

EVALUATION OF THE COMBINED EFFECT OF TEMPERATURE AND SALINITY ON THE FILTRATION, CLEARANCE RATE AND ASSIMILATION EFFICIENCY OF THE MANGROVE OYSTER *CRASSOSTREA CORTEZIENSIS* (HERTLEIN, 1951)

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Abstract - An experimental trial was conducted to evaluate the effect of the combination of four temperatures (23°, 26°, 29° and 32°C) and four salinities (25, 30, 35 and 40 PSU), on clearance (FR) and filtration (CR) rates, as well as on the assimilation efficiency (AE) of the mangrove oyster *Crassostrea corteziensis*. The interaction temperature-salinity had a significant effect on the feeding physiology of the oyster; optimum results were observed in the combination of 32°C and 35 PSU with a FR of 38.08 L·h⁻¹·g⁻¹, and a CR of 1.61 mg·h⁻¹·g⁻¹. The AE was higher in the combination of 29°C and 35 PSUs with a value of 65.1%. Results suggest that *C. corteziensis* maintains its feeding physiology in the gradient of temperature and salinity evaluated, which characterizes the bivalve as an eurythermal and euryhaline organism, with a better performance at moderate temperatures (29-32°C) and salinities (~35 PSU).

Key words: Mangrove oyster, *Crassostrea corteziensis*, feeding physiology, clarification

INTRODUCTION

The mangrove oyster, *Crassostrea corteziensis*, is a bivalve mollusk distributed from the Gulf of California to the coast of Panama (Keen 1971). The species mostly inhabits the marine intertidal zone, in estuaries and coastal lagoons associated with mangrove roots.

The species supports artisanal and semi-commercial fisheries in the states of northwestern Mexico (Ramírez-Granados and Sevilla 1965, Stuardo and Martínez-Guerrero 1975, Mazón-Suástegui et al., 2001); in addition, some signs of overexploitation have been reported (Hoyos-Chairez and Robles-Mungaray 1990, Chávez-Villalba et al., 2008).

Due to its biological characteristics, good taste and market demand (Cáceres-Puig et al., 2007), this oyster is considered an excellent prospect for aquaculture. Studies have been conducted to evaluate its aquacultural potential (Orbe 1974), gonadal development and growth (Cuevas-Guevara and Martínez-Guerreo 1979, Rodríguez-Jaramillo et al., 2008), seed settlement seasons (Bush-Medina and Castro-Castro 1990), nutrition and response to temperature of juveniles (Cáceres-Puig et al., 2007, Rivero-Rodríguez et al., 2007), maturation and larval production of parent stocks (Mazón-Suástegui et al., 1992, Hurtado et al., 2008), growth, gametogenesis and condition index in culture systems (Chávez-Villalba et al., 2008, and population genetics (Pérez-Enríquez et al., 2008). In spite of the above studies, information about the

feeding physiology of the species (especially at the adult stage) and its relation to environmental variables is scarce.

Peña-Messina et al. (2009) evaluated the filtration and clarification rates of *C. corteziensis* and the blood clam *Anadara tuberculosa* on the effluents of a commercial shrimp farms. However, they did not consider the effect of temperature and salinity in the evaluation.

The effects of environmental variables such as temperature, salinity and others, on the feeding physiology of bivalve mollusks are widely described in the literature (Bayne et al., 1976, Widdows, 1985, Bougrier et al., 1995, Calvo et al., 2001, Tang et al., 2005, Resgalla Jr. et al., 2007, Sarà et al., 2008). However, information related to *C. corteziensis* is still scarce. Thus, the aim of this study was to evaluate the combined effect of four temperatures and four salinities on biological variables of *C. corteziensis* related to its feeding physiology. The results can be useful to advance the characterization of the species and its aquacultural potential.

MATERIALS AND METHODS

Adult individuals of *C. corteziensis* with a length of 30-50 mm and a weight of 0.13-0.25 g were collected in Estero de Urías, Mazatlan, Sinaloa, Mexico (23°11'N; 106°21'O) during low tides. The organisms were then washed and maintained for four days in tanks with filtered (1 µm) sea water, at a temperature of 23°C and salinity of 36 PSU. The mollusks were fed the microalgae *Chaetoceros muelleri*.

A concentration of total particulate matter (TPM) of around 50 mg·L⁻¹, with an organic fraction (OPM) of 45% and inorganic fraction (IPM) of 55%, was maintained in a water column for the experiments. The concentrations of TPM were compared to basal values commonly registered in shrimp farm effluents (Miranda et al., 2005).

The IPM was obtained from the sediment of shrimp ponds, which was dried in a stove at 100°C

for 5 h; thereafter, the sediment sample was ground in a mortar, sieved through a mesh of 44 µm, and finally burned for 8 h at 450°C in a muffle to eliminate the organic fraction. To achieve the desired proportion of organic and inorganic matter, the IPM was mixed with the microalgae *C. muelleri*, cultivated under laboratory conditions. The contribution of *C. muelleri* to the organic fraction was calculated considering an individual weight of 78.66 pg·cell⁻¹ with 33.97 pg·cell⁻¹ of organic and 44.69 pg·cell⁻¹ of inorganic matter.

