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RESEARCH ARTICLE

AQUACULTURE IN MOROCCO: GROWTH PERFORMANCE OF CRASSOSTREA GIGAS IN TWO LAGOONS ON THE ATLANTIC SHORE

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Abstract

Marine aquaculture was introduced in Morocco in the 1950s and has since known little development. Oyster farming was initiated in the lagoon of Oualidia and currently constitutes 72% of Moroccan aquaculture production. For this study the pacific oyster *Crassostrea gigas* was grown using rack-and-bag culture at two sites; Oualidia lagoon and Sidi Moussa lagoon, a potential new aquaculture site, both situated on the Atlantic Moroccan shore.

The aim of this study was to examine the growth performance, condition and survival rates of the pacific oyster grown in the two lagoons. Samples were taken at a monthly frequency. Growth rates, condition and mortality were investigated in both sites from August 2014 to July 2015. Temperature, Salinity, Total Suspended Solids in the water, Nitrates and Phosphates were monitored at both sites at the same time.

Results show that at the end of the experiment, significantly greater length was observed for oysters reared at SM reaching an average of (123.2 mm). Dry weight of oysters at OA were significantly lower compared to oysters reared at SM from February to July 2015, the maximum dry weight observed at the end of the experiment was (4.73g) at OA and (5.95g) at SM. The Condition index ranged from 3.19 to 8.97 and from 4.04 to 7.62 at OA and SM respectively. Cumulative mortality recorded in SM was significantly lower than in OA. The good growth performance and the high survival of the Pacific oyster lead to the conclusion that the lagoon of Sidi Moussa can be a new potential site for aquaculture production.

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Introduction:-

Aquaculture production plays an important role to meet the continuously increasing global demand for aquatic Products. In Morocco, the Pacific oyster is the largest cultured species in terms of tonnage, currently constituting 72% of marine aquaculture production (FAO 2018). The choice of *Crassostrea gigas* (Thunberg, 1793), as is worldwide, is due to its efficiency as filter feeders, its fast growth rate and its tolerance to a wide range of physical

conditions, such as temperature, salinity and silt load in the water (Quayle, 1969; Bardash et al., 1972; Shpigel and Blaylock, 1991).

The oyster production in marine systems mainly occurs in protected areas or embayment of the coastal sea (Buck et al., 2003; Firestone et al., 2004), however sanitary problems and industrial pollution increased in the last decade at these sites due to increased anthropogenic activities. Such is the case of Oualidia lagoon following the expansion of the Oualidia city and its prospering touristic activity. The Oualidia lagoon and the Dakhla bay, both situated on the Atlantic shore, are the main areas of production due to the ease of farm installation and management, and food source availability.

According to fisheries plan “**Halieutis**” aiming to promote aquaculture at a national level, the lagoon of Sidi Moussa situated 30 km north of Oualidia, is recently identified as a potential site for aquaculture. The Sidi Moussa Lagoon (Moroccan Atlantic Coast) is an invaluable wetland, though agricultural activities and grazing on the edge of the lagoon intensified in the recent years. In addition to fishing and salt exploitation, shellfish harvesting is the major activity of the Sidi Moussa lagoon. Local fishmongers recorded an annual production of around 27 tonnes in the case of *Ruditapes deccusatus* (Rafik, 1991).

