Research Article

Growth and economic performance of diploid and triploid Pacific oysters *Crassostrea gigas* cultivated in three lagoons of the Gulf of California

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ABSTRACT. Diploid and triploid *Crassostrea gigas* oysters were cultivated at three farms (Guasave, Navolato and Ahome) in Sinaloa, Mexico, to evaluate their growth and economic performances. Growth rate and survival of oysters were compared in long-line cultivation and were mostly affected by water parameters rather than ploidy or their interaction. The highest growth rates for shell length (8.01 mm month^{-1}) and body weight (9.08 g month^{-1}) were obtained for the Ahome/triploid group. Survival differed significantly from 98.6% for the Guasave/triploids to 76.7% for the Ahome/diploids. After the first production cycle, more than 80% of production costs represent the purchase of cultivation equipment and salaries contributed with around 9%. The Guasave farm produced the highest profits (US$8,053.71 diploids, US$8,182.19 triploids). Use of diploids starting the production cycle on October-November to avoid mortality and improve final profit is recommended.

Keywords: oysters, suspended cultivation, growth rate, environmental conditions, profit.

INTRODUCTION

From all the cultivated bivalves, the Pacific oyster *Crassostrea gigas* (Thunberg, 1795) contributed with around 10% of the mollusks worldwide production in 2013 (FAO, 2015). Due to its fast growth (Taris *et al*., 2007), resistance to variations of temperature and salinity (Flores-Vergara *et al*., 2004), meat quality (Langdon *et al*., 2003), shell shape (Ward *et al*., 2000), and disease resistance (Villanueva-Fonseca & Escobedo-Bonilla, 2013), this species has been introduced in many countries of the world (Soletchnik *et al*., 2002), including Mexico. Despite of the growing interest for its cultivation, there are still some factors that need to be studied to support the economy of this industry, such as genetics and specific strains adapted to local conditions of new cultivation sites.

Noriega-Curtis (2012) stated that research on the systematic use of triploids represents one of the most important requirements for oyster farming in Mexico. Triploidy is widely used to obtain faster growth in different oyster species (Nell, 2002) since produces sterility (Garnier-Géré *et al*., 2002), which would divert more metabolic flux to growth reducing their energy needs for reproduction, and an increased volume of polyploid cells (Guo & Allen, 1994). An additional benefit trait of all-triploid *C. gigas* would be the reduction of genetic pollution from the escape of cultivated stock (Guo *et al*., 1996) because triploids are incapable of colonization. However, growth responses of both diploid and triploid organisms partially depend on the environmental conditions. For instance, Maguire *et al.* (1994) reported relatively small increases in growth rates of triploid Pacific oysters in Tasmania, Australia, meanwhile, Akashige & Fushimi (1992) and Chao *et al.* (1999), obtained faster growth rates of triploids in Japan and Taiwan, respectively, compared with that of diploids. It is accepted that environmental

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parameters such as water temperature, particulate organic matter, particulate inorganic matter and chlorophyll-*a* are the most important determinants of oyster growth rate (Gangnery *et al.*, 2003; Flores-Vergara *et al.*, 2004), and vary with latitude and/or location.

C. gigas was introduced in some coastal lagoons and estuaries of Mexico in the 70's (Martínez-Córdova & Robles, 1990), and so far, is the most cultivated mollusk in the northwestern of the Gulf of California, especially in the states of Baja California and Sonora. But since 1997, the oyster industry in these states has been affected by severe mortality episodes disturbing almost all the farming areas. Then, production of diploid *C. gigas* was spread out to the southeastern of the Gulf of California where is nowadays cultivated along the coastal shore of Sinaloa's State. Nevertheless, there is no information available on the growth and production record in this region. There are few local academic reports (Gutiérrez-Sepúlveda, 2015; Sotelo-González, 2015; Vázquez-Cervantes, 2015) and only one published study on the growth of diploid Pacific oyster cultivated at the southeastern of the Gulf of California (Góngora-Gómez *et al.*, 2012), in which the commercial size (≥10 cm) was reached in seven cultivation months with a final survival of 88%. Despite of the increasing interest on oyster cultivation in the region, so far, there are no reports dealing with production characteristics, costs and income.

It is important to highlight that there is limited information in Mexico about performance of triploids oysters, as well as comparisons with diploid organisms during cultivation. Studies like this represent valuable data to support new production strategies in oyster culture in Latin America. The objective of our study was to compare growth and economic performances of diploids and triploids cultivated in three lagoon systems at the southeastern of the Gulf of California.

MATERIALS AND METHODS

Study sites

The study was carried out in three cultivation sites located at the north of Sinaloa: La Pitahaya Estuary in Guasave, Bacorehuis Estuary in Ahome, and Lucernilla Cove in Navolato (Fig. 1). The climate of the study areas is categorized as temperate-subhumid with summer rains (INEGI, 2001). La Pitahaya Estuary is part of the Navachiste-San-Ignacio-Macapule lagoon system, which remains as a marine environment most of the year due to a permanent connection with the Gulf of California through two mouths. It is surrounded by mangrove communities, and receives the municipal sewage from the city of Guasave, and agricultural and aquaculture drainages that flow into this estuary (Ruíz-Luna & de la Lanza-Espino, 1999). Bacorehuis Estuary is a shallow lagoon (5 m depth) connected with the Gulf of California through a 13 m length mouth, and is surrounded by sandy barriers and part of the Agiabampo-Bacorehuis-Río Fuerte Antiguo lagoon system. Agriculture (Carrizo & Fuerte-Mayo drainages) and aquaculture activities are developed in its surroundings (Colín-Rangel, 2007). The Lucernilla Cove is a sandy bar between the Ensenada-Pabellones lagoon system and the Gulf of California. Drainages from agricultural activities (Valle de Culiacan) flow into this lagoon system (Cifuentes & Gaxiola, 2003).

Experimental animals

Diploid and triploid Japanese oyster (total n = 21,000; 3,500 for each ploidy and site) were obtained from Centro de Reproducción de Especies Marinas del Estado de Sonora (CREMES) O.P.D. (Sonora, Mexico), and cultivated in trays suspended from a long-line system 0.15 m beneath the water surface. The codes for each cultivation site/ploidy group are reported as follows: GD: Guasave/diploid, GT: Guasave/triploid, AD: Ahome/diploid, AT: Ahome/triploid, ND: Navolato/diploid, NT: Navolato/triploid. Initial shell length (SL) and body weight (BW) were 11.12 mm and 0.54 g for diploids, and 13.13 mm and 0.61 g for triploids. Juvenile oysters were maintained as mentioned by Gallo-García *et al.* (2001); placed in plastic mesh sacks (2 mm diameter) and then located into the trays which were suspended from a long-line system (n = 500 oysters tray^{-1}). When oysters reached 30-40 mm SL, they were placed directly into the trays until reaching the commercial size (≥100 mm). That is, cultivation operations consisted in reducing the density of oyster within the trays in the three first months (June, July and August), from 500 at the beginning to 42 oysters at the end of the cultivation period, when bivalves had reached 40 mm length and placed into the plastic trays. The study started in June 2013 and animals were harvested on April 2014. Epibiotic organisms and mud accumulated in the ropes and trays of the suspended cultivation system were cleaned off with a soft brush and spatula at each sampling month.