The experimental organisms were acclimated during two weeks in 35 L fiberglass aquariums to the particular condition of the trial.

The salinities to be evaluated were obtained from marine water (35 PSU and 50 mg·L⁻¹ of TPM) adding marine non-industrialized salt to achieve the salinity of 40 PSU, and distilled water to achieve the salinities of 30 PSU and 25 PSU. The temperature was regulated with electric heaters (± 1°C).

In a 12 h experimental trial, each water sample was collected every 3 h. The initial time was considered when the bivalves opened the shells and began to produce feces.

The experimental units consisted of 16 individual chambers of 1 L, in which three oysters per chamber were placed. In an additional chamber used as control, three valves of oyster were placed (Hildreth and Crisp, 1976). Water was supplied to the chambers by means of a continuous flux system, using two peristaltic pumps to maintain a flux of 4.2 L·h⁻¹.

The clarification rate (CR), which represents the volume of cleaned water per time unit, was calculated using the equation proposed by Hildreth and Crisp (1976):

$$CR = F (C_1 - C_2) C_0^{-1}$$

F is the flux through the experimental chamber in L·h⁻¹; C₁ and C₂ are the concentrations of particles at the inlet and outlet of the chambers respectively; C₀

is the concentration of particles around the oysters. The concentration of particles was determined using a laser counter (Spectrex model PC-2000).

The filtration rate (FR), which estimates the amount of particulate matter removed from the water column per time unit, was calculated by multiplying the CR by the dry weight of the total particulate matter collected at the outlet of the control chamber, according to Winter (1978): the results are expressed in $\text{mg}\cdot\text{h}^{-1}$.

The assimilation efficiency was calculated according to Conover (1966) as:

$$\text{AE (\%)} = (\text{F}-\text{E}) / ([1-\text{E}] \text{F})^{-1} \cdot 100$$

F is the ratio of organic/dry weight of the TPM; E is the same rate of the feces collected.

To determine the organic weight of the TPM, samples of water were collected every 3 h, and filtered by vacuum using 47-mm GFC Whatman filters. The filtrates were washed with ammonium formate to eliminate salt residues; afterwards, they were dried for 48 h at 60°C and burned in a muffle for 4 h at 450°C. The organic matter was estimated by weight difference (Conover, 1966).

The biodeposits (feces and pseudo-feces) were collected every 0.5 h by using a semiautomatic pipette and refrigerated for posterior analysis. The organic matter was determined the same way used for TPM.

The three feeding physiology variables (CR, FT and AE) were standardized at 1 g of dry weight of oyster meat, extracting soft tissue from the experimental organisms which was dried for 48 h in a stove. The standardization was done by the equation of Bayne et al. (1983):

$$Y_s = (W_s/W_e)^b \cdot Y_e$$

Y_s is the variable to be standardized; W_s is the standard weight; W_e is the dry weight of the experimental

organism; Y_e is the variable recorded; $b = 0.67$ is the corresponding allometric coefficient (Yukihira et al., 2000)

The results were submitted to normality (Lilliefors) and homoscedasticity (Bartlett) tests (Conover, 1999, Zar, 1999). As data complied with both tests, a parametric ANOVA was used to analyze the results. Significant differences were identified by a *post hoc* Tuckey tests. Regarding the physiological variables, a multiple regression was performed, which permitted adjustment to a polynomial regression to evaluate the dependence of each variable with respect to the factors of temperature and salinity, by the equation:

$$Z = a + bT + cT^2 + dS + eS^2 + fT \cdot S$$

Z represents any of the variables; T and S are the linear effect; T^2 and S^2 are the quadratic effect; $T \cdot S$ is the interactive effects of temperature and salinity. All the statistical analyses were done with the software STATISTICA 8 (StatSoft, Inc).

RESULTS

The TPM varied from 24.33 mg L^{-1} to 35.82 $\text{mg}\cdot\text{L}^{-1}$ (Table 1) and the organic fraction from 0.39 mg L^{-1} to 0.50 mg L^{-1} . The CR was significantly affected by the temperature (Table 2) independently of the salinity; the lower CR values were recorded at 23°C, varying from 0.262 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 0.450 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$, whereas CR increased at 32°C (0.705 to 1.607 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$). A wider variation was found between 29 and 32°C, with values twice as large at 32°C (except at 40 PSU).

The salinity had a less marked effect on the CR, which recorded their higher values at 35 PSU, whereas the lowest CR was registered at 40 PSU. An increase of 5 PSU (from 35 to 40 PSU), indicated a reduction of 50% on the CR, independently of temperature.