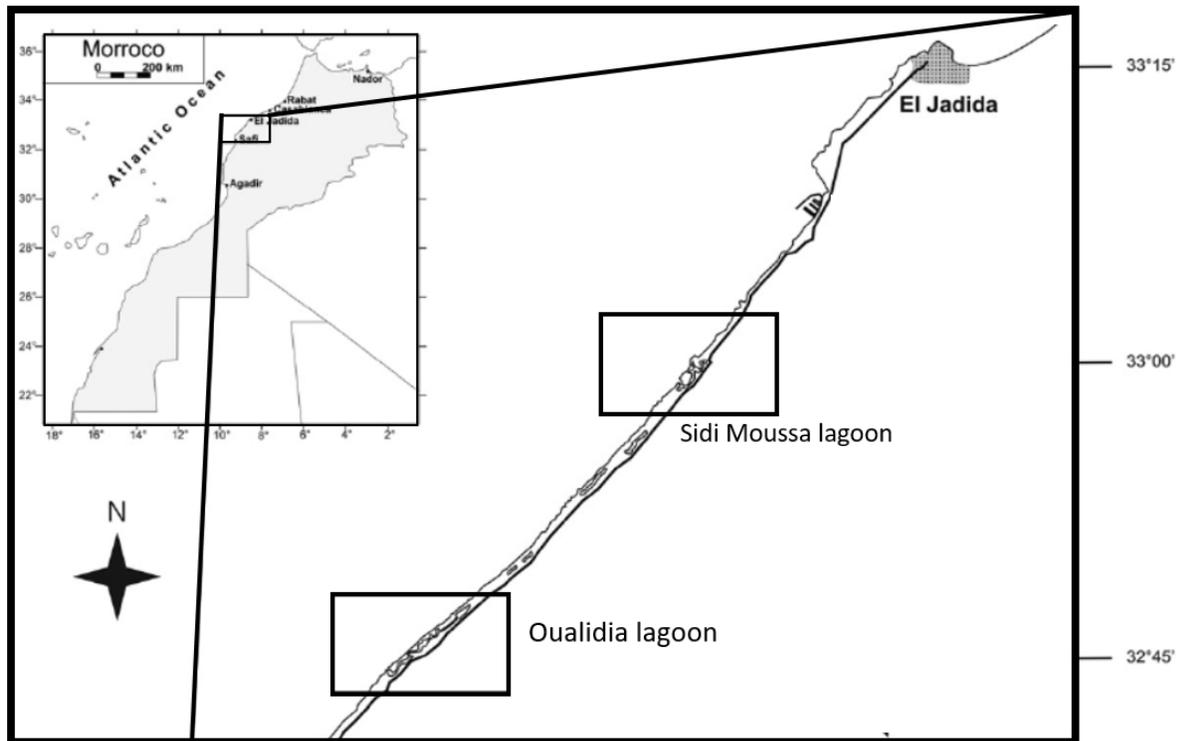
At present, no information is available on growth performance of oysters farmed in other sites than Oualidia and Dakhla. From the biological perspective, this study aims to assess whether oyster cultivation in Sidi Moussa offers a promising potential regarding growth performance. This is the first study focusing on cultivation and performance characteristics of the Pacific oyster (*C. gigas*), reared in Sidi Moussa and in comparison to those reared in Oualidia lagoon. From August 2014 to July 2015 we examined growth performance, condition and mortality of oysters in both sites and also analyzed site-specific criteria for the cultivation at Sidi Moussa. Water Temperature, Salinity, Total Suspended Solids, Nitrates and Phosphates were also measured since local variations in water quality affect the life cycle and reproduction of oysters in coastal areas (Héral et al., 1984; Héral et al., 1987; Brown and Hartwick, 1988).

Materials and Method:-

Study sites

Oualidia-Sidi Moussa is a laguna complex located on the Atlantic Moroccan coast, consisting of 2 lagoons, 4 swamps and 7 salines. The complex is among the most important Moroccan wetlands and is characterized by a rich biodiversity and a diversified avifauna (El Hamoumi et al., 2000; El Hamoumi & Dakki, 2010). It is classified as a Ramsar Site, a Site of Biological and Ecological Interest (SIBE) and Important Area for Bird Conservation (IBA).

Fig. 1:-Map of cultivations sites (Oualidia and Sidi Moussa lagoons)



The Oualidia lagoon (7 km long and ~ 0.5 km wide) is located on the Atlantic ocean between 32° 40'42" N-32°47'07" N and 8°52'30" W-9°02'0 50" W (Fig. 1). The water renewal is done through a major inlet (~ 150 m wide and ~ 2 m deep). At spring tides there is also a minor shallower inlet ~ 50 m wide. The lagoon morphology is characterized by several channels connected to a main channel (2-5 m in depth) (Bidet and Carruesco, 1982). During summer times, Oualidia lagoon is particularly subject to intense tourism activities. Discharging farm and domestic sewage water cause increasing in heavy metal contamination in Oualidia lagoon (Zourarah et al., 2007).

The Sidi Moussa lagoon (5.5 km long and ~0.5 km wide) is also located on the Atlantic ocean (32°59'49" N, W8°44'13" W) (Fig. 1). The lagoon morphology of Sidi Moussa is also characterized by several narrow dendritic channels connected to the main channel (~ 5 km long, ~300 m wide, and 5-6 m deep) (Maanan, 2003; Khoukhouchi et al., 2018). The predominant wind directions in both lagoons shift between WSW-NW (wet season) and NNE-NE (dry season). The sporadic and violent winds "Chergui" occasionally blow from ENE in dry season may contribute to high evaporation rates over both lagoons, as well as to extreme air temperatures up to 40° C. The winds blowing from the northern sector will produce southerly geotropic currents along the coast, offshore transport and coastal upwelling of nutrient-rich deep waters close to the coast. The region is classified in the semi-arid stage, but the lagoon has a Mediterranean climate linked to an oceanic shade (Atillah, 1994). The tidal regime at the lagoon level is of the semi-diurnal type with two full seas and two low seas every 25 hours with a tidal range of between 2 and 4 m (Hilmi et al., 2002).

