Comparative production of two mussel species (*Perna perna* and *Mytilus galloprovincialis*) reared on an offshore submerged longline system in Agadir, Morocco

Mohamed Id Halla, Hassan Nhhala, Jawad Kassila*, El Mustapha AIT CHATTOU, Abdellatif ORBI et Abdellatif MOUKRIM

Abstract— The principal objective of this study was to examine the first submerged longline system used for mussel farming in offshore of Agadir (Morocco). Furthermore, the growth performance of *Perna perna* and *Mytilus galloprovincialis* were compared, and the effect of season of seeding on their biomass production was investigated. The seeding with high densities, more than 4100 seed.m^{-1}, resulted in important seed losses. The cumulative losses ranged from 86 ± 7 % to 88 ± 7 % in both species ($p > 0.05$). The results showed that *P. perna* achieved higher productions than *M. galloprovincialis*, reaching 23.0 kg per meter rope after one-year of culture. The productions of both species were affected by the time of seeding as mussels seeded in summer grew faster than those seeded in spring ($p < 0.001$ in *P. perna* and $p < 0.0001$ in *M. galloprovincialis*). The marketable productions in *Perna perna* and *M. galloprovincialis* were improved by 26% and 70% respectively when mussels were seeded in summer. Moreover, the culture period can be reduced by two months as more than 90% of mussels in both species reached the commercial size (≥ 60 mm) after 10 months of culture. These results indicate that the submerged longline system tested can be commercially convenient. The excellent productions of mussels during the present study may led to suggest that offshore cultivation is as an opportunity for commercial enterprises.

Index Terms— biomass, commercial size, crowding, density, seed losses, yield.

1 Introduction

Mussel growth depends on a combination of operational variables, such as culture density, shell length at the time of seeding, technological design of the cultivation systems [1-2-3] on the environmental characteristics of the cultivation area [4-5], predation [6] and genetic components of seed [7]. Cultivation time and seeding season have a significant effect on growth in both length and total weight of mussels [8]. Suspended cultures entail loading high densities of seeds, often resulting in intraspecific crowding, reduced growth and mussel yield. Competition for food will affect the commercial yield of cultured mussels, where local-scale seston depletion could produce asymmetric competition resulting in a skewed size distribution caused by the mortality of small individuals [9-10]. There are mechanisms by which bivalves minimize physical and interference competition, such as density-dependent migration [11]. This density-dependent loss of mussels mostly related to the high packing densities at seeding is often explained by self-thinning. Two mechanisms generally explain self-thinning in bivalves: competition for food and competition for space ([12-13]. However, it can be difficult to determine which one of these is the limiting factor [14]. [15] observed that juvenile mussels have the ability to cut their byssal threads, move, and reattach themselves in other locations.

The aquaculture production in Morocco barely exceeds 1.000 tons, representing about 0.1 ‰ of the National fisheries production. Ever since the emergence of marine shellfish culture in the 1950s, output has remained virtually unchanged at around 200 tons, producing mainly cupped oysters, for the local market. There is an urgent need to promote aquaculture as a food source to reduce production of commercial species by extractive fisheries. The government has released a maritime strategy “Plan Halieutis” aiming to develop the use of its marine resources sustainably, generating jobs and added value, and setting ambitious ta rgets for 2020. The country is targeting 200,000 tons per annum in marine species harvests (seaweeds, bivalves, fishes, and shellfish).

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The mussel production in Morocco achieved has not increased enough to meet demand. Few mussel farms are often limited to sheltered coastal lagoons. However, these ecosystems are subject to environmental constraints associated with pollution from industrial and domestic sources. Due to these challenges, the offshore mussel culture system has been often suggested as a solution to meet the growing demand in concurrence with previous studies [16-17]. However, there are a few studies available for offshore submerged design to serve as models for entrepreneurs interested in mussel longline cultivation. The offshore farms allow higher growth rates, better meat yield, and heavier production compared with inshore farms due to lower stress, reduced turbidity and better water exchange [16-18]. The available systems for offshore mussel culture have been designed through the modification in coastal structures or techniques such as longlines or rafts [19]. Many studies have determined that the most convenient offshore system would be longline systems [16-18-20-21]. Long-line culture is often an alternative to raft culture in areas less protected from wave action as in offshore. The cultured mussels grow better on a longline system because they are flushed by phytoplankton-rich seawater [21].

Many fishermen wish to turn towards mussel culture, as conditions along the Atlantic coast of Agadir (Morocco) are particularly favourable for this lucrative activity. Mussels grow here faster, acquiring the desirable size for consumption rapidly [22-23-24], and sufficient spats of both species can be collected on suspended ropes at a depth 1m, from March to November [24]. The seed supply is critical for the development of industrial mussel cultivation.

In this study, we tested a submerged longline system without thinning-out at a commercial-scale, in offshore of Agadir. The culture of both species *P. perna* and *M. galloprovincialis* were conducted, over two years from March 2001 to March 2002 and from June 2002 to June 2003. Their growth performance and production were compared to select the most profitable species to cultivate for commercial purpose at large scale in Morocco. It is the first comparative study of productions in *P. perna* and *M. galloprovincialis*, reared in offshore on a submerged longline system. The seasonal effects of seeding (spring and summer) on growth and biomass yield in both species were also investigated.

2 Materials and methods

Culture site

Field experiments were carried out in offshore of Agadir at 30° 34.2 'N and 09° 45.1' S at a depth 22 m, located on the Atlantic coast of Morocco. The designated area was about 1 km^2, located at 1.5 miles from the coast, far from any human activities. It was exposed to relatively energetic waves from the North Atlantic. More than 70% of waves in winter have significant heights ranging 1.5-3.5 m [25]. In summer, the directional range also covers the North. More than 90% of incoming waves during this season have significant heights ranging 1-2 m. This clear seasonal wave pattern highlights the predominance of a swell-dominated regime in winter and more fair-weather mixed swell and shorter-fetch wave conditions in summer. Tides are semi-diurnal and mesotidal with a mean spring range of 2.9 m and a mean neap range of 1.3 m.

