension and bottom methods was ascertained by Chi-square test of independence.

3. Results

3.1. Physico-chemical parameters

Variations in temperature (26.37 ± 0.07 ºC - 29.50 ± 0.50 ºC) and pH (7.18 ± 0.01 - 8.82 ± 0.01) were minimal throughout the study period (Table 1). Dissolved oxygen (DO) ranged from 0.63 ± 0.01 mg/l to 6.53 ± 0.18 mg/l, salinity from 0.20 ± 0.01 ‰ to 40.33 ± 1.20 ‰, turbidity from 2.00 ± 0.58 NTU to 144.67 ± 7.75 NTU, nitrate concentration recorded Below Detection Point (BDP) to 18.87 ± 7.75 mg/l, and phosphate concentration from 0.08 ± 0.04 to 0.78 ± 0.27 mg/l. Comparatively, low values of DO, salinity and nitrate concentrations as well as high levels of turbidity and phosphate concentrations were recorded in the rainy months, June and July 2017 (Table 1). The mean bulk density of sediments in the Densu Estuary was estimated as 0.14 ± 0.013 g/cm^3.

3.2. Growth of cultured oysters

Generally, the cultured oysters showed a similar growth pattern on both the convex and concave surfaces of cultches under suspension and bottom culture methods (Fig. 5). Contrary to the oysters cultured by suspension method, measurements were not recorded for their counterparts at the bottom in July, owing to the heavy mortality suffered by the experimental units.

From Figure 5(a), oysters cultured on the convex surface by the suspension method grew up to 5.56 ± 0.10 cm SH, with mean growth rate of 1.02 ± 0.24 cm/month, whereas those at the bottom had 4.60 ± 0.14 cm SH with mean growth rate of 0.80 ± 0.23 cm/month (see Appendix A). There was a significant difference between the treatments ($F = 36.26$, $p = 0.001$).

From Figure 5(b), the suspension and bottom cultured oysters on the concave surface grew up to 5.59 ± 0.14 cm SH and 4.68 ± 0.14 cm SH, with mean growth rates of 1.00 ± 0.24 cm/month and 0.81 ± 0.23 cm/month, respectively (Appendix B). The treatments showed significant difference ($F = 22.32$, $p < 0.001$).

3.4. Survival of cultured oysters

Generally, the survival of oysters cultured by the suspension and bottom methods on the oyster shell cultches showed a similar pattern (Fig. 6). From Figures 6(a) and 6(b), before the extermination of oysters cultured at the bottom, the difference in survival of oysters cultured by the suspension and bottom methods on both the convex and concave surfaces were statistically not significant ($\chi2 = 0.06$, $p = 0.99$; $\chi2 = 0.19$, $p = 0.99$, respectively). However, oysters cultured by the suspension method on the convex and concave surfaces had a survival of 47.45 % and 46.73 %, respectively in July 2018.

3.5. Regression of physico-chemical parameters on growth and survival of cultured oysters

Simple linear regressions of growth and survival of cultured oysters in relation to temperature, DO, salinity, pH, turbidity, nitrate and phosphate concentrations are presented in Tables 2 and 3. The regression coefficients (R^2) of oyster growth and survival were significant for DO (p = 0.004; 0.039) and salinity (p = 0.027; 0.012), respectively. The order of decreasing relationship between growth and physico-chemical parameters were DO (81.18 %), salinity (58.79 %), pH (43.57 %), nitrate (29.58 %), phosphate (27.77 %), turbidity (6.17 %), and temperature (3.03 %), whereas that of survival were salinity (70.06 %), DO (52.95 %), nitrate (41.35 %), pH (40.19 %), phosphate (32.24 %), and temperature (0.0 %).