Experimental design and sampling

A batch of 4,000 spat (1.0 ± 0.1 mm) of *Crassostrea gigas* imported from France were reared in Oualidia lagoon (April-July 2014) until they reached the average length of 30-40 mm. 2000 oysters were then placed (August 2014- July 2015) at each locations; Oualidia lagoon: (OA) and Sidi Moussa lagoon: (SM) and reared in the same manner as commercially-grown oysters. Cage density was around 250 juveniles, placed on metal trestles 1m off the bottom. The cages were exposed during low tide at both sites.

30 oysters were randomly hand collected at low tide every month (August 2014- July 2015) from each site and the mortalities were recorded. Maintenance was performed by cleaning or replacing trays. To remove encrusting

organisms, oysters were scrubbed under running tap water. Linear dimensions of individuals were measured to the nearest 0.01 mm using a Vernier calliper, and mean live weight was determined to the nearest 0.1 g with a field balance.

Dry meat weight was determined by drying soft tissues for 48h at 80°C, and the shells were rinsed and also dried at 80°C for 48h. Condition Index (CI) was calculated according to the formula: $CI = (W_1 \times 100) / W_2$, where W_1 is the dry meat weight (g) and W_2 is the shell dry weight (g) (Walne and Mann, 1975).

Environmental parameters

The two stations were sampled to determine the variation of environmental conditions. Temperature and salinity were recorded at each station during each sampling event with a multi-parameter probe (YSI, Yellow Springs, Ohio). TSS was also measured at each station during each sampling event by using a portable handheld measurement instrument for turbidity/solids. P-PO₄ was measured colorimetrically using the blue-molybdate method (Murphy and Riley, 1962) while N-NO₃ was measured by the spectrophotometric method by using a vanadium solution (VCl₃) (Miranda et al., 2001).

Data analysis

The data were checked for normality and homogeneity of variance. Analysis of variance (ANOVA or Kruskal–Wallis) was performed among environmental variables and condition index, growth, and mortality to identify differences between cultivation sites. Post hoc comparisons of means were conducted using Tukey's analysis and statistical significance was set at $P < .05$. Mean daily mortalities (MDM) were assessed using the formula of Frontier (1993): $MDM = \frac{\ln(N_{ti}) - \ln(N_{ti} - N_{d_{ti}})}{(t_i - t_{i-1})} * 100$

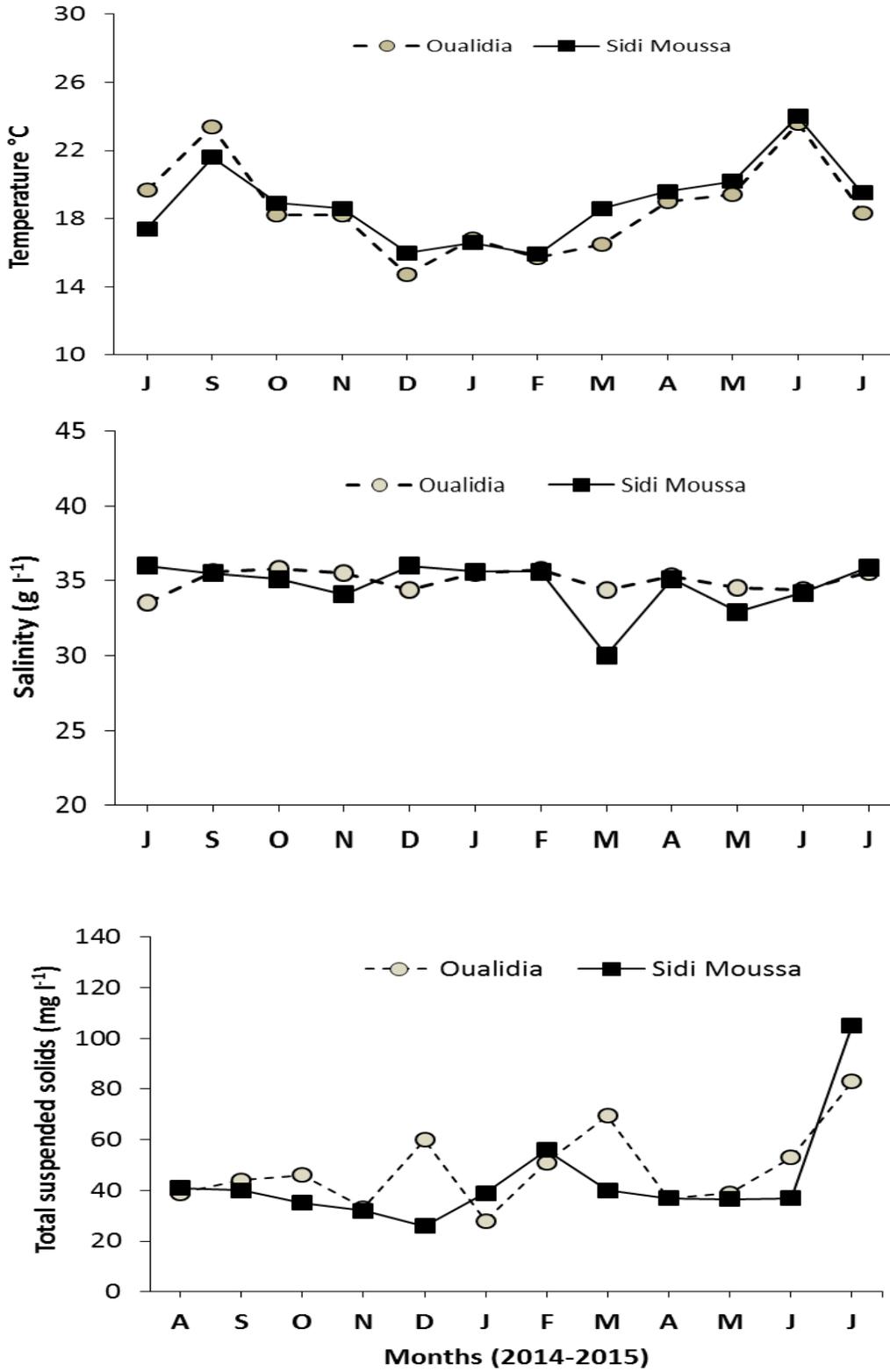
Where N represents the number of live oysters at the beginning of the interval, N_d is the number of dead or moribund oysters, and $(t_i - t_{i-1})$ is the time interval between two successive counts.