Water parameters

Water parameters were recorded every month to obtain temperature and dissolved oxygen (DO) with an oxymeter (YSI 55/12FT, Ohio, USA), salinity with a refractometer (ATAGO, S/Mill), pH by using a pHmeter (Hanna, HI 8314, USA), and depth and transparency with a Secchi disk. At the same time, water samples (2 L) were taken for determinations of

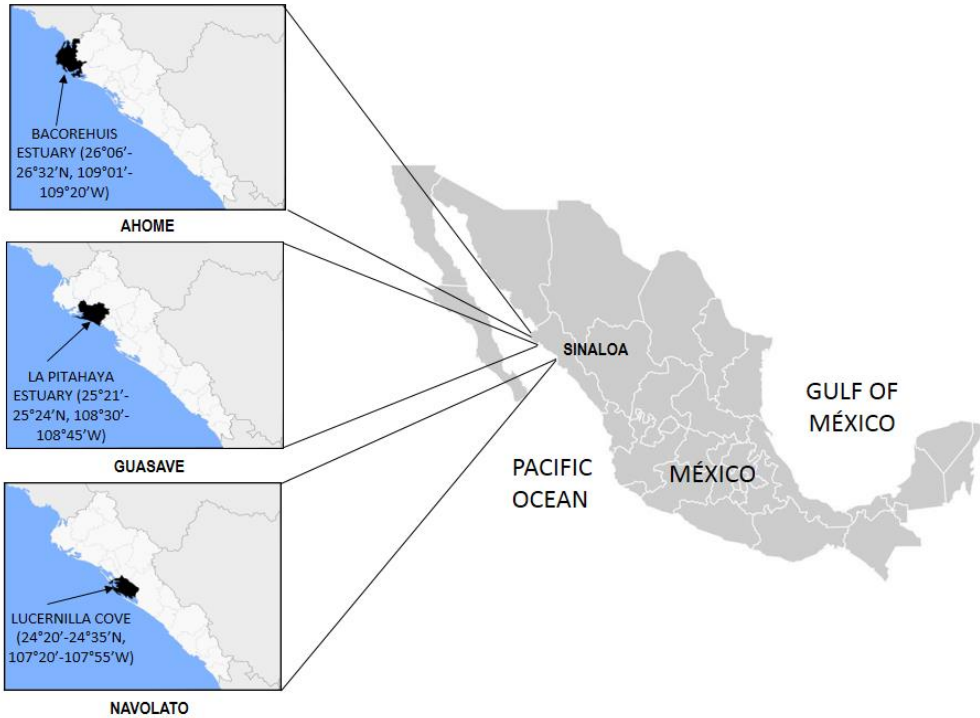

Figure 1. Cultivation sites (La Pitahaya Estuary, Guasave; Bacorehuis Estuary, Ahome and Lucernilla Cove, Navolato) located in Sinaloa, Mexico.

total suspended solids (TSS), particulate organic matter (POM) and chlorophyll-*a* (Chl-*a*). TSS and POM were determined by the gravimetric method (APHA, 1995), while Chl-*a* analysis was performed after filtration with Whatman GF/F filters (0.7 µm pore size) using Millipore vacuum filtration and was determined by standard spectrophotometric methods (Strickland & Parsons, 1972).

Biometrics, survival and condition index

Oyster biometrics and condition index (CI) were performed monthly. Total SL and BW of 50 oysters were measured *in situ* with a Vernier caliper (0.2 mm) and a portable balance (0.00 g), respectively. To determine CI, 30 oysters were cleaned, measured, weighed and sacrificed. Then, the soft tissue and shells of oysters were dried (24 h at 100°C). CI was obtained using the formula described by Chávez-Villalba *et al.* (2008), $CI = P1\times1000/P2$, where P1= dry weight of soft tissue (g), and P2 = dry weight of the shells (g). Survival was calculated by counting dead animals at each sampling and expressed as a percentage of the original number of oysters (Sotelo-González, 2015).

Data analysis

All data set were tested for normality, and statistical tests were chosen accordingly. Comparison of means by one-way analysis of variance (ANOVA) and Tukey's test were monthly performed in shell biometrics, BW and CI of diploids and triploids at each site. Student´s *t*-test was used to test a statistical significant difference between means of growth and survival of ploidies for the same month. Two-factor ANOVA (ploidies and sites) was applied to test interaction of factors in oysters growth. Pearson rank order correlations were computed with biometrics of bivalves, environmental variables and water organic content at each site cultivation and ploidy (Bhujel, 2008). The Statgraphic Plus 5.0 sofware package (Statistical Graphics Corp., Herndon, VA, USA) was used to perform these analyses. The significant level was set at 5%.

A preliminary analysis was conducted to explore the economic assessment of culturing diploid and triploid at the three sites. Exchange rate for all calculations was US\$1 = \$18.00 Mexican pesos. For this purpose, it was considered purchase of new cultivation equipment (trays, ropes, buoys and bottom subjection units), and depreciation rate (20% year^{-1}) was adjusted according to Jolly & Clonts (1993). Farm facilities consists in rustic cabins in the beach as storage and guardhouse, and the long-lines nearby to the coastal shore. Site tenure is given by a concession from government. One cultivation unit consists in seven overlaid plastic trays

(60×60×10 cm) attached to a 200 m length plastic rope (1 inch diameter) at 75-85 cm to each other. Five trays contained the oysters; empty plastic bottles and stones are placed in the upper and lower trays of each cultivation unit for floating and sinking, respectively. Bottom subjection units are built up with cement and metallic ribs (150-200 kg). Employment in oyster farms includes the owner and one partial time employee only, both between 20 to 40 years old. The seed oyster price (US$3.33 and US$4.44/1000 diploid and triploid oysters, respectively) was used and profit was calculated using the production results obtained with the time to reach the commercial size, final survival rates of oysters and the price of *C. gigas* offered at the farm. Typically, oyster is sold according to a farm-gate "basic" price. The price was taken from local farmers (US$2.22/dozen oysters) from which the minimum commercial SL of oyster is established at ≥10 cm. Production characteristics and costs (variable and fixed) were used to estimate the financial performance of each production system (Nasr-Allah *et al*., 2014). It is important to notice that this preliminary analysis was performed with data generated exclusively from the data set originally analyzed in this cultivation cycle (3,500 organisms/ploidy/site), but according to local farmer experience, it is needed to consider an initial stock of 250,000 oysters to start a commercial production. The economic assessment was extrapolated to such amount of oysters pretending to provide an economic framework for comparison of the oyster ploidies in the cultivation sites only.