Experimental design

The mussel cultures were carried out in offshore on a submerged longline system during both culture periods. The first culture began in March 2001 and finished in March 2002 while the second culture began in June 2002 and completed in June 2003. The longline system established at 2 m below the water surface was designed according to site conditions (Figure 1). Two submerged longlines of 100 m long each one separate 50 m were implemented during each culture period. Both local species, *P. perna* and *M. galloprovincialis,* were cultivated separately on each longline. The longline was anchored at both sides with cement blocks (350kg) and buoys (30L) attached along the longline were used to keep it afloat. Four marker buoys were used on the edges of the experimental area to mark and protect the site for navigation purposes. The longlines were oriented parallel to the dominating current direction so that water could flow through the channels delimited by the long-lines and the vertical polypropylene ropes (50 mm diameter), reducing the hydrodynamic resistance. Each longline held 40 socks 2 m apart stocked with mussels at high density (4000-5500 mussels/ 1m of sock). The socks with a length of 5 m each were deployed for 1 y on March 28, 2001 (spring seeding) and on June 29, 2002 (summer seeding).

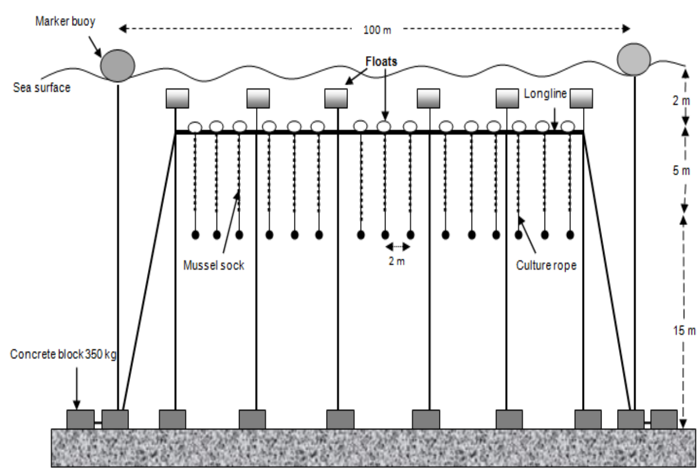

Figure 1. Schematic representation of the submerged longline system used for mussel culture in offshore. Individual mussel socks are attached to the longline, which is weighted down at the both ends with concrete blocks

Mussel seeds were collected at the low water tides from the rocky shore of Cape Ghir, 3 km away from the study site, where they are cleaned in order to eliminate sand, detritus, and possible competitors and predators. Mussel seeds of both species were separated and sorted to ensure that initial populations were from the same cohort. A uniform size was selected at seeding, 13.6±2.06 mm for *P. perna* and 13.9±2.44 mm for *M. galloprovincialis* (spring seeding), and 21.3±2.06 mm for *P. perna* and 19.7 ± 2.21 mm for *M. galloprovincialis* (summer seeding). The spring seeding was done on March 28, 2001 (spring in the northern hemisphere) and the summer seeding on June 29, 2002 (summer in the northern hemisphere). Seeding consisted of inserting separately the seeds of both species into the socks (cotton stocking) along with a length of rope. The culture ropes measured ≈ 8 m in length, of which 5 m submerged in seawater was available for mussel culture (from -2 m to -7 m). Sock degrades over time after 2-3 weeks, leaving a mussel rope covered in spat.

Environmental variables

Temperature and salinity were measured monthly during the experimental periods using a probe (6600 V2 YSI). Seawater samples were collected at the experimental site from a 5 m depth using a Niskin bottle of 3 L. Three replicas were considered. The water samples were transferred to a laboratory and filtered onto Whatman GF/C filters after acetone extraction to determine chlorophyll a (µg L^{-1}).

Density and seed losses

For each species, monthly triplicate mussel samples were taken by divers grazing linear portions of the "rope" that were 50 cm in length. The mussels were transferred to the laboratory and into a 100-L tank filled with sea water. After cleaning the mussels from incrustations and fouling, the samples were counted to determine densities (ind .m^{-1}). A total of 500 individuals were collected randomly from the samples. The following measurements were considered: total weight with a 0.01 g precision electronic scale and the total shell length with a 0.1 mm precision calliper.

Monthly losses were determined according to the following equation:

$$\text{Losses (\%)} = (N_t / N_0) \times 100$$

Where N_t is the number of mussels per meter rope remaining after time t, and N_0 is the number of mussels per meter rope at the beginning of the time period.

Biomass and relative biomass production

Biomass per meter rope (kg m^{-1}) was estimated as:

$$B_t = W_t \times D_t$$

With Wt is the mean wet weight of mussels including shell at time t, and Dt is the mean density of mussels per meter rope at time t.

Relative biomass production (RBP) is the ratio between mussel biomass at any given point in the culture cycle and the mussel biomass seeded. It was calculated as:

$$RBP = B_t / B_{seed}$$

With Bt is the mussel biomass per meter rope at time t (kg m^{-1}), and B_{seed} is the mussel biomass seeded per meter rope (kg m^{-1}).