The multiple regression analysis showed that CR was significantly affected by salinity ($P = 0.0005$), as well as by the quadratic effect ($P = 0.001$); the sum of both explained the 35.2 % of variation (Table 3).

Table 1. Means \pm *sd* of the total particulate matter (TPM) and its organic fraction (*f*) supplied to *Crassostrea corteziensis* in the treatments

TPM		T [°C]			
		23	26	29	32
S [PSU]	25	31.63 \pm 2.61	32.56 \pm 0.66	30.52 \pm 6.33	35.22 \pm 5.09
	30	27.48 \pm 2.68	28.13 \pm 5.86	31.44 \pm 7.80	26.12 \pm 1.31
	35	24.34 \pm 4.34	30.61 \pm 4.50	27.76 \pm 2.36	25.69 \pm 2.49
	40	24.33 \pm 4.17	35.59 \pm 0.36	34.31 \pm 5.49	35.82 \pm 9.38
<i>F</i>	25	0.44 \pm 0.03	0.45 \pm 0.04	0.48 \pm 0.05	0.40 \pm 0.07
	30	0.50 \pm 0.09	0.43 \pm 0.05	0.46 \pm 0.05	0.48 \pm 0.04
	35	0.50 \pm 0.05	0.42 \pm 0.04	0.44 \pm 0.04	0.42 \pm 0.04
	40	0.46 \pm 0.03	0.39 \pm 0.04	0.39 \pm 0.05	0.39 \pm 0.05

Table 2. Means \pm *sd* of clarification rate (L·h⁻¹·g⁻¹) of *Crassostrea corteziensis* in the treatments ($P > 0.05$; a < b < c < d < e).

		T °C				X \pm d. e.
		23	26	29	32	
S [PSU]	25	0.358 ^a \pm 0.28	0.311 ^a \pm 0.11	0.748 ^{abc} \pm 0.30	1.293 ^{cde} \pm 0.52	0.677 ^a \pm 0.51
	30	0.382 ^a \pm 0.17	0.658 ^{ab} \pm 0.27	0.687 ^{ab} \pm 0.17	1.325 ^{de} \pm 0.50	0.763 ^{ab} \pm 0.49
	35	0.450 ^{ab} \pm 0.17	0.990 ^{bcd} \pm 0.47	0.815 ^{abcd} \pm 0.35	1.607 ^e \pm 0.20	0.966 ^b \pm 0.52
	40	0.262 ^a \pm 0.16	0.451 ^{ab} \pm 0.23	1.282 ^{cde} \pm 0.65	0.705 ^{ab} \pm 0.37	0.675 ^a \pm 0.55
X \pm d. e.		0.363 ^a \pm 0.20	0.603 ^b \pm 0.39	0.883 ^c \pm 0.46	1.232 ^d \pm 0.52	

Table 3. Multiple regression of the Clarification rate (L·h⁻¹·g⁻¹) of *Crassostrea corteziensis* in different combinations of salinities (S) and temperatures (T). T, T² = lineal and quadratic effect of temperature. S, S² = lineal and quadratic effect of salinity. T^S = interaction effect between temperature and salinity.

Variation source	Standard error	t	R ²	P
T	0.060805	0.01793	0.000010	0.985720
T ²	0.001062	0.74439	0.000939	0.457905
S	0.028595	3.56359	0.291283	0.000503
S ²	0.000382	-3.33137	0.060334	0.001109
T·S	0.000510	-1.29710	0.012089	0.196761
			0.364655	0.000000

$$TC = 1.7382 + 0.0011 \cdot T + 0.1019 \cdot S + 0.0008 \cdot T^2 - 0.0013 \cdot S^2 - 0.0007 \cdot T \cdot S$$

Table 4. Means \pm sd of the filtration rate (FR in $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$) of *Crassostrea corteziensis* in the treatments ($P>0.05$; $a<b<c\dots$).

		T [$^{\circ}\text{C}$]				X \pm d. e.
		23	26	29	32	
S [PSU]	25	10.327 ^{ab} \pm 8.2	10.888 ^{ab} \pm 4.8	23.549 ^{bc} \pm 9.6	31.099 ^{cd} \pm 13.5	18.966 ^{ab} \pm 12.7
	30	10.570 ^{ab} \pm 4.8	18.220 ^{abc} \pm 8.2	22.936 ^{bc} \pm 5.9	30.203 ^{cd} \pm 11.3	20.482 ^{ab} \pm 10.5
	35	11.018 ^{ab} \pm 4.5	26.795 ^{cd} \pm 9.1	18.430 ^{abc} \pm 8.3	38.083 ^d \pm 2.2	23.582 ^b \pm 12.0
	40	5.270 ^a \pm 3.2	17.334 ^{abc} \pm 8.5	25.644 ^{cd} \pm 13.7	19.508 ^{bc} \pm 10.5	16.939 ^a \pm 12.0
X \pm d. e.		9.296 ^a \pm 5.8	18.309 ^b \pm 9.4	22.640 ^b \pm 9.7	29.723 ^c \pm 11.9	

Table 5. Multiple regression of the filtration rate ($\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$) of *Crassostrea corteziensis* in different combination of salinities (S) and temperatures (T). T, T² = linear and quadratic effect of temperature. S, S² = linear and quadratic effect of salinity. T^S interaction effect between temperature and salinity.