4. Discussion

In the current study, oysters cultured by the suspension method on recycled oyster shell cultches grew significantly better than their bottom counterparts. A similar finding was made by Obodai (1997) in investigating the efficiency of suspension and bottom culture methods in the Benya lagoon using coconut shell cultches. The author attributed the poor growth performance of oysters cultivated by the bottom method to low sediments bulk density. The estimated sediment bulk density of the current study was the lowest among the estimates for Benya lagoon (0.41 g/cm^3), Nakwa lagoon (1.09 g/cm^3) and Jange lagoon (1.32 g/cm^3) in Ghana by Obodai (1997).

The better performance of suspension culture method of oysters in soft bottom water bodies is consistent with the findings of Cham (1991) and Newkirk (1995), working in the Gambia River and Tam Giang lagoon in Vietnam, respectively. Moreover, Lodeiro et al. (2002) found that pearl oysters (*Pinctada imbricata*) cultivated in suspension had better growth than their bottom counterparts in the Golfo de Cariaco, Venezuela. However, in a similar study and same species by Urban (2000) in the Colombian Caribbean, the findings indicated that there was no difference between the growth rates of oysters cultured by suspension and bottom methods.

The low sediment bulk density in this study could explain the slower growth rates of oysters cultured at the bottom. Fine sediment particles at the bottom of the Densu Estuary probably interfered with the filter-feeding and respiratory activities of the bottom oysters to a greater extent, thereby negatively influencing their growth. Quayle (1988) maintained that bottom cultured oysters outperform their suspension counterparts in water bodies with hard substratum.

The loss of cultured oysters (i.e., massive mortality) in July 2018 by the bottom method could be ascribed to smothering by sedimentation, as evidenced by high turbidity (Table 1), caused by immense freshwater influx as well as the low sediment bulk density (0.14 ± 0.013 g/cm^3). Spencer (2002) and Quayle (1988) documented significantly higher survival rates of oysters cultured in suspended trays than those cultured on the ground. The difference in survival rates was ascribed to the soft nature of the bottom sediments.

Based on results of Figures 4 and 5, the suspension culture method should be preferred to the bottom method.

Cultured oyster growth slowed in June for those cultivated by bottom approach and in July for their counterparts in suspension (Appendices A and B). Perhaps, the bottom oysters might have experienced harsher unfavourable conditions. The relatively unfavourable conditions at the bottom is evidenced in the extermination of bottom cultured oysters in July. The slowed growth rate and low survival in both treatments could be ascribed to the extremely low salinity and low DO (Appendices A & B; Table 1). These physico-chemical factors were found to influence both growth and survival of cultured oysters significantly (Tables 2 & 3). The high turbidity and low pH might have contributed to the reduced growth rate and caused high mortality during the rainy period (Table 1). For nitrate and phosphate concentrations, it has been reported that proliferation of algae could be caused by the increase of any of the two nutrients (National Research Council, 2000). Therefore, the low levels of nitrate concentrations may not affect food production (algae). Also, temperature appeared to be optimal for oyster growth and survival according to Angell (1986) and Arakawa (1990).

5. Conclusion

The main finding of the study is that growth and survival performance of *C. tulipa* were better using the suspension method than the bottom method, which was attributed to mainly low bulk density of sediments. Moreover, growth and survival of oysters were influenced significantly by DO and salinity.

Declarations

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Conflict of interest: The authors declare no conflict of interest.

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Tables

Table 1: Mean monthly changes in temperature, dissolved oxygen, salinity, pH, turbidity, nitrate and phosphate concentrations in the Densu Estuary (± standard errors of means)