Data analysis

Environmental parameters, density, shell length, seed loss, and production were analyzed by analysis of variance (ANOVA). Statistically significant were considered those with p values < 0.05. The assumptions of normality and homogeneity of variance were previously tested with Shapiro-Wilk and Levene tests respectively. Where neither normality nor homogeneity was met, we applied Kruskal–Wallis test to compare differences. Logarithmic transformation of chlorophyll a was verified in order to be linearly correlated with temperature, by means of Pearson correlations. Three size ranges were established to analyze the composition by seeding season categorized as follows: below commercial size (SL < 60 mm), medium size (SL ≥ 60 and < 80 mm) and larger size (SL ≥ 80 mm). At the end of both culture periods, frequency values were compared by Student's t-test. Statistically significant were considered those with p values < 0.05. For all analyses, XLSTAT software for MS Windows was used.

3 Results

Durability of submerged longline system

The design of the system tested in offshore did not cause any serious problem for mussel culture activity even during the storms. There were no abrasions or punctures on the buoys because of the appropriate materials used in the strong installation of the system. However, there were some fouling organisms that settled on hawsers and at the bottom of the buoys. This settlement did not cause any reduction in buoyant force. The culture system installed did not interfere with shipping or cause any visual pollution due to its submerged design. The strong anchors used prevented the slippage of the longline system. At the ninth month after seeding, additional buoys have been added to support the heavy ropes.

Environmental variables

The temperature ranged between minimum values of 15°C in February and maximums around 21°C in August (Figure 2A). Salinity varied within a narrow range (34.9-36.2) and presented the lowest values during winter (Figure 2A). Chlorophyll-a concentration displayed significantly marked seasonal changes, but with a similar trend during the both culture periods (Figure 2B). Chlorophyll-a concentration presented minimum values during winter (0.5-0.6 µg L^{-1}) and tended to increase during spring and summer periods, showing major peaks (2.2-2.4 µg L^{-1}) in August. There was significant a correlation between chlorophyll *a* and temperature (r = 0.87, $p < 0.001$).

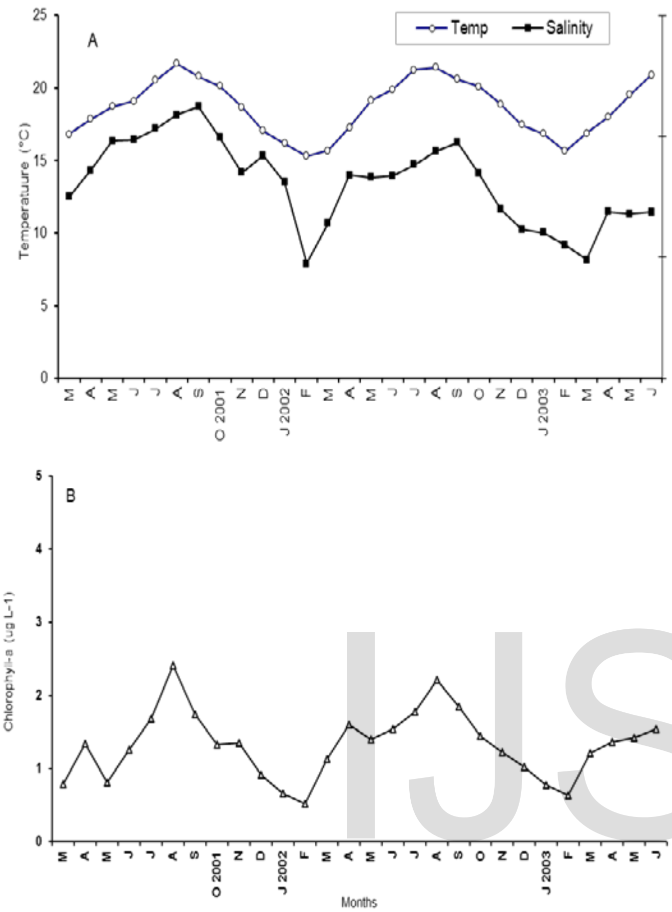

Figure 2. Monthly changes in mean temperature, salinity (a) and chlorophyll a (b) from March 2001 to June 2003

Density and seed losses

The monthly densities of *P. perna* and *M. galloprovincialis* per meter rope shifted from 4887 ± 226 and 4168 ± 217 in March 2001 to 640 ± 83 and 473 ± 87 in March 2002 respectively (Figure 3A). In the second culture, the monthly densities of *P. perna* and *M. galloprovincialis* per meter rope shifted from 5440 ± 263 and 5260 ± 326 in June 2002 to 735 ± 49 and 685 ± 69 in June 2003 respectively (Figure 3B). The density of both species followed a similar pattern over the both cultures. Two main phases have been identified in the both cultures: the first started from 0 to 180 days marked the fall of densities and the second started from 180 to 360 days marked a slow decrease in densities. The losses fell away since the sixth month after seeding.