Variation source	Standard error	t	R ²	P
T	1.62431	1.57698	0.008649	0.117090
T ²	0.02838	-1.02096	0.001562	0.309062
S	0.76386	3.21921	0.218184	0.001603
S ²	0.01022	-3.12591	0.057780	0.002162
T·S	0.01362	-1.04086	0.003385	0.299762
			0.289558	0.000000

$$\text{TF} = -74.4724 + 2.5615 \cdot \text{T} + 2.4590 \cdot \text{S} - 0.0290 \cdot \text{T}^2 - 0.0319 \cdot \text{S}^2 - 0.0142 \cdot \text{T} \cdot \text{S}$$

Table 6. Means \pm sd of assimilation efficiency (EA) of *Crassostrea corteziensis*, in the treatments ($P>0.05$; $a<b<c\dots$).

		T [$^{\circ}\text{C}$]				X \pm d. e.
		23	26	29	32	
S [PSU]	25	0.427 ^a \pm 0.20	0.607 ^{abc} \pm 0.08	0.430 ^{ab} \pm 0.07	0.435 ^{ab} \pm 0.07	0.475 ^a \pm 0.14
	30	0.541 ^{abc} \pm 0.09	0.556 ^{abc} \pm 0.08	0.499 ^{abc} \pm 0.06	0.503 ^{abc} \pm 0.07	0.525 ^{ab} \pm 0.08
	35	0.570 ^{abc} \pm 0.15	0.506 ^{abc} \pm 0.10	0.651 ^c \pm 0.10	0.480 ^{abc} \pm 0.09	0.552 ^b \pm 0.13
	40	0.623 ^{bc} \pm 0.22	0.432 ^{ab} \pm 0.15	0.522 ^{abc} \pm 0.09	0.502 ^{abc} \pm 0.14	0.520 ^a \pm 0.16
X \pm d. e.		0.540 ^a \pm 0.18	0.525 ^a \pm 0.12	0.525 ^a \pm 0.11	0.480 ^a \pm 0.10	

Table 7. Multiple regression of the assimilation efficiency AE (%) of *Crassostrea corteziensis* in different combination of salinities (S) and temperatures (T). T, T² = linear and quadratic effect of temperature. S, S² = linear and quadratic effect of salinity. TS = interaction effect between temperature and salinity.

Variation source	standard error	t	R ²	p
T	0.069207	0.68500	0.000602	0.494491
T ²	0.001209	-0.70111	0.006519	0.484415
S	0.032546	1.90841	0.041159	0.058415
S ²	0.000435	-1.87609	0.021673	0.062755
T·S	0.000580	-0.36205	0.000133	0.717865
			0.070087	0.071485

$$\text{EA} = -1.0778 + 0.0474 \cdot \text{T} + 0.0621 \cdot \text{S} - 0.0008 \cdot \text{T}^2 - 0.0008 \cdot \text{S}^2 - 0.0002 \cdot \text{T} \cdot \text{S}$$

The FR was also significantly affected by temperature (Table 4), recording values from 5.270 to 11.018 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ (a mean around 9.5 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ for all the salinities) at 23°C, whereas the FR ranged from 19.508 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 38.083 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ at 32°C, with a mean of 29.7 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$, three-fold times higher than that for 23°C.

The salinity also had direct and significant effects on FR, with the highest values at 35 PSU and the lowest at 25 PSU and 40 PSU. A reduction of 28% was observed in FR when salinity increased from 35 PSU to 40 PSU (23.582 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 16.939 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$).

The regression analysis showed that salinity and its quadratic effect ($P=0.001$ and $P=0.002$ respectively) had a significant effect on FR, the sum of both explained 27.6% of the variation (Table 5).

The AE ranged in all the treatments from 42.7 a 65.1% (Table 6) and it was independent of the temperature. The salinity had a significant effect on AE with the lowest values recorded at 25 PSU; no significant differences were detected among the rest of the treatments. The regression analysis showed that AE was not correlated with temperature and/or salinity (Table 7).

DISCUSSION

Previous studies have documented that temperature and salinity are two of the most important variables affecting the feeding behavior of bivalve mollusks (Vladimirova et al., 2003, Barnes 2006, Rsgalla Jr. et al., 2007, Heilmayer et al., 2008, Sarà et al., 2008). However, it is necessary to point out that the combined effect of the two parameters on the feeding physiology of adult *C. corteziensis* has not been previously evaluated. The only related references are documents reporting bivalves thriving in temperatures from 16°C to 32°C and salinities from 21 PSU to 37 PSU (Ramírez-Granados and Sevilla 1965, Stuardo and Martínez-Guerrero 1975, Barraza 1983, Cáceres-Puig et al., 2007).

