Environmental impact on the growth and productivity of *Mytilus galloprovincialis* from the Cala Iris Sea of Al Hoceima, Northern Morocco

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Abstract. Seasonal fluctuations, occurring during 2022, in mussels (Mytilus galloprovincialis) cultivated in different sites of Cala Iris Sea of the Moroccan Mediterranean coasts were investigated biometric parameters. The significantly higher ($p<0.05$) contents of the total weight (38.48 g), the fresh flesh weight (FFW) (7.93 g) and the dry flesh weight (DFW) (1.47 g) of Mytilus galloprovincialis registered in summer period were coincided with the maximum phytoplankton biomass (1.0774 µg/l), and the seawater temperature (20.29 °C) and salinity (39.60 PSU). Significant high ($p<0.05$) values of length (L (72.29 mm), height (H) (42.61 mm) and width (W) (27.81) (27.81 mm) were also observed in the season of summer. Positive correlations were observed between salinity, and temperature, and the growth of the animals. Based on the biometric parameters studied for the bivalves, it can be concluded that the best sales period for these bivalves was the summer season, due to a good content of the meat and a good size value of mussels. For a good cultivation and marketing of mussels, it is necessary to take into account the factors related to climate change.

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1 Introduction

Mytilus galloprovincialis, commonly known as the Mediterranean mussel, is a bivalve species widely distributed along the Mediterranean and Atlantic coasts. It is a filter-feeding shellfish living in shallow water, attached to a hard substrate (solids: rocky substrate, boat hull, etc.) [1, 2, 3, 4, 5, 6]. These bivalves ensure their exchanges with the aquatic environment in which they live by maintaining permanent circulation through their gills; the water passing through the animal ensures the intake of food, respiratory gas exchanges and the expulsion of waste and undesirable elements [7, 8]. This aquatic biota plays a major ecological role in marine ecosystems by filtering large quantities of water, thus contributing to trophic balance. Mussels also occupy an important place in global aquaculture, particularly in Mediterranean countries such as Morocco, Spain, Italy and Greece [9, 10].

In Morocco, aquaculture is booming, driven by the law of 2023 and the National Agency for the Development of Aquaculture [3]. The sector focuses on shellfish and fish farming, with projects developing along both coasts (the Mediterranean and the Atlantic) to stimulate and diversify the country's blue economy and reduce pressure on wild fisheries resources [9, 11, 12].

Bivalve growth and production are important biological factors to consider in any mussel farming operation [13, 14, 15]. Indeed, the animal's physiological parameters (growth and size) are highly dependent on the environmental conditions of its habitat. These environmental parameters include: water temperature, salinity, food availability, water quality, and the hydrodynamic factors of the environment [16, 17].

Added to this are increasingly significant anthropogenic pressures, including marine pollution (heavy metals, hydrocarbons, pesticides, microplastics), eutrophication, and the impacts of climate change, such as ocean acidification and warming waters. These constraints alter not only mussel physiology, but also their market availability and quality, calling into question the sustainability of mussel farming activities [18].

Thus, the growth and productivity of this species are the result of complex interactions between the bivalve's physiological capacities and environmental conditions [16, 19]. Understanding the impact of these parameters is essential not only for optimizing mussel farming practices, but also for the conservation of wild populations, which are increasingly degraded and disappearing from the natural environment, in the context of climate change and increasing anthropogenic pressures [20, 21]. In this context, the study of the interactions between *M. galloprovincialis* and its environment appears to be a crucial step in better understanding the tolerance and adaptation mechanisms of this species, while making it possible to anticipate the risks that weigh on its production [20, 22, 23].

It is known that the seawater environmental parameters as well as food availability may influence the growth and the meat yield of the mussels. However, there is no information in the literature data on the growth performance of *M. galloprovincialis* cultured on the Moroccan Mediterranean coast, nor on their seasonal variations. The main objective of the present study was to better understand the seasonal growth and production of *M. galloprovincialis*, a mussel of high commercial importance in aquaculture, on the Cala Iris sea of Al Hoceima of the Moroccan Mediterranean coasts, the climate changes and their influences on this mussel farming were also analyzed.