Month	Temperature (°C)	Dissolved oxygen (mg/l)	Salinity (ppt)	pH	Turbidity (NTU)	Nitrate (mg/l)	Phosphate (mg/l)
Dec-17	29.5 ± 0.50	3.1 ± 0.28	11.7 ± 1.67	8.2 ± 0.01	32.7 ± 9.83	18.9 ± 1.55	0.4 ± 0.2
Jan-18	26.3 ± 0.07	6.2 ± 0.08	39.0 ± 0.58	8.5 ± 0.01	4.0 ± 1.53	12.9 ± 0.26	0.1 ± 0.04
Feb-18	28.5 ± 0.40	6.5 ± 0.18	40.3 ± 1.20	8.5 ± 0.01	2.0 ± 0.58	11.4 ± 1.7	0.1 ± 0.02
Mar-18	27.3 ± 0.03	2.5 ± 0.01	23.0 ± 1.15	8.2 ± 0.02	13.3 ± 1.45	16.2 ± 9.38	0.2 ± 0.15
Apr-18	29.4 ± 0.03	2.5 ± 0.04	30.0 ± 1.15	8.8 ± 0.01	6.0 ± 0.58	10.3 ± 1.92	0.2 ± 0.05
May-18	27.8 ± 0.06	2.2 ± 0.01	27.0 ± 0.58	7.7 ± 0.01	3.0 ± 0.58	12.0 ± 4.69	0.1 ± 0.02
Jun-18	27.8 ± 0.24	1.1 ± 0.17	4.67 ± 0.33	7.2 ± 0.01	144.0 ± 7.75	BDP	0.8 ± 0.27
Jul-18	27.6 ± 0.07	0.6 ± 0.01	0.2 ± 1.96	7.4 ± 0.04	31.4 ± 2.91	2.3 ± 1.22	0.5 ± 0.07

*BDP = Below Detection Point

Table 2: Regression analysis of *Crassostrea tulipa* growth on physico-chemical parameters in the Densu Estuary

Parameter	Term	R^2 (%)	Coef	SE Coef	T-Value	P-Value
Temperature	Constant		-20.6	22.4	-0.92	0.400
	Temperature	3.03	0.88	0.80	1.09	0.326
Dissolved	Constant		6.09	0.54	11.25	0.000
	DO	81.19	-0.74	0.14	-5.19	**0.004***
Salinity	Constant		6.08	0.87	6.97	0.001
	Salinity	58.79	-0.10	0.03	-3.09	**0.027***
pH	Constant		21.43	7.45	2.88	0.035
	pH	43.57	-2.19	0.92	-2.37	0.064
Turbidity	Constant		0.21	0.27	0.80	0.460
	Turbidity	6.17	0.27	0.23	1.18	0.291
Nitrate	Constant		5.17	1.18	4.82	0.005
	Nitrate	29.58	-0.21	0.11	-1.88	0.119
Phosphate	Constant		0.93	0.27	3.39	0.019
	Phosphate	27.77	0.63	0.35	1.82	0.129

**p*-values = significant parameters

Table 3: Regression analysis of *Crassostrea tulipa* survival on physico-chemical parameters in the Densu Estuary

Parameter	Term	R^2 (%)	Coef	SE Coef	T-Value	P-Value
Temperature	Constant		174	225	0.78	0.473
	Temperature	0.00	-3.30	8.05	-0.41	0.699
Dissolved	Constant		64.13	7.83	8.19	0.000
	DO	52.95	5.74	2.06	2.78	**0.039***
Salinity	Constant		59.53	6.81	8.74	0.000
	Salinity	70.06	0.96	0.25	3.88	**0.012***
pH	Constant		-75.10	70.20	-1.07	0.334
	pH	40.19	19.52	8.70	2.24	0.075
Turbidity	Constant		1.99	0.07	27.08	0.000
	Turbidity	13.24	0.09	0.06	-1.38	0.222
Nitrate	Constant		62.47	9.89	6.31	0.001
	Nitrate	41.35	2.10	0.92	2.29	0.071
Phosphate	Constant		1.77	0.08	23.43	0.000
	Phosphate	32.24	-0.19	0.10	-1.96	0.107

**p*-values = significant parameters

Appendices

Appendix (Supplementary Data)