The results of the present study showed that the interaction temperature-salinity significantly affected the filtration and clarification rates of the oyster, but not its assimilation efficiency. It was found that at 32°C and 35 PSU, the CR and FR were 83% and 86% higher than those recorded at 23°C and 40 PSU, respectively. Griffiths and Griffiths (1987) reported that the CR for *Ostrea edulis* depended on the acclimation temperature and the maximum rate occurred 5°C above such temperature.

Peña-Messina et al. (2009) reported a CR ranging from 0.04 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 0.10 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ and a FR from 20.04 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 64.70 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ for *C. corteziensis*, values much lower than those observed in our study; however, the experimental conditions of both studies were different. Nieves et al. (2009) found a CR from 0.332 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 0.557 $\text{L}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$, at 35 PSU for *Anadara tuberculosa*. These values are lower than those found in this experiment. They also reported a FR ranging from 11.556 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$ to 20.282 $\text{mg}\cdot\text{h}^{-1}\cdot\text{g}^{-1}$, similar to our results. Maire et al. (2007) reported for the Mediterranean mussel, *Mytilus galloprovincialis* under oligotrophic laboratory conditions, a CR four-fold higher than that found for *C. corteziensis*. For the mud mussel, *Mytella strigata*, a bivalve inhabiting the same environments as our species in north-west Mexico, Marquez (2010) found a maximal FR at 29°C, which was 19% lower than that recorded in this study for the mangrove oyster.

The information available indicates that the filtration variables of mollusks increase concomitantly with temperature up to an optimal level; however, the filtration capacity severely decreases above this optimal level (Shumway 1982, Newell et al., 1977, Mondal, 2006, Han et al., 2008). For instance, Rsgalla Jr. et al. (2007) evaluated a combination of temperatures and salinities for the mussel *Perna perna*, and found that the optimal response of filtration variables occurred at 25°C, and that it significantly decreased at 15°C and 30°C. A similar trend was observed for the clam *Sanguinolaria rostrata*, which showed the greatest clarification rate and assimilation efficiency at 25°C and the lowest at 20°C and 30°C (Hai-Lun 2004).

It is important to point out that the optimal temperatures for the mollusk feeding responses are related to the characteristics of their natural habitat. In this context, the above referred species inhabit environments with lower temperature than the mangrove oyster.

Both CR and FR of *C. corteziensis* increased with temperature. However, an inflexion point was not observed; thus, the temperature limit at which CR and FR are negatively affected is still to be elucidated. These results suggest that the mangrove oyster has tolerance to high temperatures. Cáceres-Puig et al. (2007) reported that *C. corteziensis* has a thermal tolerance above 32°C, but it has an optimal performance within an interval of 24°C and 30°C during its larval phase.

The effect of temperature on the physiological response of mollusks has been explained from different perspectives. Jørgensen (1990) suggests that when temperature increases, the water viscosity decreases, which favors the filtration capacity of the organisms. Yukihiro et al. (2005) attribute the variations to the combinations of two opposite effects: an increase on the chemical reactions during metabolism due to the temperature increase versus a denaturation of the enzymes that catabolize them. Nakamura (2004) found that for the clam *Ruditapes philippinarum*, the CR increased more than 2.5-fold when temperature changed from 12°C to 21°C, and suggests that such results are related to the abundance of phytoplankton that change dramatically from season to season. In this context, Sol-Hernández (2001) recorded in the estuary La Sirena, Sinaloa, Mexico (near to the site where the experimental organisms were collected), high concentrations of chlorophyll during July and August when the temperature was around 31.8°C, and a much lower concentration during February and March, when the temperature was around 28°C.

The assimilation efficiency of the mangrove oyster in this experiment was in general independent of temperature. A similar response was reported for *Perna perna*, in a range of 15°C to 30°C (Resgalla Jr. et al., 2007). Nieves et al. (2009) found that AE was

also independent of temperature for *Anadara tuberculosa*. Some other studies have documented that the relation between temperature and AE is inconsistent (Bayne and Newell 1983, Mondal, 2006, Yukihiro et al. 2000). The AE in our study observed values lower than those reported by other studies; probably this was in part because we did not separate feces and pseudo feces, which may have led to underestimation of the AE (Nieves et al., 2009).

The salinity had a less marked effect on CR and FR than temperature. Both variables increased at 35 PSU, and decreased at 40 PSU. Results suggest that the filtration capacity of *C. corteziensis* is greater at intermediate salinities, and decreases at extreme salinities. A similar trend was found for *Perna perna*, which recorded the lowest CR at 15 PSU and 40 PSU, while the greatest values were found at 20 PSU (Resgalla Jr. et al., 2007). The clam *Sanguinolaria rostrata* exhibited a low CR at 5 PSU and 30 PSU, and a drastic increase at 20 PSU and 25 PSU (Hai-Lun 2004).