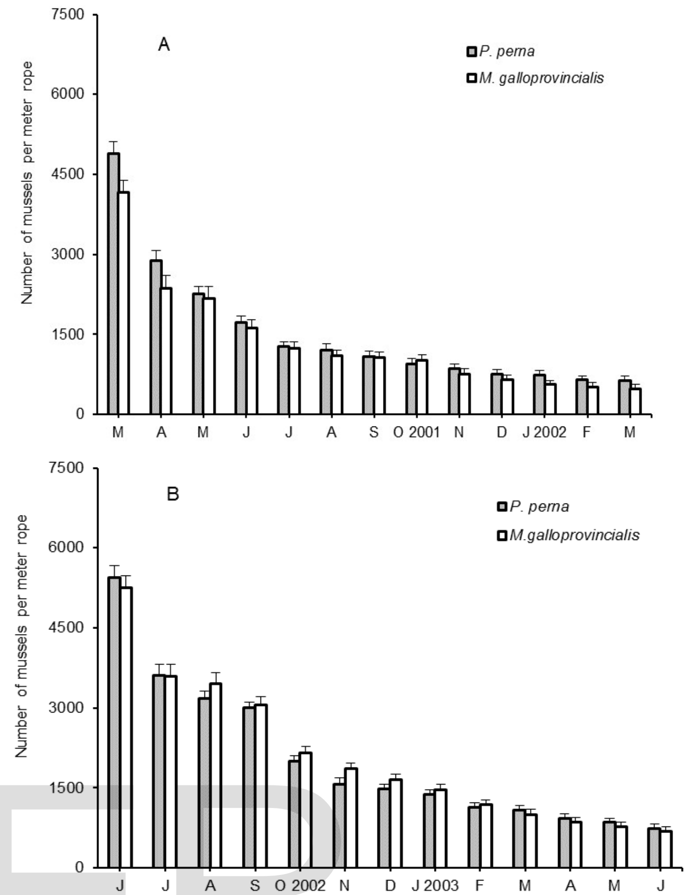

Figure 3. Monthly changes in density of *P. perna* and *M. galloprovincialis* seeded at spring (March 2001) (A) and summer (June 2002) (B). Means are reported with standard deviations.

The cumulative losses after 12 months of culture were ranged from 86 ± 7 % to 88 ± 7 % in *P perna* and *M. galloprovincialis* respectively (P>0.05), whatever the initial density at seeding (Table 1).

Table 1. Cumulative losses (C.L.) of *P. perna* and *M. galloprovincialis* seeded at spring and summer seasons after 12 months of culture. Mean values are reported with standard deviations. The different letters indicated significant difference ($p < 0.05$).

Sp.	*Seeding season*	*Seeding period*	*Density at seeding (ind m⁻¹)*	*Density at harvest (ind m⁻¹)*	*C.L. (%)*
P	Spring	March 2001	4887 ± 226ᵃ	640 ± 83ᵃᵇ	86 ± 8
	Summer	June 2002	5440 ± 263ᵃ	735 ± 49ᵃ	86 ± 9
M	Spring	March 2001	4168 ± 217ᵇ	473 ± 87ᵇ	88 ± 8
	Summer	June 2002	5260 ± 326ᵃ	685 ± 69ᵃ	87 ± 7

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Biomass production

Monthly changes in biomass yield of both species are shown in Figure 4. In the first culture (spring seeding), the biomass of *P. perna* and *M. galloprovincialis* increased by 307% and 239% from March to August 2001 respectively (Figure 4A). The following autumn, biomass increased only in *P. perna* (+10%) before stabilizing at least at 18 kg m^{-1} between January and March 2002, while biomass of *M. galloprovincialis* settled at 10 kg m^{-1}. We found a significant difference in the final biomasses between the both species ($P<0.0001$). In the second culture (summer seeding), biomass in both species reached different levels at the fifth month after seeding: 20.3 and 15.8 kg m^{-1} in *P. perna* and *M. galloprovincialis* respectively ($P<0.05$). The biomass in *M. galloprovincialis* remained rather stable around of 16-18 kg m^{-1} until the end of the culture, while biomass in *P. perna* increased significantly ($P>0.05$) to reach 25.1 kg m^{-1}, as a max value in May 2003. We found also significant difference in the final biomasses between the both species ($P< 0.05$) as in the first culture.

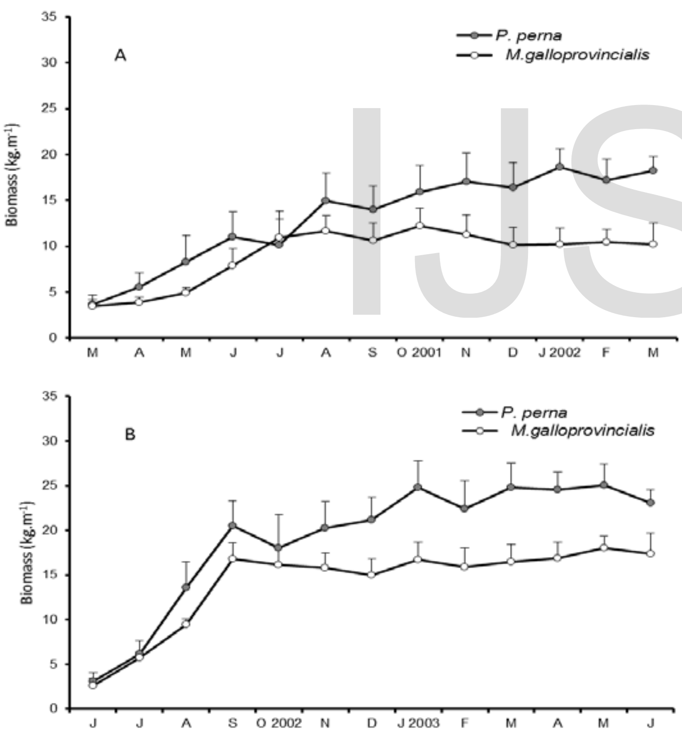

Figure 4. Monthly changes in biomass of *P. perna* and *M. galloprovincialis* seeded at spring 2001 (A) and summer 2002 (B). Means are reported with standard deviations.

Length frequency distributions

Figure 5 shows size frequency distributions at seeding and harvest in both species seeded at spring (Figure 5A) and summer seasons (Figure 5B). Throughout the both cultures the size frequency distributions of both species often fitted a unimodal curve, except for *P. perna* where a minor second mode having low frequency appeared at harvest. At seeding, no significant differences in the average size were found between species whatever the season of seeding (ANOVA; $P>0.05$). The final average size did not differ significantly among the both species after spring seeding ($P=0.215$), while final average size of *P. perna* was significantly greater than that of *M. galloprovincialis* after summer seeding ($P<0.001$). Considering the seeding season, mussels of both species seeded at summer reached significantly greater sizes in comparison with those seeded at spring; ($P<0.001$ in *P. perna* and $P<0.0001$ in *M. galloprovincialis*).