Appendix A: Convex surface of oyster shell cultches

	Suspension	Bottom			Suspension	Bottom
MONTH	Mean SH	Mean SH	SE	SE	Growth rate (cm/m)	Growth rate (cm/m)
J,2018	0.43	0.54	0.05	0.03		
F	2.25	2.11	0.07	0.07	1.82	1.57
M	3.43	2.88	0.09	0.08	1.18	0.77
A	4.57	3.79	0.12	0.08	1.07	0.85
M	5.03	4.46	0.15	0.11	0.46	0.67
J	5.55	4.6	0.14	0.14	0.57	0.15
J	5.56		0.1			
				SE	**0.24**	**0.23**
				Mean	**1.02**	**0.80**

Appendix B: Concave surface of oyster shell cultches

	Suspension	Bottom			Suspension	Bottom
MONTH	Mean SH	Mean SH	SE	SE	Growth rate (cm/m)	Growth rate (cm/m)
J,2018	0.52	0.6	0.05	0.04		
F	2.35	2.17	0.07	0.07	1.83	1.57
M	3.3	2.97	0.09	0.12	0.95	0.8
A	4.57	3.94	0.12	0.11	1.19	0.91
M	5.09	4.57	0.15	0.12	0.52	0.63
J	5.58	4.68	0.14	0.14	0.53	0.12
J	5.59		0.14			
				SE	**0.24**	**0.23**
				Mean	**1.00**	**0.80**

Figures

Figure 1

Map of study area, showing the experimental station in the Densu Estuary, Ghana (Osei et al., 2021)

Figure 2

A photograph of an oyster shell cultch (adapted from Osei et al., 2021)