Since bivalve mollusks are unable to perform extracellular osmoregulation, their ionic concentration changes quickly when salinity does (Tang et al., 2005). This change affects the functional activity up to an eventual suspension of feeding because the organism closes its valves to impede the passage of salt to the perivisceral chamber (Berger and Kharazova 1977). In some mollusks such as *Scrobicularia plana* and *P. perna*, the closing behavior may last for some days, and it is explained as a protection strategy (Akberali, 1978, Salomão et al., 1989). This strategy is probably used by *C. corteziensis* to face the drastic increase of salinity up to 39 PSU in the estuary where the experimental organisms were collected (Sol-Hernández, 2001).

The salinity scarcely affected the AE, being relatively higher at 35 PSU and 40 PSU. Resgalla Jr. et al., (2007) reported for *P. perna* an AE independent of salinities from 20 PSU to 35 PSU, but decreasing significantly at 15 PSU and 40 PSU. Similar results have been reported for other mussels, with lower AE at 20 PSU and higher at 40 PSU (Bayne et al., 1976). Contrarily, for the scallop *Argopecten purpuratus*, the AE

was independent of salinity (Navarro and Gonzáles, 1998).

Based on the results of the present study, it can be concluded that *Crassostrea corteziensis* showed a plasticity to adjust its feeding physiology to different temperatures and salinities, confirming that it is a eurythermal and euryhaline organism adapted to the variable conditions prevailing in northwest Mexico. Its best filtering response was found at temperatures around 32°C, and salinities around 35 PSU. These results suggest the possibility of culture of the oyster in tropical and subtropical regions, or to its use as a bioremediator of aquaculture effluents.

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REFERENCES

- Akberali, H.B. (1978). Behaviour of *Scrobicularia plana* (Da Costa) in water of various salinities. *Journal of Experimental Marine Biology and Ecology* **33**, 237-249.
- Barnes, P.A.G. (2006). Shellfish culture and particulate matter production and cycling: literature review. BC Aquaculture Research and Development Committee, Project AE 02.03-02.01. *Final Report*. Center for Shellfish Research, British Columbia. pp. 5-28.
- Barraza, R.H. (1983). Contribución al conocimiento sobre algunas especies comerciales de moluscos bivalvos *Crassostrea corteziensis* Hertlein, 1951, *Saccostrea palmula* Carpenter, 1857 y *Atrina maura* Sowerby, 1835 en el estero El Pozole, Sinaloa, México, 1982-1983. Tesis Profesional, Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa, Sinaloa 203 pp.
- Bayne, B.L., Thompson R.J. and J. Widdows (1976). Physiology I, In: *Marine mussels their ecology and physiology*, (Ed. B.L. Bayne), 121-15. Cambridge University Press, New York.
- Bayne, B.L. and R.C. Newell (1983). Physiological energetic of marine mollusks. In: *The mollusca. Physiology* 1 (Eds. A.S.M. Saleuddin and K.M. Wilbur), 407-515. Academic Press, New York. Berger, V.J. and A.D. Kharazova (1997). Mechanisms of salinity adaptations in marine molluscs. *Hidrobiologia* **335**, 115-126.
- Bougrier, S., Geairon, P., Deslous-Paoli, J.M., Bacher, C. and G. Jonquière. (1995). Allometric relationships and effects of temperature on clearance and oxygen consumption rates of *Crassostrea gigas* (Thunber). *Aquaculture* **134**, 143-154.
- Bush-Medina, R.E. and D. Castro-Castro. (1990). Periodo de incidencia de fijación de larvas de ostión *Crassostrea corteziensis* (Hertlein, 1951), mejillón y balánidos en el ecosistema Teacapán-Sinaloa, durante 1977-1980. Tesis de Licenciatura, Universidad Autónoma de Sinaloa, 58 pp.
- Cáceres-Puig, J.I., Abasolo-Pacheco, F., Mazón-Suastegui, J.M., Maeda-Martínez, A.N. and P.E. Saucedo. (2007). Effect of temperature on growth and survival of *Crassostrea corteziensis* spat during late nursery culturing at the hatchery. *Aquaculture* **272**, 417-422.
- Calvo, G.W., Luckenbach, M.W., Allen, Jr, S.K. and E.M. Burreson. (2001). A Comparative field study of *Crassostrea ariakensis* (Fujita 1913) and *Crassostrea virginica* (Gmelin 1791) in relation to salinity in Virginia. *Journal of Shellfish Research* **20**, 221-229.
- Chávez-Villalba, J., Hernández-Ibarra, A., López-Tapia, M.R., and J.M. Mazón-Suástegui. (2008). Prospective culture of the Cortez oyster *Crassostrea corteziensis* from Northwestern Mexico: growth, gametogenic activity and condition index. *Journal of Shellfish Research* **27**, 1-10.
- Conover, R. J. (1966). Assimilation of organic matter by zooplankton. *Limnology and Oceanography* **11**, 338-345.
- Conover W. J. 1999. *Practical nonparametric statistics*. John Wiley, New York. 584 p.
- Cuevas-Guevara, C.A. and A. Martínez-Guerrero. (1979). Estudio gonádico de *Crassostrea corteziensis* Hertlein, *C. palmula* Carpenter y *C. iridescens* Hanley, de San Blas, Nayarit, México (Bivalvia: Ostreidae). *Anales del Centro de Ciencias del Mar y Limnología* **6**, 81-98.
- Griffiths, C.L. and R.J. Griffiths. (1987). Bivalvia. In: *Animal energetic*, Vol 2 (Eds. T.J. Pandian and F.J. Vernberg), 1-88. Academic Press, New York.
- Hai-Lun, K. (2004). Effects of temperature, salinity and algal concentration of the filter feeding *Sanguinolaria rostrata*. Master Thesis, National University of Sun Yatsen, Taiwan. 103 pp.
- Heilmayer, O., Digialleonardo, J., Qian, L. and G. Roesijadi (2008). Stress tolerance of a subtropical *Crassostrea virginica* population to the combined effects of temperature and salinity. *Estuarine, Coastal and Shelf Science*, **79**, 179-185.
- Hildreth, D.I. and D.J. Crisp. 1976. A corrected formula for calculation of filtration rate of bivalve mollusks in experimental