2 Material and Methods

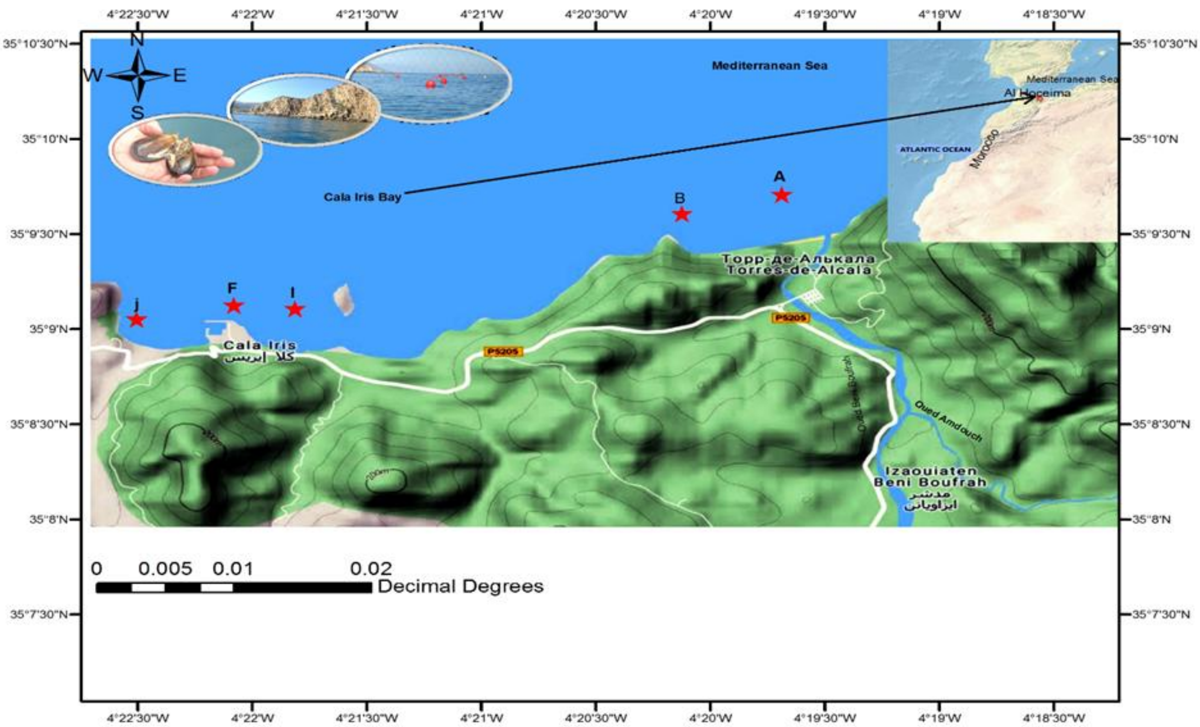

Fig. 1. Map showing sample collection sites.

2.1 Sampling sites and sample collection

Mytilus galloprovincialis specimens were harvested in northern of Moroccan Mediterranean coasts from five mytiliculture sites (**fig. 1**). Sampling waters were also collected in bottles from the same sites of bivalve samples. Bottle seawaters and biota specimens were transported in a cold box at + 4 °C to the laboratory to be analyzed [9, 24].

2.2 Determination of environmental factors

Temperature, salinity, and dissolved oxygen were determined *in situ*, at different sampling sites [21] using the multiparameter apparatus (HQd Series portable meters, HACH, Safety Mark). Upon arrival at the laboratory, chlorophyll a was immediately analyzed in seawater taken from the different sampling locations, using the colorimetric method as described in the different works carried out in our laboratory [14, 15]. Different measurements were carried out seasonally during the sampling period.

2.3 Growth and production analyses

A sample of sixty mussels is collected every season of 2022 from different sites of the mussel farming on the Al Hoceima costs, in order to carry out a series of measurements of the size and weight [9]. The samples were washed and cleaned on the same site before being transported to the laboratory for analysis [3]. The soft tissues of animals were removed from each mussel using scalpel to obtain the entire soft body and the shell. These components were dehydrate in an oven during 48 h at 100°C to obtain dry weight values (g). The whole body weight (TW, g), fresh shell weight (FSW; g), dry shell weight (DSW; g), fresh flesh weight (FFW; g), and dry flesh weight (DFW; g)) were carried out to the nearest 0.001 g, using an analytical balance [25, 26, 27]. For the measurement of size represented by shell length (L; maximum anterior–posterior axis), shell height (H; maximum dorso-ventral axis) and shell width (W; maximum lateral axis), a digital caliper was used to within 0.1 mm [9].