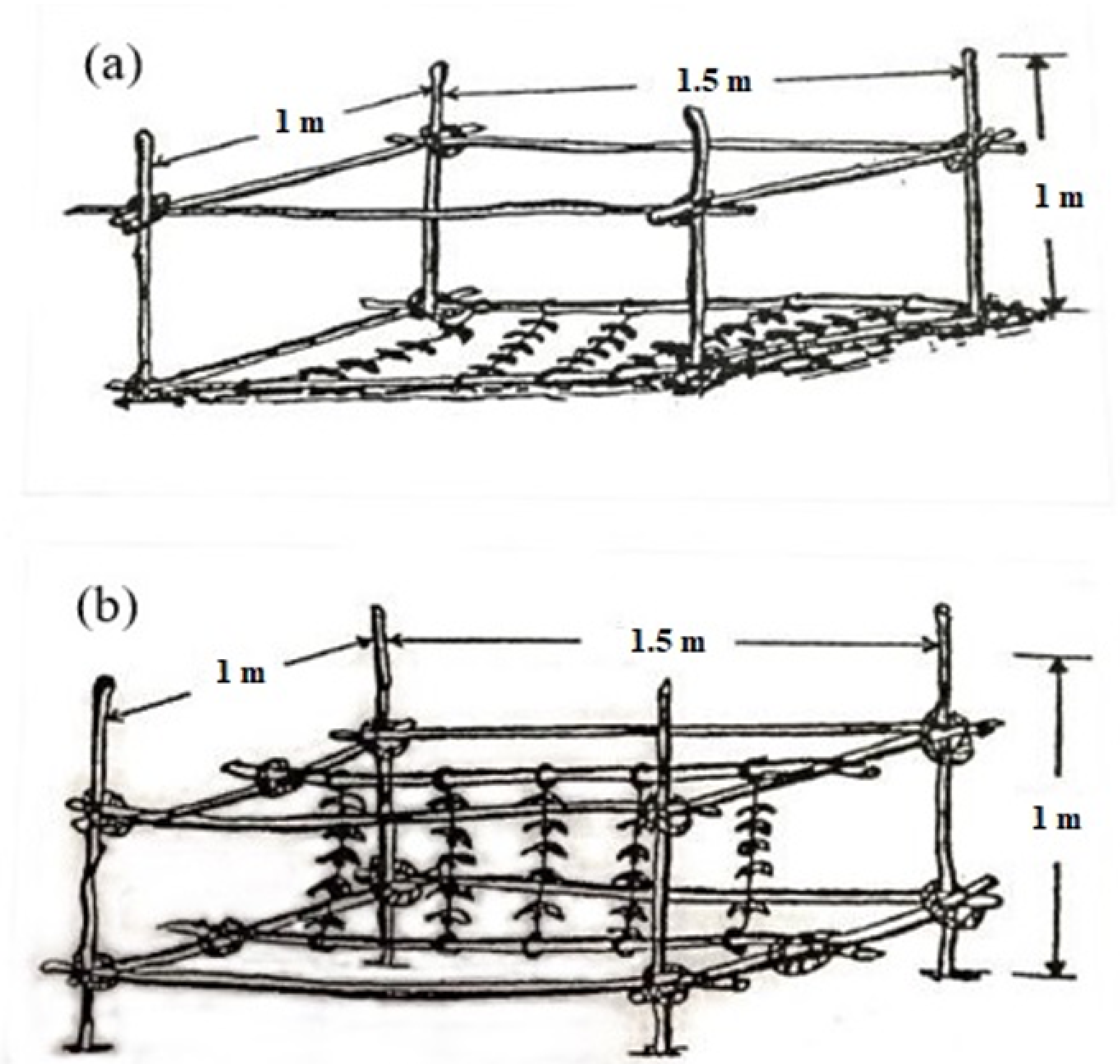

Figure 3

A sketch of bamboo racks, showing oyster shell cultches tied (a) horizontally at the bottom and (b) vertically in suspension (adapted from Obodai & Yankson, 2000)

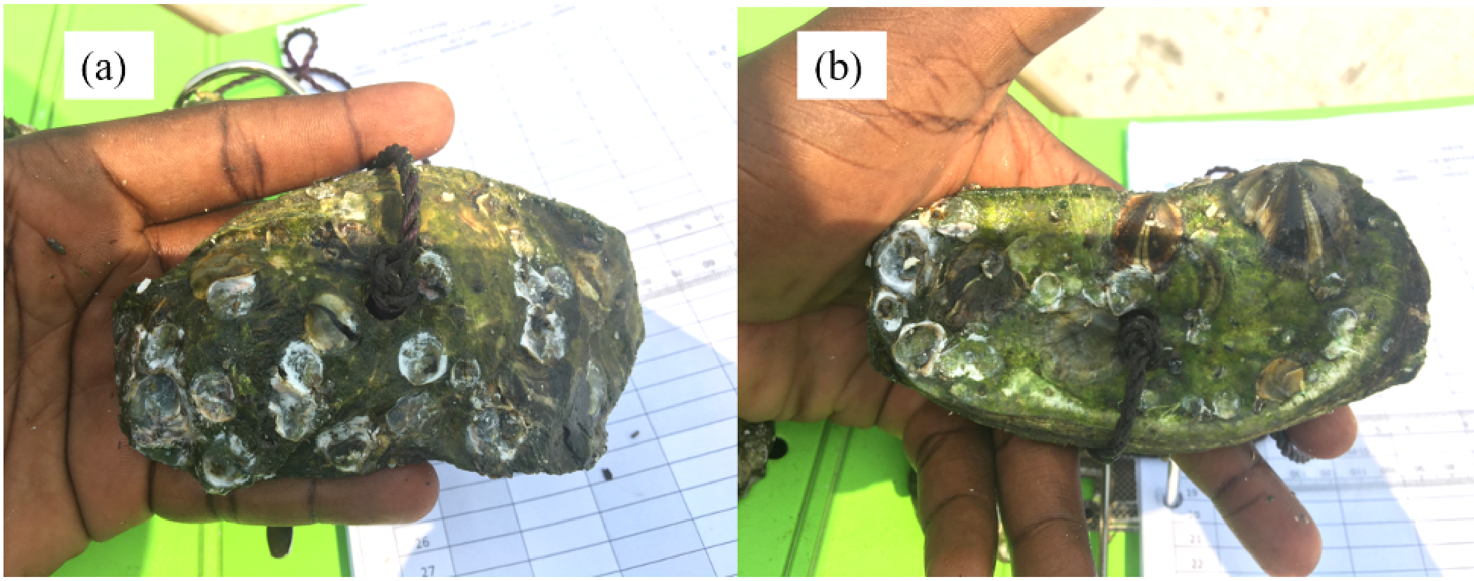

Figure 4

Oyster spat on the (a) convex surface and (b) concave surface of recycled oyster shells