Results:-

Environmental conditions

Both sites had similar temperature trends, with no significant differences among them ($P > 0.05$) (Fig. 2). Temperature at both sites peaked on June 2015 (23.6°C and 24°C in OA and SM respectively). The minimum temperature recorded (14.7°C) occurred on December 2014 in OA, while the lowest temperature at SM was 15.9°C on February 2015. The salinity Peak (35.8 g l⁻¹ in OA and 36.0 g l⁻¹ in SM) was detected in respectively October and December 2014, and similar values (35.6 g l⁻¹) were observed in January-February 2015, followed by a significant decrease at both sites to reach the lowest values in March 2015 (34.4 g l⁻¹ at OA and 30.0 g l⁻¹ at SM) (Fig. 2).

Total Suspended Solids (TSS) concentrations followed different patterns in both locations. Mean concentrations of TSS at SM varied, with maximum values in July 2015 (~105 mg l⁻¹), and minima in December 2015 (~26 mg l⁻¹). TSS concentrations at OA showed three peaks, 60 mg l⁻¹ (December 2014), 69.5 mg l⁻¹ (March 2015), and 83 mg l⁻¹ (July 2015), with a minima in January 2015 (~28 mg l⁻¹) (Fig 2). Nutrient (NO₃ and PO₄) concentrations characterizing the suitability for shellfish cultivation at the two sites (OA and SM) followed different patterns (Fig. 2). During the experimental period, mean concentrations of nitrates was 21.6 and 22.3 µg l⁻¹ in OA and SM respectively. PO₄ concentrations shifted between 1 and 37 µg l⁻¹ in OA, and between 2 and 27 µg l⁻¹ in SM, mean concentrations was 11.6 µg l⁻¹ (OA) and 8.5 µg l⁻¹ (SM).