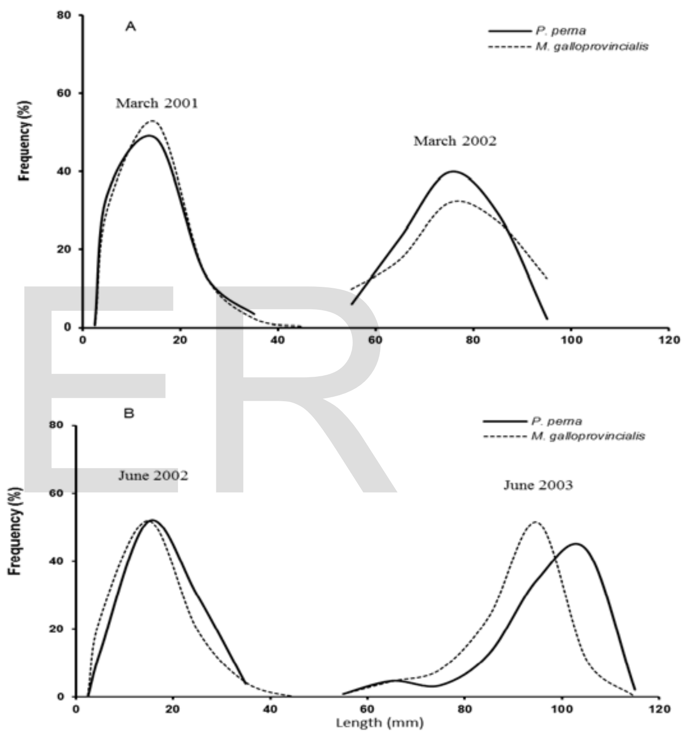

Figure 5. Size frequency distribution, in initial and final samples of *P. perna and M. galloprovincilias* seeded at spring 2001 (A) and summer 2002 (B).

Relative biomass production

Table 2 displays the density and the weight of seeds used in both cultures (spring and summer seeding). Relative biomass productions (RBP) in both species were calculated monthly and averaged as mean RBP. Final RBP´s were calculated for each species at the end of both cultures. The results showed that maximum RBP in *P. perna* averaged per seed season, decreased from 8.0 (summer seeding) to 5.1 (spring seeding) while maximum RBP in M. *galloprovincialis* decreased from 6.9 (summer seeding) to 3.5 (spring seeding).

Table 2. Relative biomass production (RBP) of P. perna and M. galloprovincialis seeded at spring and summer seasons.

Sp.	*Seeding period*	*Seed density (ind m⁻¹)*	*Seed weight (g)*	*Seed biomass (kg m⁻¹)*	*Final biomass at harvest (kg m⁻¹)*	*RBP (kg kg⁻¹)*	*Max RBP (kg kg⁻¹)*	*Average RBP (kg kg⁻¹)*
Perna	March 2001	4887	0.75	3.66	18.24	4.9	5.1(Jan-2002)	3.9
	June 2002	5440	0.57	3.10	23.02	7.4	8.0 (Mar-2003)	6.5
Mytilus	March 2001	4168	0.82	3.41	10.20	3.0	3.5 (Oct-2002)	2.8
	June 2002	5260	0.50	2.63	17.40	6.6	6.9 (Mar-2003)	5.7

The average RBP's of *P. perna* ranged between 3.9 (spring seeding) and 6.5 (summer seeding). For *M. galloprovincialis,* average RBP ranged from 2.8 (spring seeding) to 5.7 (summer seeding). It should be noted overall that the highest RBP's of both species were recorded in the second culture, at summer seeding.

Commercial culture yields

The time required for 80% in a number of *P. perna* seeded at spring to reach the commercial size (> 60 mm) was ten months (Figure 6A), and about of nine months for the population seeded at summer (Figure 6B).

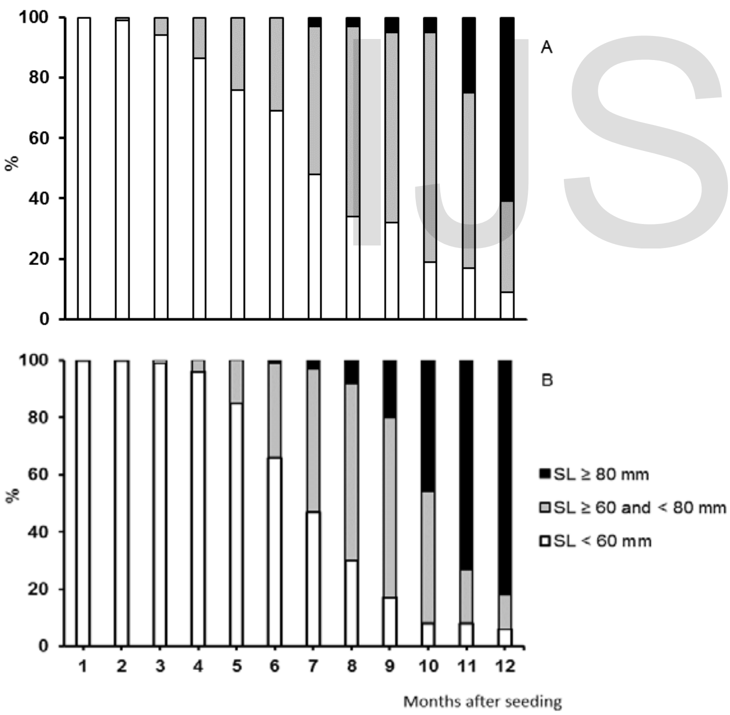

Figure 6. Percentage of *P. perna* < 60 mm, between 60 and 80 mm and > 80mm in shell length per seeding season: (A) spring and (B) summer.