RESULTS

Environmental conditions

Temperature showed similar pattern at the three sites. The peak values were 32°C for Ahome, 32°C for Guasave, and 30.75°C for Navolato, while the minimum values were 19, 22.2 and 21°C for Ahome, Guasave, and Navolato, respectively. The salinity fluctuations were 40.5-30, 35-31 and 36-32.5 for Ahome, Guasave and Navolato, respectively (Fig. 2). For the DO, the concentration varied from 2.87 mg L^{-1} obtained at Guasave in September, to 8.11 mg L^{-1} recorded at Navolato in Febraury. Chl-*a* concentration fluctuated among the sites. Ahome (0.64 mg m^{-3} in December -10.26 mg m^{-3} in March) and Guasave (1.11 mg m^{-3} in May - 6.43 mg m^{-3} in November) displayed the widest ranges. The pH showed more variation in Navolato than in the other sites, the lowest record was 6 in December with an increasing tendency until August (8.33). TSS showed similar pattern at the three sites, the peak values were 49 mg L^{-1} for Ahome, 58.52 mg L^{-1} for Guasave, and 56.52 mg L^{-1} for Navolato, while the minimum values were 22.21, 25 and 24.36 mg L^{-1} for Ahome, Guasave, and Navolato, respectively. There was one peak in the concentration of POM at each site (20.86 mg L^{-1} at Guasave in January; 20.61 mg L^{-1} at Navolato and 21.63 mg L^{-1} at Ahome, both in December). The lowest POM value (6.18 mg L^{-1}) was registered at Ahome in January. Transparency was similar at the three sites, with the highest value (1.8 m) found at Navolato in September, and the lowest (0.3 m) measured at Ahome in October. Depth differed at the three sites, the peak values were 2 m for Ahome, 2.6 m for Guasave, and 4 m for Navolato, while the minimum values were 0.3, 1 and 3 m for Ahome, Guasave, and Navolato, respectively (Fig. 2).

Growth, survival and CI

Initial SL and BW for diploids and triploids (June 2013) were similar ($P > 0.05$) at each site. Growth in SL and BW was more or less constant for diploid and triploid oysters throughout the study period. Excepting GT, loss in weight was detected in March for the rest of the oysters (Fig. 3). In eleven months, the total SL of diploids increased from 11.12 mm to 96.18, 92.79 and 96.17 mm for GD, ND and AD, respectively, and from 13.13 mm to 90.13, 89.48 and 101.33 mm for the GT, NT and AT triploid groups, respectively.

A similar trend was observed in the BW measurements, for which the total BW of diploids increased from 0.19 to 90.13 g (GD), 89.48 (ND) and 101.33 g (AD), meanwhile, initial BW of triploids (0.24 g) registered an increase to 84.02, 71.56 and 100.15 g for the GT, NT and AT groups, respectively. An analysis of variance showed monthly significant differences for SL and BW during the cultivation period (Table 1).

The growth rate varied from 6.94 mm $month^{-1}$ obtained in the NT group to 8.01 mm $month^{-1}$ found for AT oysters. In the case of BW, the lowest growth rate (5.87 g $month^{-1}$) was presented for the GD organisms, meanwhile, the highest growth rate (9.08 g $month^{-1}$) was obtained for the AT oysters (Table 2). Mortality differed significantly among ploidies and sites (F = 21.46; P = 0.000): 2.28% (GD), 1.4% (GT), 23.31% (AD), 18.6% (AT), 19.2% (ND) and 13.91% (NT) oysters (Fig. 4).

GD and GT oysters showed the lowest mortalities. *C. gigas* cultivated in Ahome presented a decreased in survival for both ploidies from June to August, meanwhile survival of ND and NT oysters decreased from August to October. From October, no mortality was observed in any groups.

The two-factor ANOVA's test indicated a strong effect of site ($P < 0.05$) for the SL during all months of cultivation. Meanwhile, the site and the site-ploidy inte-