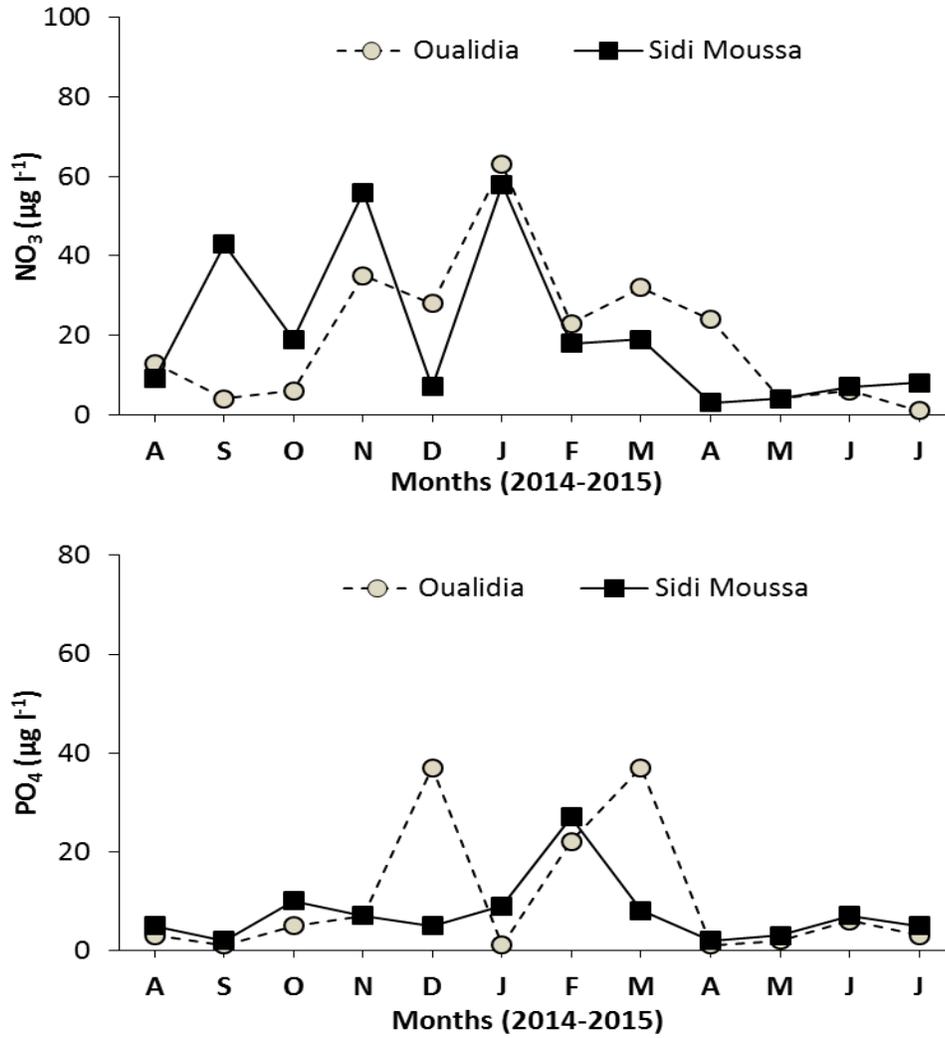


Fig. 2:-Temperature, Salinity, TSS (total suspended solids), Nitrates and Phosphates recorded in both lagoons (Oualidia: OA and Sidi Moussa: SM)

Growth

The location \times time interaction was significant for the shell length (Table 1), revealing a different growth temporal variations among treatments (Fig. 3). No significant difference in shell length was found among treatments at the beginning of culture (August 2014) ($P > 0.05$), ensuring that oysters at both locations started with similar size during the study (Fig. 3). The growth of individuals at SM, expressed in terms of shell length, was more or less steady (35.7 – 117.1 mm) throughout the 8 months of cultivation (August 2014-April 2015), but slower in the following three months; the average length at the end of the study was 123.2 mm (Fig. 3). Growth of individuals at OA was also steady (35.7 – 99.9 mm) until April 2015, but not significantly different ($P > 0.05$) in the following three months reaching only 93.7 mm as mean length in July 2015. Nevertheless, oysters at SM grew significantly more than oysters cultivated at OA ($P < 0.0001$). At the end of the experiment (July 2015), lengths of oysters reared at SM were significantly greater (Tukey; $P < 0.0001$).

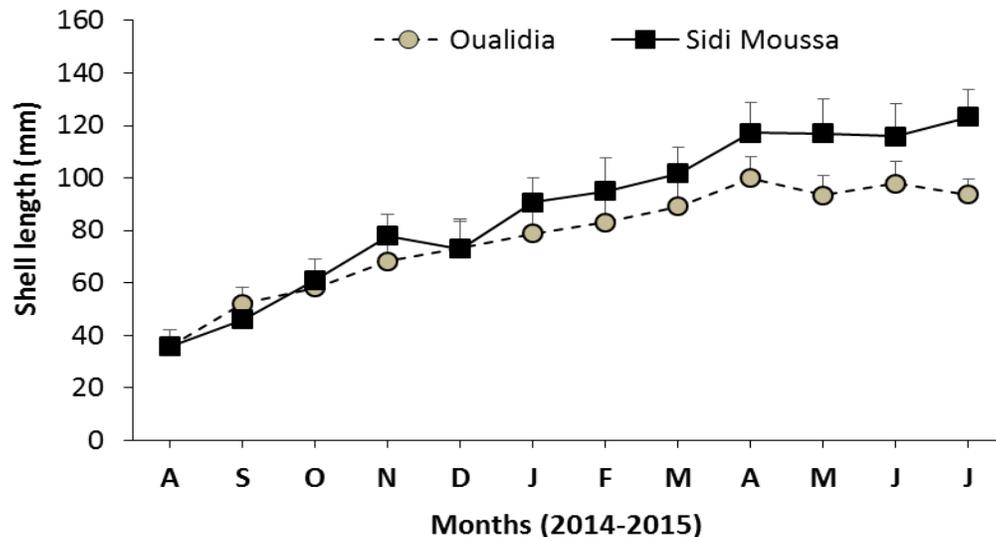


Fig. 3:-Growth (mean shell length \pm SD) of *Crassostrea gigas* raised in both lagoons (Oualidia: OA and Sidi Moussa: SM)