- flowing system. *Journal of Marine Biological Association of United Kingdom* **56**, 111-120.
- Hoyos-Chaires, F., and M. Robles Mungaray (1990). Estudio sobre el cultivo piloto de ostión *Crassostrea corteziensis* (Hertlein, 1951), en un criadero comercial: II. Crecimiento a talla comercial. Resúmenes del IV Congreso Nacional de Acuicultura, AMAC, 90, Hermosillo, Sonora, México. 81 pp.
- Hurtado, M. A., Ramírez, J. L. Rodríguez-Jaramillo, C. Tovar, D. Ibarra, A. M. Soudant, P. and E. Palacios. (2008). Comparison of continuous and batch feeding systems on maturation biochemical composition and immune variables of the oyster *Crassostrea corteziensis* (Hertlein 1951). *Aquaculture Research* **40**, 464-472.
- Keen, M. (1971). *Sea shells of tropical West America, marine mollusks from Baja California to Peru*. Stanford University Press, Stanford, 1080 pp.
- Kinne, O. (1971). Temperature. 3.3. Animals: 1 Invertebrates. In: *Marine ecology environmental factors* (Ed. O. Kinne), 407-514. Wiley-Interscience, London.
- Marquez, D. (2010). Balance energético del mejillón *Mytella strigata* (Hanley, 1843) (Bivalvia: Mytillidae) a diferentes temperaturas, en condiciones de laboratorio. Tesis de Licenciatura, Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa, México. 75 p.
- Mazón-Suástegui, J.M., Robles-Mungaray, M. Flores-Higuera F. and S. Avilés-Quevedo. (1992). Experiencias en la producción de semilla de ostión de placer *Crassostrea corteziensis* en el laboratorio. *Memorias del IV Simposio Nacional de Acuicultura y Pesca*, 16-18 de octubre, 1992, Antigua, Guatemala. pp. 19-21.
- Mazón-Suástegui, J.M., Robles-Mungaray, M. S. Avilés-Quevedo, Flores-Higuera, F., Monsalvo-Spencer P. and M. Osuna-García. (2001). Avances en la producción y cultivo de semilla de ostión nativo *Crassostrea corteziensis* en Bahía de Ceuta, Sinaloa, México, *Memorias del 1er Foro Estatal de Ciencia y Tecnología*, Culiacán, Sinaloa, México. p. 132.
- Miranda, B. (2005). Remoción de materia particulada en efluentes de estanquería de camarón con *Anadara tuberculosa* (Pelecypoda: Arcidae) (Sowerby, 1833). Tesis de Doctorado, Centro de Investigación Científica y de Educación Superior de Ensenada, B.C., México, 124 pp.
- Mondal, S.K. (2006). Effects of temperature and body size on food utilization in the marine pearl oyster *Pinctada fucata* (Bivalvia: Pteriidae). *Indian J. Mar. Sci.* **35**, 43-49.
- Navarro, J.M. and C.M. Gonzalez. (1998). Physiological responses of the Chilean scallop *Argopecten purpuratus* to decreasing salinities. *Aquaculture* **167**, 315-327.
- Nieves, M., Román-Reyes, J.C., Piña, V., Medina-Jasso, A., Leal, S., Miranda-Baeza, and J. Muñoz-Duran (2009). Balance energético de *Anadara tuberculosa* (SOWERBY, 1833) a diferentes temperaturas. *Revista de Investigaciones Marinas* **30**, 135-144.
- Orbe, M.A. (1974). Estudio ostrícola realizado en el Pacífico. Dirección de Acuicultura, Secretaría de Recursos Hidráulicos, *Resúmenes del 5º Congreso Nacional de Oceanografía*, Guaymas, México, 22-25 Octubre, 1974, Sonora, México p. 10.
- Peña-Messina, E., Martínez-Córdova, L. Bükle-Ramírez, F. Segovia-Quintero, M. and J. Zertuche-González (2009). A preliminary evaluation of physiological filtration variables for *Crassostrea corteziensis* (Hertlein, 1951) and *Anadara tuberculosa* (Sowerby, 1833) in shrimp aquaculture effluents. *Aquaculture Research* **40**, 1750-1758.
- Pérez-Enríquez, R. Ávila, S. and A.M. Ibarra. (2008). Genética poblacional de ostión de placer *Crassostrea corteziensis* en el noroeste de México. *Ciencias Marinas* **34**, 479-490.
- Ramírez-Granados, R. and M.L. Sevilla. (1965). Las ostras de México. Datos biológicos y planeación de su cultivo. *Anales del Instituto Nacional de Investigaciones Biológico Pesqueras. Secretaría de Industria y Comercio*, México. 7: 1-36.
- Resgalla, Jr C, Brasil, E.S. and L.C. Salomão (2007). The effect of temperature and salinity on the physiological rates of the mussel *Perna perna* (Linnaeus 1785). *Brazilian Archives of Biology and Technology* **50**, 543-556.
- Rivero-Rodríguez, S., Beaumont, A.R. and M.C. Lora-Vilchis. (2007). The effect of microalgal diets on growth, biochemical composition, and fatty acid profile of *Crassostrea corteziensis* (Hertlein) juveniles. *Aquaculture* **263**, 199-210.
- Rodríguez-Jaramillo, C., Hurtado, M.A. Romero-Vivas, E. Ramírez, J.L. Manzanero, M. and E. Palacios. (2008). Gonadal development and histochemistry of the tropical oyster, *Crassostrea corteziensis* (Hertlein, 1951) during an annual reproductive cycle. *Journal of Shellfish Research* **27**, 1129-1141.
- Salomão, L.C. and J. Lunetta. (1989). The effects of salinity changes on the osmotic ionic concentrations in the hemolymph of *Perna perna* (Mollusca: Bivalvia). *Boletim de Fisiologia Animal* **13**, 29-38.
- Sarà, G. and A. Pusceddu (2008). Scope for growth of *Mytilus galloprovincialis* (LMK., 1819) in oligotrophic coastal waters (Southern Tyrrhenian Sea, Italy). *Marine Biology* **156**, 117-126.
- Sol-Hernández, M.J. (2001). Empleo del factor de condición del mejillón de estero (*Mytella strigata*) y el ostión (*Crassostrea corteziensis*) como posibles indicadores de diferencias hidrobiológicas en un área del Estero de la Sirena en