By cons for *M. galloprovincialis*, eleven months are required for 80% in population seeded at spring to reach the commercial size (Figure 7A), and only nine months for the population seeded at summer (Figure 7B). For populations seeded at summer, 20% present sizes over 80 mm after nine months in *P. perna*, and only 6% in *M. galloprovincialis*. At the end of the both cultures, less than 12% in populations of both species seeded at spring and summer seasons, did not reach commercial size (<60 mm).

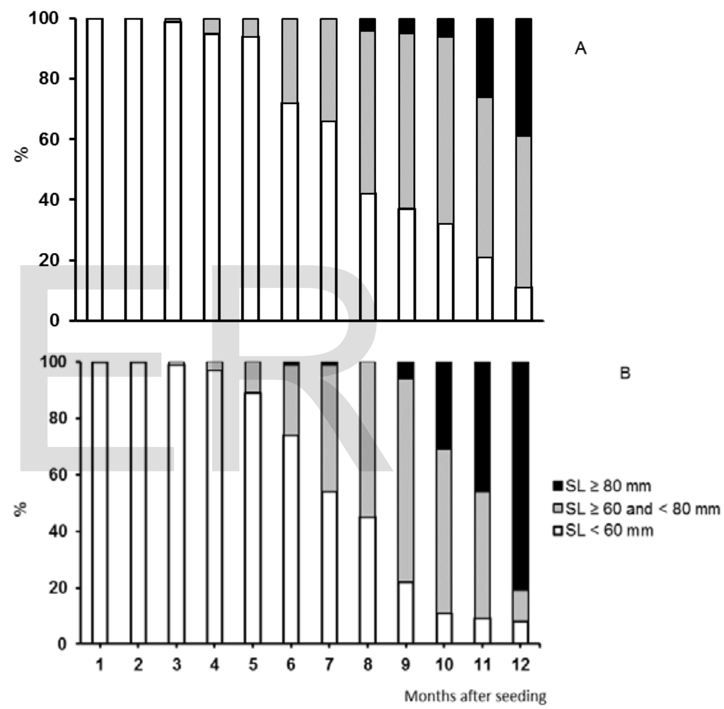

Figure 7. Percentage of *M. galloprovincilias* < 60 mm, between 60 and 80 mm and > 80mm in shell length per seeding season: (A) spring and (B) summer.

Figure 8 shows monthly changes in marketable biomass of both species seeded at spring and summer seasons. The maximum yields were recorded at summer seeding after 11 months of growing; 23.0 and 16.4 kg m^{-1} in *P. perna* and *M. galloprovincialis* respectively (P<0.001). These values dropped slightly at harvest. When mussels were seeded at spring, the yields did not exceed 16.4 and 9.1 kg m^{-1} in *P. perna* and *M. galloprovincialis* respectively, after 12 months of culture (P<0.001).

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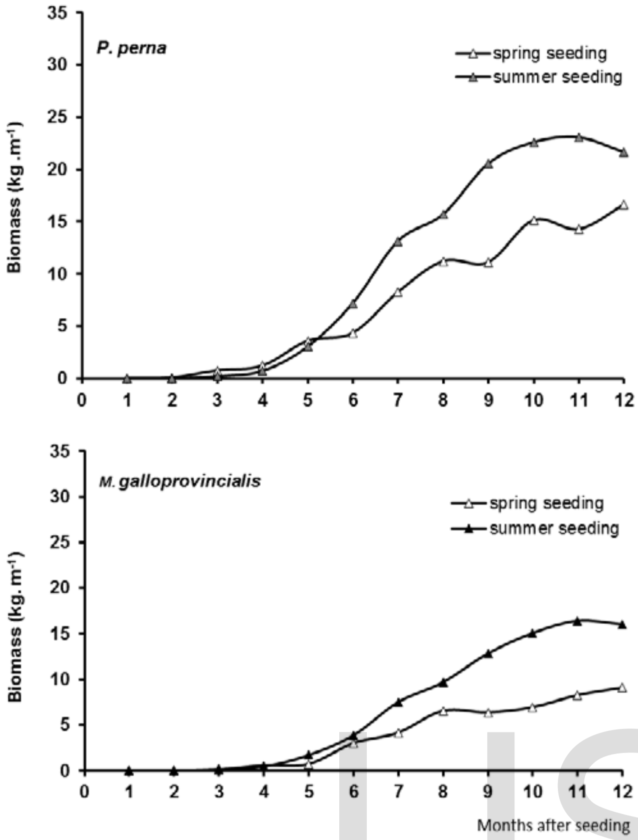

Figure 8. Monthly changes in marketable biomasses of *P. perna* and *M. galloprovincialis* (> 60 mm in shell length) seeded in spring 2001 and summer 2002.

Table 3 shows annual productions per rope and per longline of both species after removal of individuals that did not reach the commercial size (< 60 mm). The productions per rope in *P. perna* and *M. galloprovincialis* seeded at spring dropped slightly to 83.0 and 45.4 kg/rope respectively, after this removal. These production values were not significantly different from the production values observed before removal of non-commercial size mussels (P>0.05 in both species). Also, the productions per rope in *P. perna* and *M. galloprovincialis* seeded at summer dropped not significantly to 108.2 and 80.1 kg/rope (P>0.05) respectively, after this removal. Likewise, commercial productions per rope were higher in *P. perna* than that in *M. galloprovincialis* whatever the season of seeding. It is should be noted that the effect of seeding season on commercial production is more pronounced in *M. galloprovincialis*. Indeed, the commercial production per rope of *M. galloprovincialis* seeded at summer was almost twice the production obtained after spring seeding. The highest production rate per longline per year (4328.0 kg) occurred on ropes seeded with *P. perna* at summer while the lowest production (1816.0 kg) occurred on ropes seeded with *M. galloprovincialis* at spring.