Meat dry weight and condition index

The location \times time interaction was significant for the meat dry weight (Table 1), revealing a different temporal variation (Fig. 4). No significant difference in dry weight was found among treatments at the beginning of culture (August 2014) ($P > 0.05$), ensuring that oysters at both sites started at similar conditions.

Oysters dry weight at SM and OA showed similar pattern: at the beginning of the experiment (August 2014 - February 2015), the growth in both sites showed little variation, after that, oysters dry weight increased continuously throughout the study at both locations, to reach maximums in July 2015 (5.95 g at SM and 4.73 g at OA) (Fig. 4). Statistical analyses indicated that oysters dry weight from February to July 2015 at SM was significantly higher than OA ($P < 0.0001$).

Mean condition index (CI) of individuals cultivated at SM had similar patterns to those maintained at OA (Fig. 4). The CI ranged from 3.19 to 8.97 and from 4.04 to 7.62 at OA and SM respectively throughout the study. The first peaks in CI occurred at both locations in October 2014 followed by continuous drops until December 2014. As a result, the mean values of CI declined to less than 4.1 at both locations. After this period, the oysters followed a similar trend, with a large increase in CI ($P < 0.0001$), reaching peaks in July 2015 (8.97 and 7.62 at OA and SM respectively). Statistical analysis showed that CI of oysters was not significantly different among treatments during both periods: August-October 2014 and April-June 2015 ($P < 0.0001$). However, CI values of oysters were significantly different between locations during the January-March period, with the highest CI value at SM and lowest value at OA ($P < 0.001$). At the end of the experiment, oysters at OA reached an unexpected great CI with a mean value of 8.97 ($P < 0.001$).