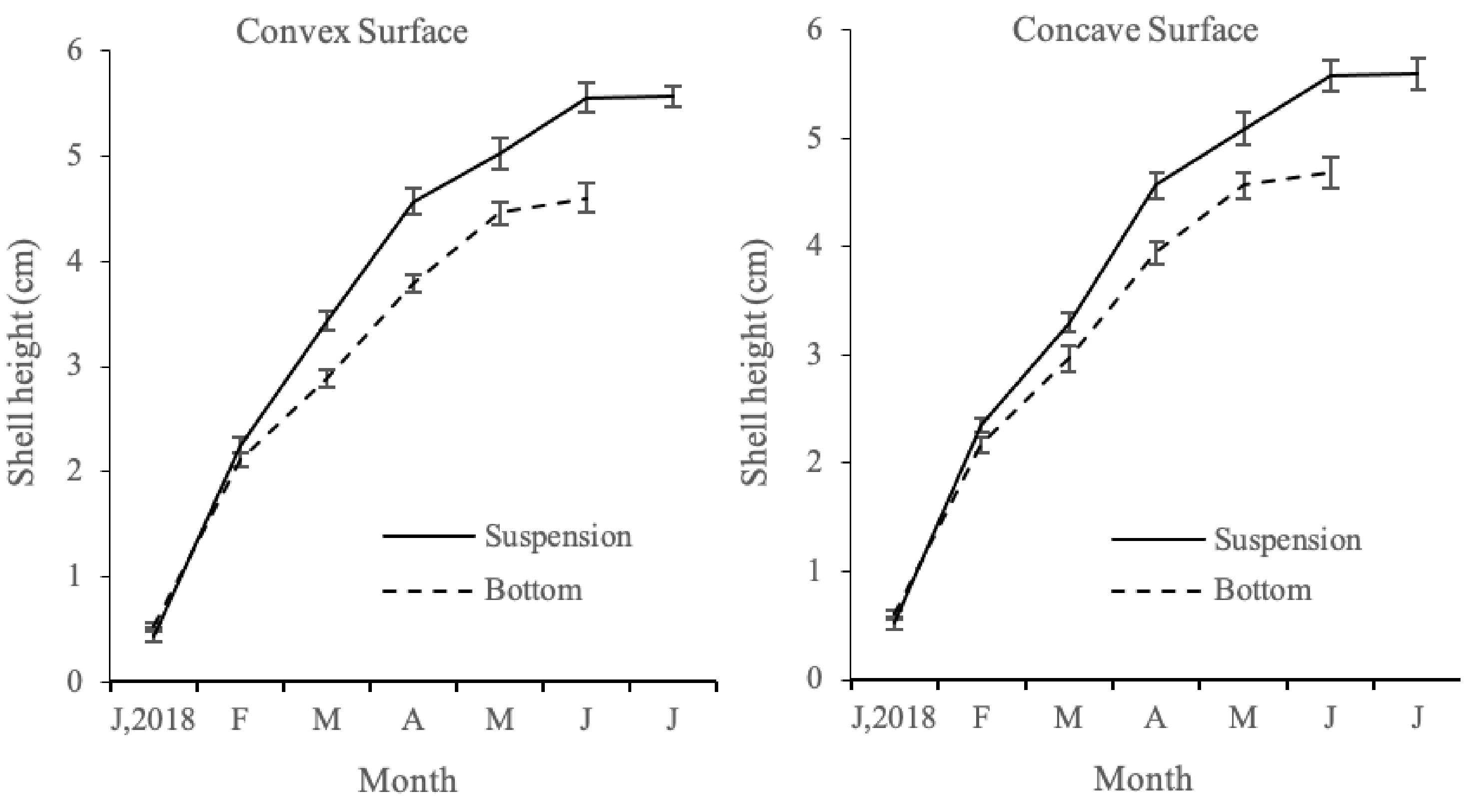

Figure 5

Growth of Crassostrea tulipa cultured on the (a) convex surfaces and (b) concave surfaces of oyster shell cultches using suspension and bottom methods in the Densu Estuary (vertical bars indicate standard errors of means)