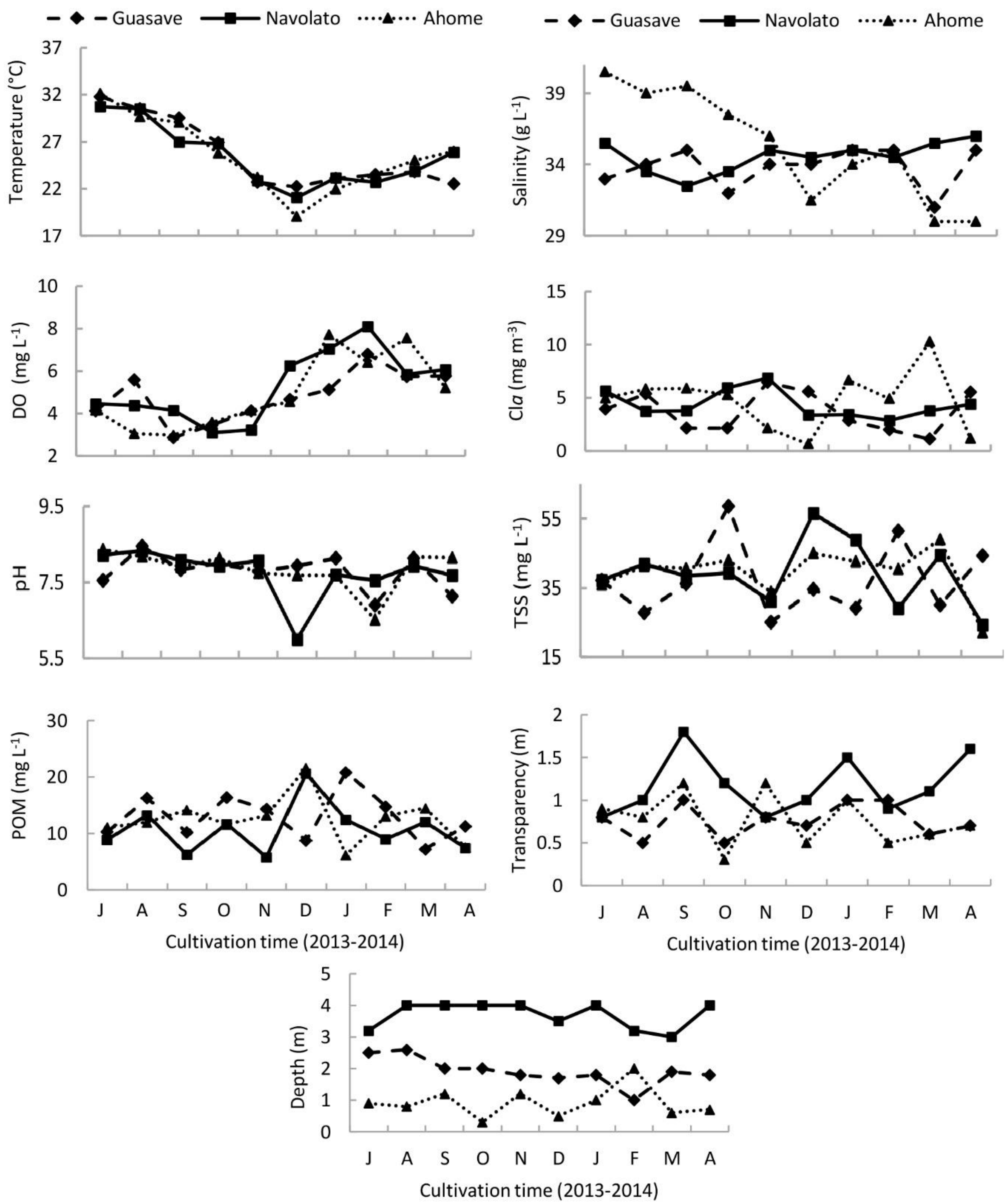

Figure 2. Monthly variation of temperature, salinity, dissolved oxygen (DO), pH, chlorophyll-*a* (Chl-*a*), total suspended solids (TSS), particulate organic matter (POM), transparency and depth at three oyster farms in the Gulf of California.

raction mostly affected BW. Probability data are listed in Table 3.

Pearson rank correlations for oyster biometrics, organic content in water and environmental variables for each ploidy-site combination showed a strong correlation ($r > 0.95$) between SL and BW at the three sites (Table 4). Water temperature was negatively correlated with SL and BW for the oysters cultivated at Guasave and Navolato sites ranging from $r = -0.6523$ with the SL of GD, to $r = -0.8060$ with SL of GT. Only

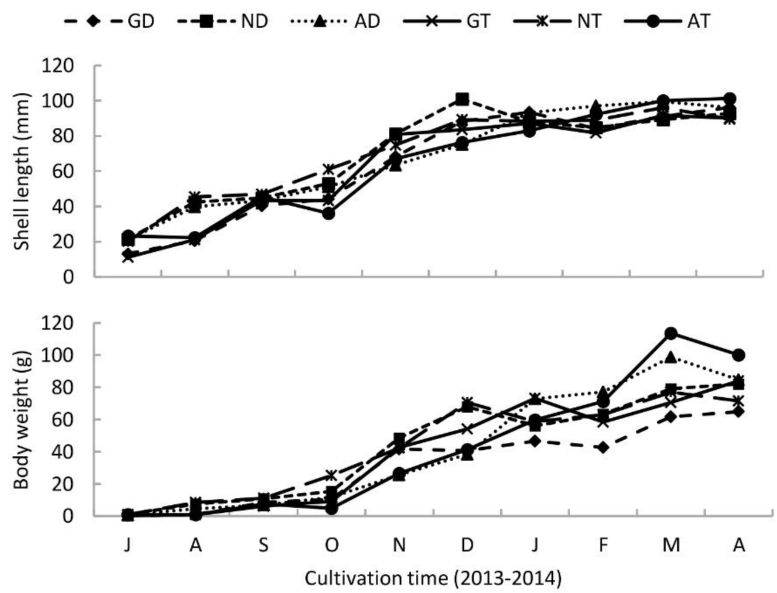

Figure 3. Monthly shell length (SL, mm) and body weight (BW, g) of diploid and triploid *Crassostrea gigas* cultivated at three sites (GD: Guasave/diploid, ND: Navolato/diploid, AD: Ahome diploid, GT: Guasave/triploid, NT: Navolato/triploid, AT: Ahome/triplod), in Sinaloa, Mexico.

for organisms at Navolato, Chl-*a*, MOP and SST concentrations were correlated to each other.

The ANOVA test practiced to CI showed similarities ($F = 0.91$, $P = 0.47$) among the ploidies with peak values of 64.31, 63.96, 43.88, 49.40, 50.34, and 49.65 for ND, NT, GD, GT, AD, and AT groups, respectively (Fig. 5). Oyster from the three sites displayed the first CI peak value after four cultivation months (October).

Oyster production characteristics

Production characteristics for rearing diploid and triploid oysters at the three sites are listed in Table 5. The overall production costs for an initial production cycle indicated that more than 80% of the variable costs represent the purchase of trays, ropes, flotation and bottom subjection units, meanwhile, salaries contributed with around 9%. From the total costs, fixed costs were below 2%. Total costs (Table 6) fluctuated from US$37,141.05 for the GD site, to US$38,319.60 obtained for the NT farm. The higher profits were registered for both ploidies from the Guasave farm (US$8,053.71 for GD and US$8,182.19 for GT). After ten cultivation months, the ND (US$-1,009.22) and AD (US$-2,125.76) farms obtained negative profit (Table 7).

DISCUSSION

Growth rate is the most utilized criteria for comparing oyster performance. Compared with the mean daily growth rates for the SL (0.268-0.279 mm day^{-1}) and BW (0.19-0.3 g day $^{-1}$) of *C. gigas* in this study, Góngora-Gómez *et al.* (2012) and Gallo-García *et al.* (2001) reported higher values (0.502 mm day^{-1} and 0.427 g day^{-1}, and 0.473 mm day^{-1} and 0.345 g day^{-1}, respectively) in locations of the Pacific coast of Mexico, but our values were similar than that reported by Cáceres-Martínez & García-Bustamante (1990) of 0.232 mm day^{-1} and 0.314 g day^{-1}, and better than those reported by Cáceres-Martínez *et al.* (1988) of 0.245 mm day^{-1} and 0.07 g day $^{-1}$, and Martínez-Córdova & Robles (1990) of 0.324 mm day^{-1} and 0.062 g day^{-1}, rearing the same oyster species in the Gulf of California. Under similar cultivation technique (long-line), our growth rate values considering body weight (BW) (0.19-0.30 g day $^{-1}$) were higher than those reported by Boudry *et al.* (2003) in the Atlantic coast of France (0.047-0.175 g day^{-1}), and Pieterse *et al.* (2012) for an oyster cohort from US at two sites in South Africa (0.173 and 0.037 g day $^{-1}$). Also, the final growth rates for BW obtained here were two to three times higher than those using intertidal cultivation method in Portugal (0.098 g day^{-1}; Batista *et al.*, 2007) and at different locations of the coast of France (0.046-0.083 g day^{-1}, Soletchnik *et al.*, 2002; 0.178 g day^{-1}, Dégremont *et al.*, 2005). Higher growth rates than ours were obtained in South Africa (Pieterse *et al.*, 2012) but rearing oyster cohorts from Chile (0.298-0.58 g day $^{-1}$). Differences in results are attributed to the location, culture system, time and management, among other factors.