Table 3. Annual productions (P.) per rope (5 m) and per longline (40 ropes) (in kg) of *P. perna* and *M. galloprovincialis*, seeded at spring and summer seasons. Mean values ± SD

Productions	***P. perna***		***M. galloprovincialis***	
	Spring seed.	**Summer seed.**	**Spring seed.**	**Summer seed.**
Annual tot. P. by rope	91.2 ± 5.96	115.1 ± 7.96	51.0 ± 11.5	87.0 ± 13.0
Annual commercial P. by rope	83.0 ± 4.03	108.2 ± 5.83	45.4 ± 9.43	80.1 ± 9.87
Annual commercial P. by longline	3320 ± 161	4328± 233	1816 ± 3 72	3204 ± 394

Discussion

Submerged longline system

This is the first experiment in Morocco where a submerged longline system was installed to resist offshore site conditions and to evaluate system strength criteria. In comparison to other systems, the longline system was chosen to the easy deployment and the cheaper investments costs [26]. The submerged longline system tested could withstand the harsh weather conditions, and the polypropylene lines resisted storm conditions with wind waves of up to 3 m and current velocities of 80 cm/s. This system is very convenient in adjustment of the required flotation throughout the growing period in accordance with crop weight. In summary, the system equipment was strong, abrasion resistant, inexpensive and durable against fouling and environmental effects.

Environmental variables

The survival and growth rates of mussels are directly related to environmental conditions included temperature, salinity, total particulate matter, and chlorophyll-a of the seawater [27-28-29]. The data of the environmental parameters recorded in this study showed that the both experiments were conducted at temperatures and salinities compatible to the optimum development of *P. perna* and *M. galloprovincialis* [30-31]. In term of food availability, the chlorophyll a concentrations recorded in this study were often higher than the minimum recommended concentrations of 1ug L^{-1} [32]. This indicates that the food availability in the study area is adequate to sustain the bivalve farming. The chlorophyll-a did not exceed 2.5 µg L^{-1} in spite of the influence of a coastal upwelling that has a key role in stimulating primary productivity [33]. The suitability of this area for mussel farming can be more meaningful if the phytoplankton composition can be included in this assessment as recommended by [34]. With such inclusion, the site suitability could become an important management tool for effective selection of potential farming sites for mussels in the future.

Density and seed losses

The densities of both species declined considerably during the first six months after seeding, before stabilizing towards the late of both cultures. When we started these cultures, we had no idea about the optimal stocking density. Until 2004, no studies have investigated the effect of stocking density on mussel growth in suspended cultures. The ropes were seeded at high densities: 4168-5440 ind. m^{-1}, in order to maximize yields at harvest. However, the highly dense multilayered disposition of mussels as in both cultures can lead to space and food limitations [13-35] and to self-thinning as the individuals grow [36-37]. The high densities of mussels may result in a density-related seeding loss with maximum values of 75% within four weeks [38]. Our results demonstrated that there was no relationship between the losses and the densities at seeding, as the seed losses were very similar at all seed densities (Table 1). Indeed, the cumulative losses at harvest in both species were found not to be different, varying between 86 and 88%. These losses were probably related to the self-thinning process, whereby populations of bivalves in high densities can self-regulate population size according to the available resources [12-39-40]. [41] found that the losses from seeding to harvest reached 92% in the smallest seeds collected from spat collectors and 54% in half-grown mussels fished from natural beds. [42] obtained lowest losses (4.5-6.6%) at intermediate densities (800-1000 seeds m^{-1}) in Arousa ría (Galicia, Spain). These crowding conditions induced shell distortion [43], density-dependent migration by increasing the mussel dislodgement [11] and subsequent financial losses. Whereas we have emphasized overcrowding and food limitation, high densities also increase the risk of falloff and thus loss of commercial product [44], and predation [45]. Seed losses decreased with mussel size and increased with seeding density [41]. Movement and emergence of juveniles serve to adjust initial densities to alleviate crowding and inhibition of gape and feeding [46]. Even where density is maintained at higher levels, mussels "solve" crowding by behavioural sorting such as emergence, to grow normally.

In the traditional mussel cultures in Galicia (Spain), mussel density on culture ropes was reduced by the "thinning-out" process, after 4–7 months when mussels reached shell lengths of 40–50 mm. This process consists of detaching the individuals from the ropes and replacing them in order to reduce the density and homogenize the size distributions [47], but this method requires considerable labor and financial investment. Recently, [42] obtained suitable results at higher seed densities (1200 seeds. m^{-1}) without thinning-out, enable improvements in biomass, economic yields, and operating costs for mussel productions. In this study, the seed densities have been maximized to obtain higher commercial yields but overstocking lead to production losses as in many bivalve aquaculture sites [48].

Biomass and relative biomass production

The highest biomass increments in *P. perna* and *M. galloprovincialis* were recorded during the first season after seeding. This increase in biomass coincided with a decrease in density, showing that the growth in both species quickly compensates the mussel losses, according to [49-50]. In both cultures, biomass of *P. perna* reached high levels in comparison with *M. galloprovincialis*. Analysis of variation in biomass of *P. perna* and *M. galloprovincialis* indicated significant differences through the time with respect to seeding season. The lower biomass recorded in the mussels seeded at spring can be explained by the weight loss due to spawning in concurrence with a previous study [51]. The main spawning of both species occurred between June and September in the study area [22-52]. [24] found that the mean dry tissue weight in both species seeded at spring decreased between July and September from 1.25 to 0.5-0.6 g. When seeded in summer, biomass losses are compensated rapidly by growth in the following three months. These smaller seeds had a great growth rate and have not spawned between June and September 2002. Also, production in biomass increased in summer following the development of microalgae, reflected by the suitable concentrations of chlorophyll-a. The production in *P. perna* reached at harvest high levels (18.2 and 23.0 kg m^{-1}) in comparison with that obtained in Brazil (9.5 kg m^{-1}) by [40]. Using a culture raft, [53] found that maximum yield in *P. perna* was attained 9 months after seeding; 6.3 and 6.9 kg m^{-1} after spring and summer seeding respectively.