2.4 Statistical analysis

Statistical data analysis was done using STATGRAPHICS plus 5. Effect on seasonal weight and size were determined using a one-way ANOVA followed by Tukey's test. ANOVA data with a $p < 0.05$ was classified as statistically significant. Pearson correlations were used to explore interaction between biometric parameters of each mussel species and environmental variability.

3 Results and Discussion

3.1 Environmental parameters data

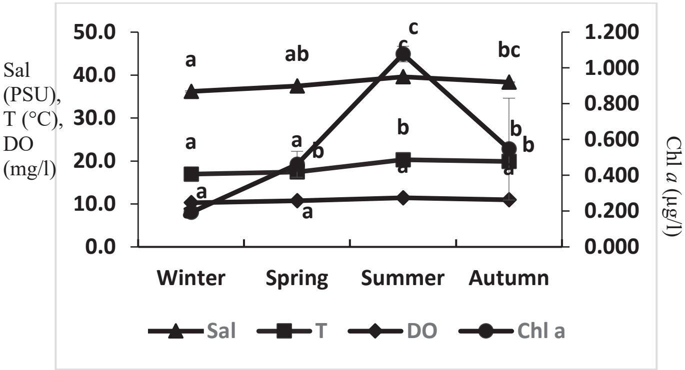

Fig. 2. Seasonal climatic changes (± SEM) in environmental parameters ((salinity (Sal), temperature (T), dissolved oxygen (DO) and chlorophyll *a* (chl *a*)) at the mussel farm on the coasts of Cala Iris in Al Hoceima, Northeastern Morocco, during the investigation period. Different letters (a, b and c) from the same parameter indicate significant differences (P < 0.05) between seasons, using Tukey test.

Seasonal variations in environmental parameters of the Cala Iris mussel farm in Al Hoceima are illustrated in **figure 2**. For salinity, the value was significantly (p<0.05) higher in summer (39.60 PSU) and lower in winter (36.20 PSU). Temperature values reach their maximum with significant values (p<0.05) in summer (20.29 °C), while the minimum values are found in winter (16.95 °C). Spring and autumn seemed to be transitional periods. The same tendency are found by many authors on the Mediterranean coasts [5, 9, 16, 28, 30]. The important decreased value in the salinity and temperature in winter period could be linked to heavy rainfall, and consequently the rivers near the mussel farm bring freshwater to the Moroccan Mediterranean Sea. For dissolved oxygen, no significant differences (p>0.05) were observed during the seasons of sampling with an average value of 10.84 mg/l, indicating that the seawater of Al Hoceima coasts were well oxygenated, as also indicated by Azizi et al. [20]. The chlorophyll *a* contents showed important seasonal variations, with highest values were recorded in summer (1.0774 µg/l) and lowest in winter (0.1928 µg/l). The environmental factors studied in the present work and the availability of nutrients (chl *a*) showed an effect on the growth performance and productivity of mussels as indicated by various investigators [3, 31].

3.2 Seasonal monitoring of growth and production of *Mytilus galloprovincialis*.

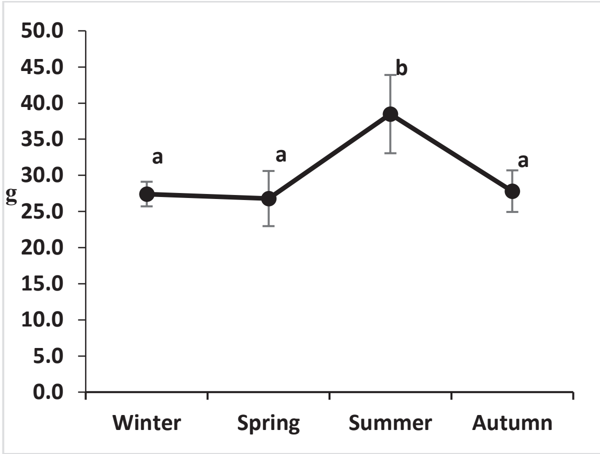

Fig. 3. The seasonal distribution of the total weight (± SEM) of *Mytilus galloprovincialis* during the sampling period at Cala Iris of Al Hoceima coasts, Moroccan Mediterranean. Different letters (a and b) indicate significant differences (P < 0.05) using Tukey test.