Table 1. Mean monthly values of shell length (SL) and body weight (BW) of diploid and triploid oysters *Crassostrea gigas* during 10 months of cultivation at three sites (Guasave, Navolato, Ahome) of the Gulf of California. *GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triploid, *F*: Fisher test. †Monthly significant differences among groups for each biometric index (SL or BW) are indicated with different superscript letters ($P < 0.05$). Values in parenthesis: Standard deviation.

	SL (mm)							BW (g)						
	GD*	GT	ND	NT	AD	AT	*F*	GD	GT	ND	NT	AD	AT	*F*
July 2013	11.12^{a†}	13.14^{b}	21.35^{c}	20.09^{c}	21.06^{c}	23.31^{d}	66.16	0.19^{a}	0.25^{a}	0.99^{c}	0.86^{c}	0.62^{b}	0.99^{c}	36.23
	(3.08)	(3.27)	(4.76)	(4.38)	(4.16)	(5.69)		(0.12)	(0.16)	(0.56)	(0.53)	(0.33)	(0.55)	
August	21.08^{ab}	20.45^{a}	42.55^{d}	45.41^{e}	39.73^{c}	22.26^{b}	451.64	0.96^{a}	0.80^{a}	7.32^{c}	8.44^{d}	4.61^{b}	0.86^{a}	315.67
	(2.52)	(2.71)	(4.66)	(5.34)	(4.69)	(2.59)		(0.31)	(0.31)	(1.88)	(2.36)	(1.43)	(0.22)	
September	43.21^{b}	40.23^{a}	44.86^{bc}	46.83^{d}	43.28^{bc}	45.48^{cd}	7.98	8.50^{c}	6.21^{a}	10.61^{d}	10.98^{d}	6.88^{ab}	7.31^{b}	32.37
	(4.17)	(4.36)	^{d} (7.05)	(7.37)	(4.18)	(6.27)		(1.98)	(1.57)	(3.26)	(3.46)	(1.90)	(2.01)	
October	43.37^{b}	44.25^{b}	53.06^{c}	61.08^{d}	51.20^{c}	36.06^{a}	93.63	10.55^{ab}	9.15^{a}	15.45^{d}	25.15^{e}	11.62^{c}	14.85^{d}	72.89
	(5.01)	(5.72)	(8.88)	(6.67)	(6.25)	(5.10)		(2.06)	(2.71)	(5.51)	(5.47)	(3.16)	(1.44)	
November	68.40^{a}	68.36^{b}	81.25^{d}	74.72^{c}	63.38^{a}	67.00^{b}	25.19	25.90^{a}	30.02^{b}	48.52^{d}	42.42^{c}	25.50^{a}	26.48^{a}	67.67
	(10.81)	(9.26)	(10.43)	(7.12)	(8.24)	(7.65)		(4.53)	(7.38)	(14.80)	(8.97)	(4.77)	(5.85)	
December	83.65^{b}	88.27^{d}	100.91^{e}	89.20^{d}	75.17^{a}	76.32^{a}	54.36	40.62^{a}	54.27^{b}	67.79^{c}	70.50^{c}	38.30^{a}	41.45^{a}	70.87
	(8.15)	(10.43)	(10.62)	(9.25)	(7.42)	(8.29)		(7.06)	(16.11)	(11.49)	(16.17)	(10.86)	(6.80)	
Jan. 2014	87.24^{b}	93.33^{c}	88.13^{b}	88.28^{b}	93.19^{c}	82.97^{a}	11.38	46.61^{a}	73.08^{c}	56.17^{b}	58.66^{b}	72.86^{c}	59.86^{b}	29.51
	(8.37)	(11.06)	(7.27)	(7.62)	(8.20)	(6.74)		(9.82)	(20.27)	(11.21)	(12.85)	(11.29)	(11.74)	
February	81.83^{a}	84.00^{a}	84.67^{a}	88.98^{b}	97.02^{d}	92.32^{c}	23.54	42.51^{a}	58.55^{b}	63.48^{c}	63.03^{c}	77.05^{e}	71.09^{d}	56.21
	(7.58)	(9.02)	(6.46)	(6.84)	(10.36)	(9.39)		(7.90)	(10.33)	(7.46)	(10.29)	(13.05)	(15.73)	
March	91.64^{a}	90.94^{a}	89.16^{a}	96.07^{b}	99.49^{bc}	100.16^{c}	11.11	61.85^{a}	70.44^{b}	79.04^{c}	76.98^{c}	98.82^{d}	113.63^{e}	90.28
	(10.10)	(8.14)	(15.01)	(9.06)	(7.18)	(7.72)		(12.02)	(10.29)	(13.13)	(12.87)	(17.41)	(18.25)	
April	90.13^{a}	96.18^{b}	92.79^{ab}	89.48^{a}	96.17^{b}	101.33^{c}	11.96	64.84^{a}	84.02^{c}	82.11^{c}	71.56^{b}	84.75^{c}	100.15^{d}	87.25
	(7.21)	(10.12)	(8.75)	(7.00)	(11.06)	(9.77)		(10.19)	(20.99)	(14.11)	(10.45)	(15.96)	(18.04)	