The higher gain in biomass of *P. perna* compared to that in *M. galloprovincialis* was due to their higher growth rate. [23] found that the mean length in *P. perna* and *M. galloprovincialis* increased in this area by 62 mm and 53 mm respectively after 12 months of culture. The gain of biomass in both species was especially higher during the first three months after seeding. [24] found that the maximum specific growth rates (SGR) in both species, ranged from 2.58 to 3.87, were recorded in the first month after seeding whatever the seeding season, while the minimum SGR ranged from 0.12 to 0.29, were recorded just before harvest. Indeed, the older mussels have a low growth rate due to the reduction of metabolic activity [54], the filtration rate [55], the rate of food [56] and the increase of the gametes production [57].

RBP is thus the product of the relative growth and survival between these two points in time [41]. RBP is defined as the average physical product (APP), discussed in [58]. The source of the large variability in RBP is often not clear and cultivation techniques seem to have an effect on RBP primarily at seeding [41]. In this study, RBP in both species was on average 3.0-4.9 kg harvested per kg seeded in spring season, and 6.6-7.4 kg harvested per kg seeded in summer season, higher than 1.5-2.5 range obtained with extensive mussel of *M. edulis* in the Wadden sea and above 1 kg kg^{-1} in Ireland [59-60-61].

However, a maximum RBP of 6 kg kg^{-1} reported by [62] in the Wadden Sea, was very close to the RBP's values obtained at harvest after summer seeding. For Stranford Loch (Northern Ireland) a maximum of 7 kg harvested per kg seeded has also been modeled [58]. In this study, maximum RBP's averaged per seed season increased from spring seed to summer seed in both species. [41] achieved better yields with autumn seed (1.9 kg kg^{-1}) for *M. edulis* cultivation in comparison with spring seed (1.3 kg kg^{-1}). In contrast, [53] have found that growth and yield were unaffected by the season of seeding in Ubatuba (Brazil). When seeded in early summer, we found that the mussel losses in *P. perna* and *M. galloprovincialis* were compensated by growth in the following three months. The production in biomass increased, following the development of phytoplankton in summer.

The seeds used in both cultures were not different among species in term of average size, reflecting the high morphological uniformity in populations. At harvest, the size frequency distributions always fitted unimodal distribution regardless the seeding season, revealing that the asymmetric competition mentioned by [39] did not occur over the both cultures. This competition generally occurs wherein larger mussels capture a higher share of resources and interfere with growth of smaller mussels. It was also observed by [47] at intermediate densities; 800 and 1000 seeds m^{-1}.

Commercial culture yields

The higher production observed in the experimental ropes seeded at summer compared with those seeded at spring is of interest as the mussels were cultivated with the same technique. Both species seeded at summer grew faster than those seeded at spring. *M. galloprovincialis* seeded at spring presented at harvest the worst commercial production with only 45.4 kg m^{-1} per rope (Table 3). The lower productions observed in mussels seeded at spring were due to the weight loss due to spawning in concurrence with previous studies [24-51]. These variations in production can also be explained by the temperature fluctuations as suggested by [63-65]. We pointed out that the greatest productions in both species were observed in summer where the temperatures were higher (19.5-21.5°C). The lower production observed in mussels seeded at spring could be attributed to the fact that mussels are exposed to a sea temperature lower (15.8-16.8°C) than its origin.

It is should be noted that *P. perna* reached rapidly the commercial size regardless the seeding season. [24] reported that *P. perna* has a higher growth rate. In Venezuela, *P. perna* has also a rapid pace of growth, achieving high rates with sizes up to 90 mm in less than a year under suspended culture systems [66]. It has been shown that the performance of *P. perna* depends physiologically on endogenous variability such as reproduction [67]. The interaction with the environment is also important, depending mainly on the food availability periods.

When seeded in summer, the annual production per rope of *Perna perna* and *M. galloprovincialis* were improved by 26% and 70% respectively, in comparison with those obtained in spring seeding. Moreover, the culture period of both species can be reduced by two months as more than 90% in population of mussels seeded at summer, reached the commercial size after 10 months of culture. As spring seeding did not give reliable results in terms of production and growth period, it shall be avoided.

Conclusion

The suitable productions of mussels during the present study may lead to promote the offshore mussel cultivation in many areas along the Atlantic coast of Morocco. The increase in production of mussels in offshore could satisfy the regional market demand without damage for the natural beds. However, it is necessary to move towards a culture technique which combines seed collection and growth in suspended culture to allow shorter production cycle of a mussel for this specific market. Moreover, the socks should be seeded with lower densities to limit the seed losses. Indeed, the range of the final densities in both species (473-735 ind. m^{-1}) seems to be the most appropriate range to initiate the suspended culture in offshore. The use of low seeding densities can considerably reduce the seed losses and the men efforts on seeding. Further studies are required to investigate by detailed monitoring, the effects of seeding density on the production of mussels, cultivated on an offshore longline system.

The most profitable species for cultivation on the submerged longline system is *Perna perna*. The productions in both species were affected by the season of seeding. The seeding at summer gave reliable results in term of production in comparison to those obtained at spring seeding. Moreover, it is not commercially worthwhile to farm mussels more than 11 months if the ropes are seeded at spring and not more than 10 months if they are seeded in summer, due to yield drops.

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