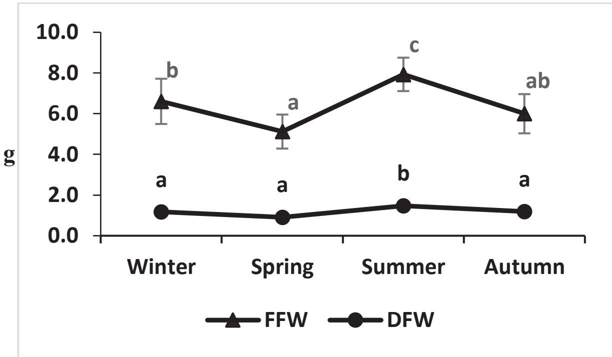

Fig. 4. The seasonal distribution (± SEM) of the fresh flesh weight (FFW) and dry flesh weight (DFW) of *Mytilus galloprovincialis* during the sampling period at Cala Iris of Al Hoceima coasts, Moroccan Mediterranean. Different letters (a, b and c) from the same parameter indicate significant differences (P < 0.05) using Tukey test.

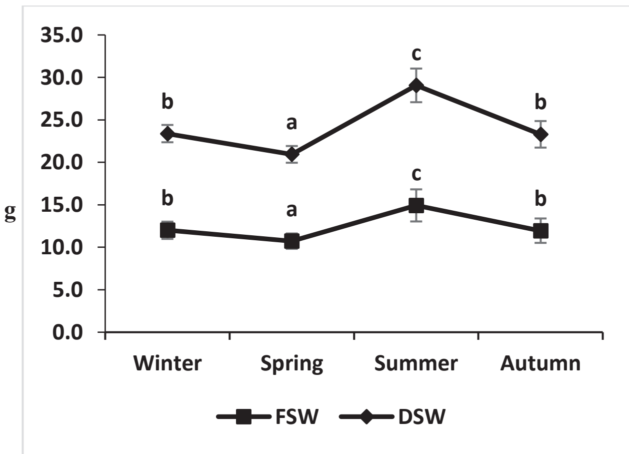

Fig. 5. The seasonal distribution (± SEM) of the fresh shell weight (FSW) and dry shell weight (DSW) of *Mytilus galloprovincialis* during the sampling period at Cala Iris of Al Hoceima coasts, Moroccan

Mediterranean. Different letters (a, b and c) from the same parameter indicate significant differences ($P < 0.05$) using Tukey test.

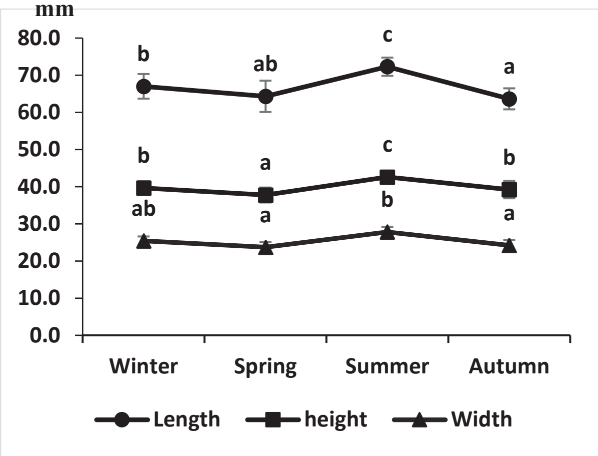

Fig. 6. Effect of climate change on the evolution of the size (length (L), height (H) and Width (W)) (mean ± SEM) of the *Mytilus galloprovincialis* in Cala Iris sea of Al Hoceima during the investigation period. Different letters (a, b and c) from the same parameter indicate significant differences ($P < 0.05$) between seasons, using Tukey test.

The total weight (**figure 3**), the fresh and dry flesh weight (**figure 4**), and the fresh and dry shell weight (**figure 5**) of mussels in the Cala Iris sea of Al Hoceima, illustrate the production of the bivalves during the experimental period, and the size indicated by length, height and Width (**figure 6**) illustrate the growth of the animals in the sampling sites.