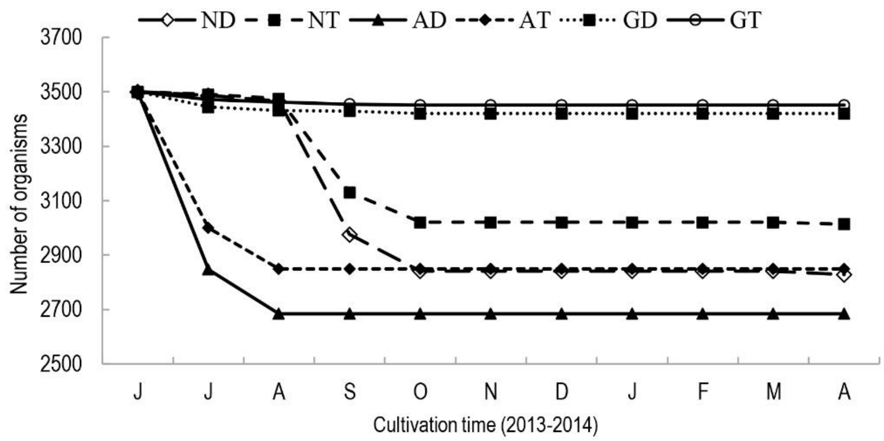

Figure 4. Survival (number of organisms) of diploid and triploid *Crassostrea gigas* cultivated at three sites (ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triplod, GD: Guasave/diploid, GT: Guasave/triploid), in Sinaloa, Mexico.

Table 2. Final growth rates for shell length (SL) and body weight (BW) of diploid and triploid oysters *Crassostrea gigas* after 10 months of cultivation at three sites (Guasave, Navolato, Ahme) of the Gulf of California. GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/ diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triploid.

	GD	GT	ND	NT	AD	AT
SL (mm month^{-1})	7.18	7.55	7.24	6.94	7.73	8.01
BW (g month^{-1})	5.87	7.61	7.44	6.48	7.68	9.08

It is important to highlight that there is limited information in Mexico about performance of triploids oysters, as well as comparisons with diploid organisms during cultivation. Thus, this study represents valuable data to support new production strategies in oyster culture not only for the Mexican Pacific coast, but also for the Latin America oyster industry. Growth rate has also been compared between diploid and triploid *C. gigas* oysters in different countries. Growth rates for diploid (0.158 g day^{-1}) and triploid (0.3 g day^{-1}) oysters evaluated by Akashige & Fushimi (1992) in Japan during eight cultivation months were similar than those obtained by Maguire *et al.* (1994) in Australia (0.11 and 0.32 g day^{-1} for diploid and triploid, respectively) after 27 months of cultivation, but higher compared with diploids (0.079 g day^{-1}) and triploids (0.084 g day^{-1}) reared in Tazmania during 42 months (Maguire *et al.*, 1994). The mean growth rate for the diploid (0.22 g day^{-1}) reared at the three sites in the present study is higher than the diploids from the aforementioned works, but the increase in daily BW was lower when comparing those triploid growth rate with our triploids mean value (0.25 g day^{-1}). Daily weight gain of triploid *C. gigas* oysters at each study above mentioned was higher than values for diploids, however. Differences in growth results can be explained by the influence and/or interaction of several factors such as oyster origin (Pieterse *et al.*, 2012), water temperature (Malouf & Breese, 1977), currents, tides (Ngo *et al.*, 2009), phytoplankton diversity and abundance (Cognie *et al.*, 2001), particulate organic matter, depth and cultivation method (Wilson-Ormond *et al.*, 1997), among others.

Monthly SL and BW were different among the ploidy/site groups and probability values (Table 3) indicate that environment influenced growth rate to a greater extent than oyster ploidy or their interaction. Body weight curves show slow growth from June to October, probably due to the high water temperature at the three sites (>25°C). On other hand, the higher mortality values for all groups were observed in the same time period. It is well documented that summer mortality of Pacific oyster are associated to water temperature exceeding 20°C (Costil *et al.*, 2005; Gagnaire *et al.*, 2006) that in many cases, promote favorable conditions for pathogens as well (Enríquez-Espinoza *et al.*, 2010). Therefore, it is possible assume that BW and survival of diploid and triploid oyster were strongly affected for the high water temperature during the first five cultivation months (summer).

The condition index of oysters represents an important tool to estimate meat quality and yield in cultured bivalve mollusks, and can be affected by multiple abiotic and biotic factors (Rebelo *et al.*, 2005). Despite of the advantages (improved meat quality and superior growth) pointed out by Guo *et al.* (1996) for triploid oysters, no differences in the CI were detected among the *C. gigas* populations cultivated at the three sites. Thus, the use of CI in this study does not allow to properly conclude.

Table 3. Probability values associated with the influence of the site (A), ploidy (B) and the combined effect of both factors (AB) on monthly shell length (SL) and body weight (BW) of diploid and triploid *Crassostrea gigas* cultivated at three sites (Guasave, Navolato, Ahome) of the Gulf of California (Two-factor ANOVA, $P < 0.05$). Numbers in italics indicate no effect on studied factors.

	SL			BW		
	A	B	AB	A	B	AB
July 2013	0.0000	0.0450	0.0060	0.0000	*0.0502*	0.0002
August	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
September	0.0000	*0.5468*	0.0017	0.0000	*0.0833*	0.0000
October	0.0000	0.0051	0.0000	0.0000	*0.2386*	0.0000
November	0.0411	*0.2309*	*0.2994*	0.0000	*0.7332*	0.0000
December	0.0000	*0.0609*	0.0000	0.0000	0.0000	0.0015
January 2014	*0.1011*	*0.1516*	0.0000	0.0000	0.0006	0.0000
February	0.0000	*0.5392*	0.0004	0.0000	0.0133	0.0000
March	0.0000	0.0456	0.0157	0.0000	0.0000	0.0001
April	0.0000	0.0128	0.0004	0.0000	0.0000	0.0000

Table 4. Pearson correlations (r) for shell length (SL), body weight (BW) and survival on diploid and triploid oysters *Crassostrea gigas* with environmental parameters as temperature (T°C), depth, pH, chlorophyll-*a* (Chl-*a*), total suspended solids (TSS), particulate organic matter (POM), salinity, dissolved oxygen (OD) and transparency in the study sites (Guasave, Navolato, Ahome). Only significant correlations ($P < 0.05$) are showed. GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triploid.