- Mazatlán, Sinaloa, sujeta a modificaciones antropogénicas. Tesis de Licenciatura, Facultad de Ciencias del Mar, UAS, México. 100 p.
- Stuardo, J. and A. Martínez-Guerrero. (1975). Relación entre algunos factores ecológicos y la biología de poblaciones de *Crassostrea corteziensis* Hertlein, 1951, de San Blas, Nayarit, México. *Anales del Centro de Ciencias del Mar y Limnología* **2**, 89-130.
- Tang, B., Liu, B., Yang H. and J. Xiang (2005). Oxygen consumption and ammonia-N excretion of *Meretrix meretrix* in different temperature and salinity *Chinese Journal of Oceanology and Limnology* **23**, 469-474.
- Vladimirova, I.G., Kleimenov, S. Yu. and L. I. Radzinskaya (2003). The relation of energy metabolism and body Weight in bivalves (Mollusca: Bivalvia). *Biology Bulletin* **30**, 392-399.
- Widdows, J. (1985). Physiological procedures. In: *The effects of stress and pollution on marine animals* (Eds. B.L. Bayne, D.A. Brown, K. Burns and D.R. Dixon), 161-178. Praeger Scientific Publications, New York.
- Winter, J.E. (1978). A review on the knowledge of suspension feeding in lamellibranchiate bivalves, with special reference to artificial aquaculture systems. *Aquaculture* **13**, 1-33.
- Yukihira, H., Lucas, J.S. and D.W. Klumpp. (2000). Comparative effects of temperature on suspension feeding and energy budgets of the pearl oysters *Pinctada margaritifera* and *P. maxima*. *Marine Ecology Progress Series* **195**, 179-188.
- Zar, J.H. (1999). *Biostatistical analysis*. Prentice-Hall, New Jersey. 663 p.