For the bivalve production parameters, significant increases ($p<0.05$) were observed during the summer season with values (38.48, 7.93 and 1.47, and 14.93 and 14.13 g for TW, FFW and DFW, and FSW and DSW, respectively) and a decrease during the spring season (26.79, 5.12 and 0.91, and 10.72 and 10.22 g for TW, FFW and DFW, and FSW and DSW, respectively). For the animal size, similar trend results were observed, with a significant increase ($p<0.05$) during the summer (72.29, 42.61 and 27.81 mm, for L, H and W, respectively) and a decrease during the spring (64.32, 37.76 and 23.72 mm, for L, H and W, respectively). The production values, represented by the total weight, the weight of the meat, and the weight of the shell of the animal, have very similar patterns: slower content in spring and an increase in summer. Similar fluctuations were observed for the growth values.

The growth and production of marine bivalves were affected by several environmental factors such as water temperature, salinity and food supply. Authors [32, 33, 34, 35, 36] indicated that temperature and phytoplankton availability are the most important factors. In our work, we observed an increase in the animal studied parameters during the summer period, which coincided with temperature, salinity and phytoplankton increased. These data were in agreement with similar investigations performed on bivalves sampled from the Ireland coastline [37] and Italy coasts [38]. The studies indicated an influence of environmental factors such as seawater temperature and phytoplankton biomass on the mussel growth and production. O'Boyle and Silke [39] indicated that during the winter period, a decrease in sea surface irradiation induces a decrease in marine phytoplankton biomass, which negatively affects the growth of bivalves.

3.3 Correlation between mussel growth and environmental parameters

Table 1. Correlation coefficients between environmental parameters and growth and size of *Mytilus galloprovincialis* using data of all seasons.

Weight / size of bivalve	T	Sal	DO	Chl *a*
Total weight	0.573*	0.596*	0.188	0.104
Fresh flesh weight	0.358	0.288	-0.026	0.064
Dry flesh weight	0.484	0.390	0.015	-0.061
Fresh shell weight	0.440	0.464	0.081	0.049
Dry shell weight	0.441	0.462	0.065	0.051
Length	0.256	0.283	0.046	0.212
Height	0.416	0.333	-0.027	0.098
Width	0.327	0.346	0.072	0.161

*Correlation is significant at the 0.05 level (2-tailed).

Statistical analyses were applied to highlight any correlation between environmental factors and weight and size of bivalves sampled from the Cala Iris sea of Al Hoceima coasts (Table 1). Only temperature and salinity showed positive correlation with total weight of *Mytilus galloprovincialis* with values of $r = 0.573$ and 0.596, for temperature and salinity, respectively, at the significance level 0.05. Dissolved oxygen and Chlorophyll *a* were not correlated with any of the biometric variables examined of the mussels. This indicated the importance of temperature and salinity in the growth and production of the biota. Similar results were indicated in previous work [3, 8] by determining the possible correlations between environmental factors and the bivalves in the Moroccan Mediterranean coasts.

Conclusion

Bivalves constitute an important food source in the socio-economic context of Morocco. Mussels are generally valued for their nutritional quality, organoleptic properties and economic potential. However, studying their production and growth in the Moroccan Mediterranean is of extraordinary importance for the income of the population of the region. Results on the biometric parameters of *M. galloprovincialis* from the Cala Iris sea of Al Hoceima, indicated higher values of production represented by total weight, fresh and dry flesh, and fresh and dry shell, and of growth represented by length, height and width of the animal, during the summer period, which coincided with the maximum phytoplankton biomass, and the high values of temperature and salinity. On the other hand, these parameters show lower values during the spring season. The fluctuation of the studied environmental parameters, and in addition to the positive correlations existing between those parameters and mussel growth, indicated the hypothesis that this study is crucial to improve mussel farming practices, and to ensure the sustainability of production of this species.

Authors' Contributions: **Ghizlane Azizi**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing; **Hamza Ngadi**: Formal analysis; Roles/Writing - original draft, **Abdelhay Benyaich**: Software; **Sara Esseffar**: Writing - review & editing; **Hicham Gueddari**: Resources; **Mourad Baghour**: Writing - review & editing; **Said Bellahcen**: Resources; **Abdelmajid Moumen**: Formal analysis, Project administration, Resources, Software, Supervision, Validation, Writing - review & editing.

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