	GD	GT	ND	NT	AD	AT
SL *vs* BW	0.9515	0.9876	0.9515	1.0000	0.9878	0.9878
SL *vs* T°C	-0.7333	-0.8060	-0.7696	-0.6969		
SL *vs* Depth	-0.6523	-0.7016				
SL *vs* pH			-0.8693	-0.7841		
SL *vs* Salinity					-0.8936	-0.8875
SL. *vs* DO					0.7939	0.7696
BW *vs* T°C	-0.7090	-0.7575	-0.6848	-0.6969		
BW *vs* Depth	-0.6646	-0.7139				
BW *vs* pH			-0.8145	-0.7841		
BW *vs* Salinity					-0.9361	-0.8875
BW *vs* DO					0.7818	0.7939
T°C *vs* Depth	0.8493	0.8493				
T°C *vs* pH			0.8206	0.8206	0.6363	0.6363
Sal. *vs* transparency	0.6894	0.6894				
Salinity *vs* DO					-0.7355	-0.7355
pH *vs* DO			-0.6808	-0.6808		
DO *vs* Chl-*a*			-0.8181	-0.8181		
Chl-*a* *vs* POM			-0.6484	-0.6484		
POM *vs* TSS			0.8060	0.8060		
Survival *vs* Salinity					0.6637	0.6637
Survival *vs* SL	-0.8127	-0.8127	-0.8398	-0.8398		
Survival *vs* BW	-0.8127	-0.8127	-0.8876	-0.8398		
Survival *vs* T°C	0.8127	0.8127	0.6468	0.6468		
Survival *vs* pH			0.7807	0.7807		
Survival *vs* Depth	0.7799	0.7799				

Food sources (Chl-*a*, POM and TSS) were not correlated with biometrics of *C. gigas* in all sites. The mean Chl-*a* level found in this work (4.28 mg m^{-3}) was similar to that reported by Chávez-Villalba *et al.* (2007) culturing oysters in the Gulf of California, but POM concentration was lower. As mentioned by Brown (1988) and Lodeiros & Himmelman (1999), the Chl-*a* concentration is one of the main factors that influence

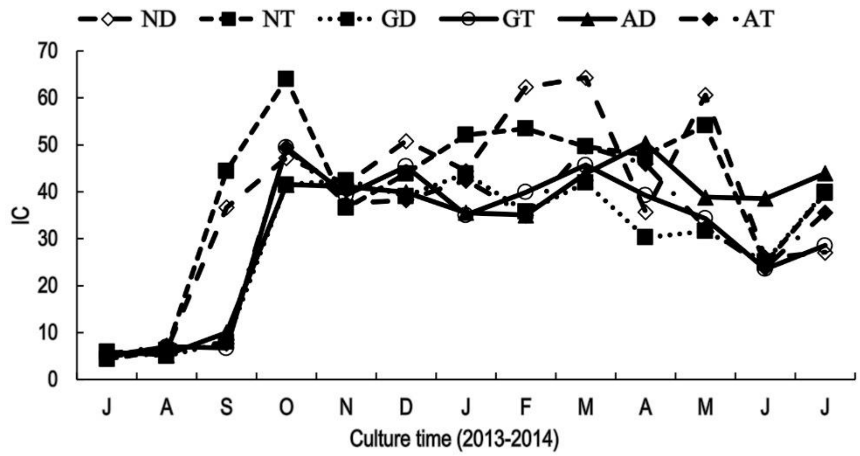

Figure 5. Condition index (CI) of diploid and triploid *Crassostrea gigas* cultivated at three sites (ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome triplod, GD: Guasave diploid, GT: Guasave triploid), in Sinaloa, Mexico.

Table 5. Summary of production characteristics for culturing diploid and triploid *Crassostrea gigas* (n = 250,000 seeds each) in farms located at Guasave, Navolato and Ahome, Sinaloa, Mexico. GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/diploid, NT: Navolato/triploid, AD : Ahome/diploid, AT: Ahome/triploid.

	GD	GT	ND	NT	AD	AT
Land ownership						
Concession	X	X	X	X	X	X
Production facility						
Number of longlines	3	3	3	3	3	3
Number of cultivation units/longline	300	300	300	300	300	300
Number of trays/longline	2,100	2,100	2,100	2,100	2,100	2,100
Flotation units/longline	21	21	21	21	21	21
Bottom subjection units/longline	10	10	10	10	10	10
Rope (m)/longline	200	200	200	200	200	200
Fuel (L week^{-1})	0	0	25	25	0	0
Average initial shell length (mm)	11.12 ± 0.54	13.13 ± 0.61	11.12 ± 0.54	13.13 ± 0.61	11.12 ± 0.54	13.13 ± 0.61
Average final shell length (mm)	90.13 ± 7.21	96.18 ± 10.12	92.79 ± 8.75	89.48 ± 7.00	96.17 ± 11.06	101.33 ± 9.77
Stocking density/tray (initial/final)	500/50	500/50	500/50	500/50	500/50	500/50
Growth rate (g month^{-1})	5.87	7.61	7.44	6.48	7.68	9.08
Cultivation period (months)	10	10	10	10	10	10
Survival (%)	97.72	98.6	80.8	86.09	76.69	81.4
Full time jobs	1	1	1	1	1	1
Partial time jobs	1	1	1	1	1	1

growth in bivalves. The Chl-*a* concentration measured at Ahome farm displayed a seasonal pattern with a peak in March, but the higher peaks for Guasave and Navolato localities were observed in November. There was no correlation between POM and Chl-*a*, which suggests that most of particulate organic material was composed of organic detritus derived mostly from agriculture and aquaculture drainages, instead of phytoplankton (Toro *et al.*, 1999). Variations in phytoplankton biomass (expressed as Chl-*a* level), POM and TSS, could partially be associated with the diverse amount and type of nutrient material flowing from inland human activities to the cultivation sites (Ruíz-Luna & de la Lanza-Espino, 1999). Barillé *et al.* (1997) mention that *C. gigas* has the capacity to select food depending on its abundance as a feeding mechanism, which could partially explain the oyster growth. The salinity drop in December and March presented in Ahome and Guasave farms was possibly caused by a dilution effect from agriculture and aquaculture drainages combined with the mean shallow depth at both places. However, it never fell below 29 during the cultivation time, well over the minimum required for growth oyster (Korringa, 1976), and no correlation between salinity with Chl-*a*, POM and TSS was found. Depth variation depended of the farm location, previously chosen by the farmer.

In this study, environment variables influenced growth rate and survival to a much greater extent than oyster ploidy. It is also relevant to potential oyster far-

Table 6. Production costs for culturing diploid and triploid *Crassostrea gigas* (n = 250,000 seeds each) in farms located at Guasave, Navolato and Ahome, Sinaloa, Mexico. GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triploid. *1 full time equivalent job (US$6.66 day^{-1}), 1 partial time equivalent job (US$4.44 day^{-1}). **Buckets, soft brushes, spatulas, etc., ***Two meals a day (US$3.33 each), ****Drinkable water.