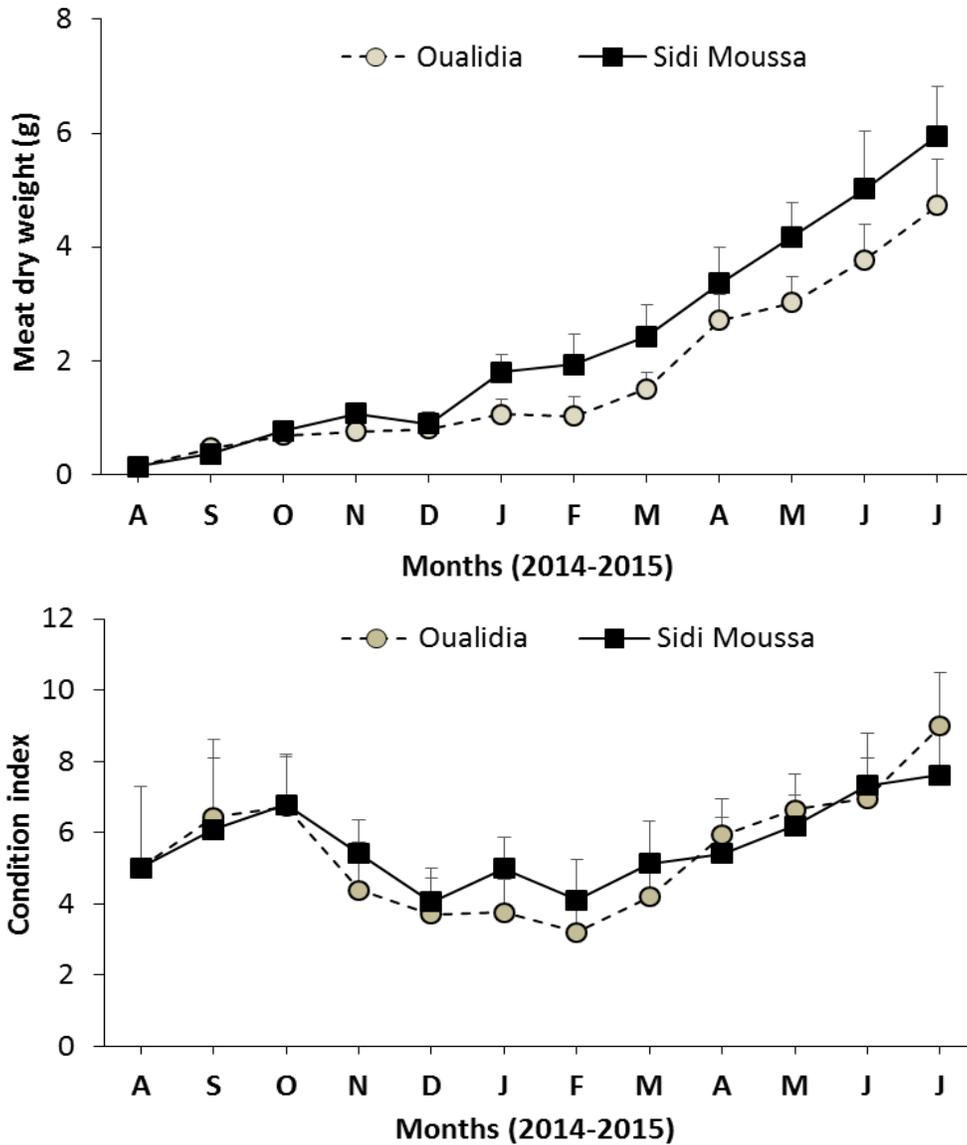


Fig. 4:-Mean meat dry weight (\pm SD) and mean condition index (\pm SD) of *Crassostrea gigas* cultivated in both lagoons (Oualidia: OA and Sidi Moussa: SM)

Table 1:-Two-way ANOVA results testing the location treatment and sampling time on the mean values of shell length (mm), and meat dry weight (g) of oysters grown in Oualidia and Sidi Moussa.

Source of variation	d.f.	S.S.	M.S.	F	p value
Shell length					
Location	1	234.4	234.4	255.6	$p < .00001$
Month	10	2582	258.2	281.6	
Site \times Month	10	159.8	15.98	17.43	
Residuals	638	584.9	0.916		
Meat dry weight					
Location	1	71.76	71.76	304.5	$p < .00001$
Month	10	1644	164.4	697.9	
Site \times Month	10	36.12	3.612	15.33	
Residuals	638	150.3	0.235		

Mortality

Mean daily mortality (MDM) through the entire cultivation period showed seasonal and spatial variations (Fig. 5). Mortality rates at OA remained less than $0.06\% \text{ day}^{-1}$ from September 2014 to February 2015. However, MDM at OA varied significantly between February and July 2015 with a peak in June 2015 ($0.19\% \text{ day}^{-1}$). Mortality rates at SM peaked at the beginning of the experimental period ($0.25\% \text{ day}^{-1}$) in September 2014, and then decreased continuously to reach minimum values less than $0.01\% \text{ day}^{-1}$ in January 2015.

Apart from the period between September 2014 and December 2014, mortality was relatively steady, fluctuating between 0.01% and $0.02\% \text{ day}^{-1}$. ANOVA test suggests significant seasonal ($P < 0.01$) and spatial differences ($P < 0.001$) on daily mortality. Mortality rates of *C. gigas* during springtime (April-June 2015) and in early summer (July 2015) were significantly lower for oysters reared at SM compared to those at OA ($P < 0.0001$). Oysters in OA had higher cumulative mortality (19.1%) at the end of the study (July 2015) than oysters in SM (16.5%) ($P < 0.05$).

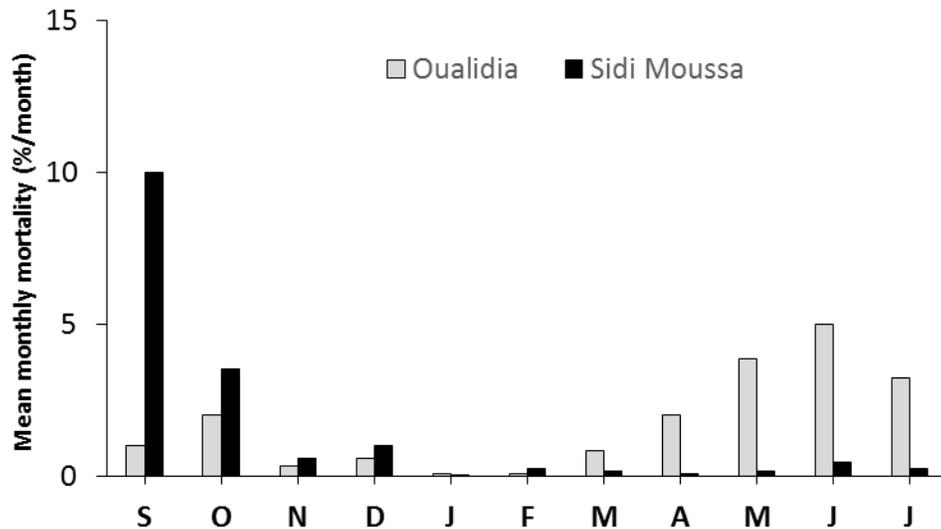


Fig. 5:-Variations of mean monthly mortality (%/month) of *Crassostrea gigas* raised in both lagoons (Oualidia: OA and Sidi Moussa: SM)