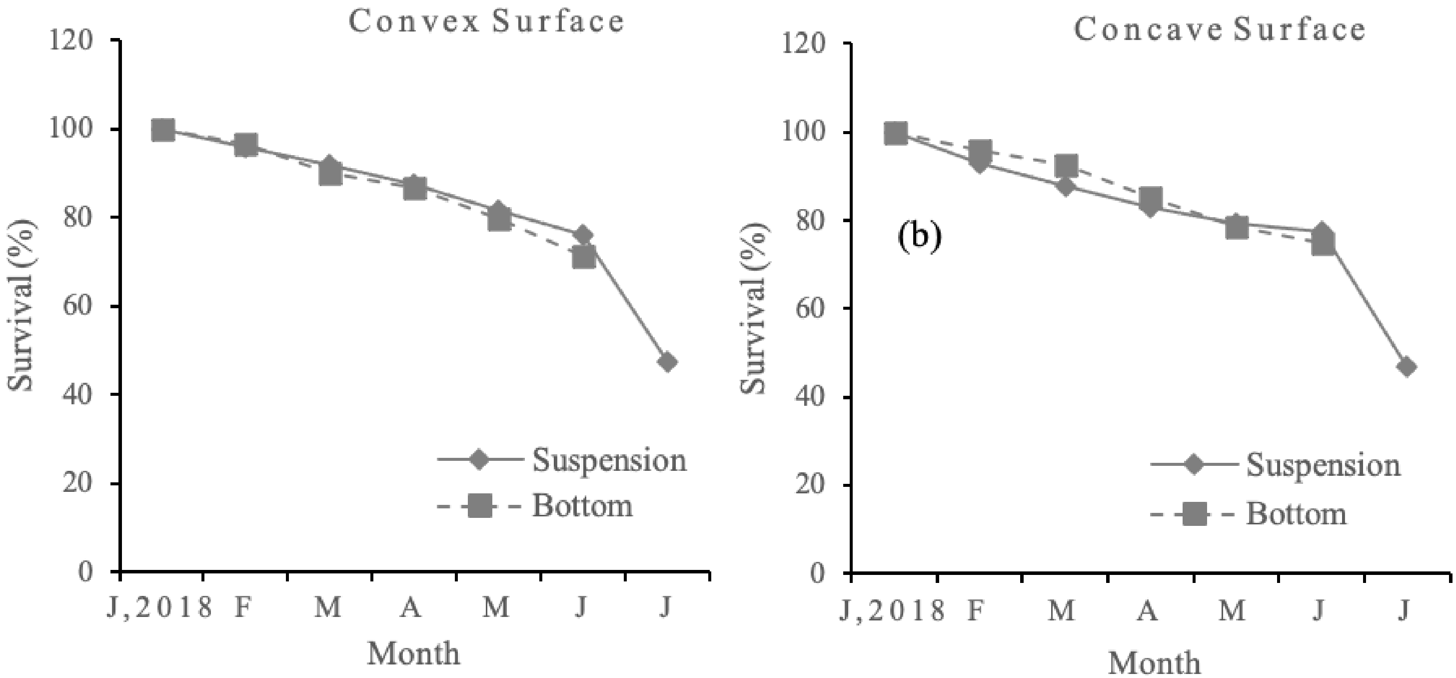

Figure 6

Survival of Crassostrea tulipa cultured on the (a) convex surfaces and (b) concave surfaces of oyster shell cultches using the suspension and bottom methods in the Densu Estuary