Item	GD		GT		ND		NT		AD		AT	
	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%
Variable costs (US$/250,000 seed)												
Oyster seed	833.33	2.2794	1,111.11	3.0163	833.33	2.2319	1,111.11	2.9539	833.33	2.2794	1,111.11	3.0163
Trays	28,000	76.5888	28,000	76.0112	28,000	74.9933	28,000	74.4395	28,000	75.5888	28,000	76.0112
Flotation units	555.55	1.5196	555.55	1.5081	555.55	1.4879	555.55	1.4769	555.55	1.5196	555.55	1.5081
Bottom subjection units and ropes	1,666.66	4.5588	1,666.66	4.5244	1,666.66	4.4638	1,666.66	4.4309	1,666.66	4.5588	1,666.66	4.5244
Fuel	0	0	0	0	777.77	2.0831	777.77	2.0677	0	0	0	0
Salaries*	3,333.33	9.1177	3,333.33	9.0489	3,333.33	8.9277	3,333.33	8.8618	3,333.33	9.1177	3,333.33	9.0489
Repairs and maintenance**	50	0.1367	50	0.1357	50	0.1339	50	0.1329	50	0.1367	50	0.1357
Food and drinks***	2000	5.4706	2000	5.4293	2000	5.3566	2000	5.3171	2000	5.4706	2000	5.4293
Other expenses****	120	0.3282	120	0.3257	120	0.3214	120	0.3190	120	0.3282	120	0.3257
Total variable costs	36,558.87	98.4325	36,836.65	98.4441	37,336.64	98.1463	37,614.42	98.1597	36,558.87	98.07	36,836.65	98.0925
Fixed costs												
Concession (annual fee)	13.88	2.3841	13.88	2.3841	13.88	1.9682	13.88	1.9682	13.88	1.9377	13.88	1.9377
Depreciation (20% year^{-1})	335.80	57.6797	335.80	57.6797	335.80	47.6190	335.80	47.6190	335.80	46.8804	335.80	46.8804
Electricity	180	30.9182	180	30.9182	300	42.5423	300	42.5423	311.11	43.4335	311.11	43.4335
Telephone	55.5	9.5331	55.5	9.5331	55.5	7.8703	55.5	7.8703	55.5	7.7482	55.5	7.7482
Total fixed costs	582.18	1.5674	582.18	1.5558	705.18	1.8536	705.18	1.8402	716.29	1.9216	716.29	1.9074
Total costs	37,141.05	100	37,418.83	100	38,041.82	100	38,319.60	100	37,275.16	100	37,552.94	100

Table 7. Financial performance for culturing diploid and triploid *Crassostrea gigas* (n: 250,000 seeds each) in farms located in Guasave, Navolato and Ahome (Sinaloa, Mexico). GD: Guasave/diploid, GT: Guasave/triploid, ND: Navolato/diploid, NT: Navolato/triploid, AD: Ahome/diploid, AT: Ahome/triploid.

Item	GD	GT	ND	NT	AD	AT
Survival (%)	97.72	98.6	80.8	86.09	76.69	81.4
Total of oysters	244,300	246,500	202,000	215,225	191,725	203,500
Dozens	20,358	20,541	16,833	17,935	15,977	16,958
Sale by dozen (US$2.22)	45,194.76	45,601.02	37,032.60	39,815.70	35,149.40	37,646.76
Total costs	37,141.05	37,418.83	38,041.82	38,319.60	37,275.16	37,552.94
Net profit	8,053.71	8,182.19	-1,009.22	1,496.10	-2,125.76	93.82
Net profit as % of sales	21.68	21.86	-2.62	3.90	-5.70	0.24

mers the understanding of the economic characteristics and analysis of their business in order to identify profitability and financial tools (Jolly & Clonts, 1993). So far, there is no available information on economic performance of oyster production at commercial level in the region.

Except for average final size, growth rate, survival and fuel, all production characteristics for culturing diploid and triploid oysters were the same. The long-line cultivation method used in the present study has been proven along the Pacific coast of Mexico (Gallo-García *et al.*, 2001; Chávez-Villalba *et al.*, 2007; Góngora-Gómez *et al.*, 2012). For cleaning the long-lines and animals, paddle transport ships was used in Guasave and Ahome meanwhile an outboard motor boat in Navolato. Gallo-García *et al.* (2004) pointed out on the importance to regularly clean the oysters to avoid mortality by removing of mud and buried worm larvae from its shells. However, survival was affected mostly by the high water temperature at the beginning of the growing season rather than epibionts. In our case, the timing of production seed from the local commercial hatchery did not coincides with the beginning of the oyster on-growing cycle, when water temperature start to decrease, which prolonged the cultivation four months more than usual in the region (Góngora-Gómez *et al.*, 2012).

The initial density (3,500 oysters per ploidy at each site) was low to perform an adequate financial assessment; therefore, the obtained data was extrapolated to a farm with a target density of 250,000 seeds based on the opinion of local oyster producers to get profit. *C. gigas* seed prices from the local hatchery were US$3.33/1,000 for diploid, and US$4.44/1,000 for triploid, which represents 33.4 and 11.2% lower than the price reported by Rhodes *et al.* (2016) for *C. virginica*. In the locations studied, the product is directly sold at the farm by dozens, equivalent to 18 cents per oyster, which is 72.3% cheaper than the individual price reported by Rhodes *et al.* (2016) for *C. virginica* at the northeastern coast of $US. So far, production and marketing strategies are most likely determined by local market. Most traders simply act as middle men, buying the oyster by dozen from the farm and selling them more expensive to small seafood stores and restaurants to finally, be offered to customers at 55 cents each.

On average, around 81% of variable costs were allocated to trays, ropes, flotation and bottom subjection units, while salaries was 9%. Total fixed costs averaged 1.7%. For the first production year, total variable costs averaged 98.2% of total costs since all equipment is considered new. From the second year onwards, total costs should be strongly reduced allowing a higher profit for all farms, no matter the oyster ploidy used. Considering the final density and SL (≥100 mm) as commercial size indicators, the revenue from sales was higher in GD and GT compared to the rest of sites, representing around 21% of sales revenues. Nevertheless, animals from Guasave and Navolato farms were around 18.5% thin than those from the Ahome site.

In conclusion, specific environment conditions of the cultivation sites influenced growth rate and survival to a much greater extent than oyster ploidy. The average initial stocking density of 250,000 small oysters assumed by this study seems to be more profitable for the Guasave farm during the first production cycle (11 months). Based on the commercial assumptions and marketing strategies in the present study, it is recommended the use of diploids starting the cultivation cycle on October-November to improve its survival and final net income. However, the use of triploid oysters should be seriously considered since being sterile, they do not come into a spawning condition during summer retaining their marketability all year round, and at same time, promote biodiversity by reducing genetic pollution.

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