Discussion:-

Growth

Oysters raised in both locations obtained positive growth rates in terms of shell length and dry mass. However oysters at Sidi Moussa showed differences in growth rates and condition compared to oysters at Oualidia; in terms of shell growth, individuals in SM grew to significantly larger sizes than oysters in OA. Also higher daily increases in dry mass were recorded at Sidi Moussa. These results can be related to the conditions offered by the lagoon of Sidi Moussa also to a better adaptation of the Pacific oyster in this lagoon. In the current study, market sizes were reached at both sites (the study started with an average length of 30-40 mm). After only 8 months, individual of 99.9 mm (OA) and 117.1mm (SM) were produced, these growth rates are relatively high and are in accordance to other studies affirming that pacific oyster shows a high grow rate in the first year of cultivation (Gangnery et al., 2003). At the end of our study lower growth rates were recorded, we assume that it is related to the investment of energy in reproduction rather than in growth, other studies confirm this finding as shell growth rates showed a progressive decrease with age, on different oyster species (Bataller et al., 1999; Mitchell et al., 2000; Pouvreau et al., 2000). Some authors affirm that the most important environmental factor in *C. gigas* cultivation is temperature (Castillo-Durán et al., 2010; Chávez-Villalba, 2014). In the current study, temperature variability was within the optimal ranges for oyster growing ($14.7\text{-}23.6^\circ\text{C}$) at OA and ($15.9\text{-}24^\circ\text{C}$) at SM.

Variations in CI outcome from multiple interactions of many factors, including food, temperature, and salinity, although the availability of food is considered as the main factor after the gametogenic cycle (Boscolo et al., 2003). Previous studies indicated that the CI of *C. gigas* did not have a direct relationship with reproduction and the

enhancements were combined with accumulation of energy reserves during autumn and winter when concentrations of POM were higher (Chávez-Villalba et al., 2007; Luna-González et al., 2008). This pattern was observed in populations reared at Sidi Moussa, since CI of oysters was significantly higher in winter (January-March 2015) with respect to oysters at Oualidia. Observations in similar environments showed that even with the low availability of food during winter, *C. gigas* was adept to make potent use of the available energy, using it for growth and storage (Castillo-Durán, 2007). However, even with elevated concentrations of TSS in July 2015, condition index of oysters in Sidi Moussa remained steady, these results are in accordance with the results reported by Chávez-Villalba et al., (2010).

Mortality

In our study, Survival rates of oysters were high at both locations (80.9 and 83.5 % in OA and SM respectively). Cumulative mortality rates of *C. gigas* were significantly lower for cultivated oysters in Sidi Moussa compared to those in Oualidia. We also observed that highest mean daily mortality (MDM) occurred in both locations (0.19 and 0.25% day⁻¹ in OA and SM respectively) were less compared to mean daily mortality (0.62% day⁻¹) reported for batches of *C. gigas* during summer mortality outbreaks in France (Royer et al., 2007). At Sidi Moussa, Mortalities recorded were highest at the beginning of the experiment (September 2014) up to 10%, while, at Oualidia lagoon, highest rate recorded was 5% in (June 2015) where Temperature was highest 23.6°C. Mortality can be directly related to the temperature of seawater (Lipovsky & Chew, 1972), as it makes oysters more susceptible to other stresses and can influence their immune system (Gagnaire et al., 2005; Zhang et al., 2006; Kantzow et al., 2016). However, the temperature ranges in Oualidia (14.7-23.6°C) and Sidi Moussa (15.9-24.0°C) are within the optimal ranges for oyster growing, as it has been evidenced that oysters can survive repeated exposure to high temperatures (Cheney et al., 2000).

The oysters used in this study were first reared in Oualidia until they reached the average length of 30-40 mm, then were transferred to Sidi Moussa where environmental conditions at the beginning of the experimental period differed; the initial temperature in August 2014 was 17.4°C in SM and 19.7°C in OA, we thus believe the cause of mortality in SM is most probably due to acclimatization stress. Physiological stress due to juvenile's fast growth may also be associated with higher mortalities (García-Esquível et al., 2000).

Seston is another causal factor responsible of oyster mortalities in lagoons, particularly to their higher rates. Mass mortalities of oysters have been observed in locations with high seston levels where the oysters show fast growth rates and accelerated sexual maturation (Gouletquer et al., 1998). In the present study, seston loads in OA (28 - 83 mg l⁻¹), as well as in SM (26 - 105 mg l⁻¹) were at moderate levels.

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Conflict of interest:

The authors declare that they have no conflict of interest

Ethical approval:

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

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