The Mutual Impact Between the Population Dynamics of *Mytilus galloprovincialis* and the Harvesting of Mussels in the Massa-Tifnit Area (Southwest Morocco)

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ABSTRACT

This study provides a comparative analysis of the population dynamics and growth parameters of *Mytilus galloprovincialis*, based on monthly monitoring in three natural beds along the Moroccan Atlantic coast south of Agadir: Sidi R'bat, Douira, and Tifnit. Conducted over two years, from January 2018 to December 2019, the research aimed to assess the impact of mussel harvesting on their spatial distribution and ecological sustainability. Parameters were determined from size frequencies using FiSAT II software (FAO-ICLARM Stock Assessment Tools). Results showed significant variations in density, biomass, and condition index across all three sites, influenced by environmental and physicochemical factors, as well as the life cycle of the mussels. Douira exhibited the highest levels in the first year. Size class frequency distributions revealed slight differences among stations, with recruitment occurring throughout the study, peaking in winter-spring and summer. The growth rate, measured using the von Bertalanffy equation, was K = 0.5 yr^{-1} at all sites, with maximum asymptotic length (L∞) and growth performance index (Φ') at Tifnit, recorded at 112mm and 3.7, respectively. Mortality rates (total mortality Z, natural mortality M, fishing mortality F) and exploitation rate (E) were at their highest at Douira (Z = 2.84 yr^{-1}, M = 0.87 yr^{-1}, F = 3.45 yr^{-1}, E = 0.81 yr^{-1}), resulting in a low survival rate (S = 0.014 yr^{-1}). The findings underscore the importance of sustainable management practices by local communities and cooperatives to ensure ecosystem sustainability and product quality.

INTRODUCTION

The Moroccan Atlantic coast is home to a remarkable diversity of marine life, making it a major center of economic and social development. This sector currently plays an important role in the national economy because of its resources, significantly contributing to the country's food self-sufficiency. The natural mussel beds of Morocco's Massa-Tifnit region, like others in the country, are home to various types of mollusks, including the *Mytilus galloprovincialis* mussel (**Lamarck, 1819**), also known as the Mediterranean

mussel. Mussel populations are characterized by a renewal process that is driven primarily by the settlement of spat. However, this renewal process can be disrupted by adverse hydroclimatic conditions, the pressures of human activities, predation and intensive exploitation, particularly harvesting by riverside populations. Excessive harvesting can lead to a decline in mussel populations by eliminating large numbers of individuals, thus upsetting the ecological balance of the ecosystem, especially if spawners or large specimens are targeted. In addition, unsustainable harvesting can alter the mussels' natural habitat by disturbing the rocky substrates or intertidal zones where they settle. This situation has prompted Morocco to adopt a strategy based on promising prospects through numerous projects aimed at the sustainable development and management of mussels, given their socioeconomic and environmental importance.

Thus, several previous studies have been conducted on the reproductive cycle, population dynamics of natural beds and/or "of Schoor" populations **(Bitar, 1987; Naciri, 1990; Id Halla *et al.,* 1997; Najimi *et al.,* 1997; Bouhaimi *et al.,* 1999; Benomar *et al.,* 2006; El Khou *et al.,* 2017)** and have explored the utilization of mussels as sentinel and bioaccumulative species, thus serving as indicators of the state of the marine environment **(Azdi *et al.,* 2006; Moukrim *et al.,* 2000; Abbassi *et al.,* 2015; Banaoui *et al.,* 2015; Elazzaoui *et al.,* 2019)**. Most of these investigations are concentrated on the North Atlantic Moroccan coast.

Recent scientific data on the population dynamics and exploitation status of the marine ecosystems of the three Sidi R'bat-Douira-Tifnit sites are rarely published. However, rational management of mussel stocks requires in-depth knowledge of their population dynamics. This is the background of the present study, which aimed to fill the gaps left by previous research through developing a comprehensive database on this species. The aim of this study was to carry out regular monthly monitoring of the dynamics, growth, total mortality, exploitation and recruitment of the *M. galloprovincialis* population in three natural beds located approximately 60km south of Agadir on the southern Atlantic coast of Morocco: Tifnit, Douira and Sidi R'bat.

This approach was motivated by three main objectives:

- To gain a thorough understanding of the exploitable characteristics of the species studied in these three beds.

- To compare their spatial distributions in relation to fluctuations in population dynamics over two years at the three sites;

- To investigate the origins of these changes in relation to variations in natural environmental parameters and adverse anthropogenic constraints on the environment.

Such scientific knowledge is crucial to guide any sustainable exploitation initiatives, including aquaculture projects planned in the region, and to support local cooperatives, particularly those run by women. The implementation of appropriate conservation and management measures, such as the designation of protected areas, the introduction of seasonal closures, and awareness-raising and education programs aimed at informing and

involving collectors and the local population, is imperative. The aim is to ensure sustainable and rational management of this exploited ecosystem while enabling local communities to continue to benefit from it in harmony with the imperatives of preserving marine resources.

MATERIALS AND METHODS

1. Sampling sites

Our study was conducted at three coastal sites located in the Moroccan Atlantic of the Massa commune, south of Agadir (Fig. 1): Tifnit (30°11'34.0"N 9°88'23.2"W), Douira (30°07'41.6"N 9°39'17.7"W), and Sidi R'bat (30°05'29.4"N 9°40'02.2"W). This area is characterized by a semiarid climate with oceanic dominance. The annual precipitation is very low (≤100mm), and the temperatures are mild and moderate due to the coastal location. Importantly, this coast is subject to climatic-marine dynamics (upwelling) **(Roy, 1991; Agoumi & Orbi, 1992)**, as well as the influence of the Azores anticyclone, which varies in absolute value and geographical position **(Amraoui *et al.*, 2011)**.

It is important to mention that the three selected mussel beds belong to the mediolittoral zone, with approximately ten kilometers between each site. They rest on rocky flats that are easily accessible on foot and are home to numerous mollusks, with the Mediterranean mussel *M. galloprovincialis* predominating. As a result, this species is subject to heavy uncontrolled harvesting by residents and summer visitors, both for resale and for human consumption.
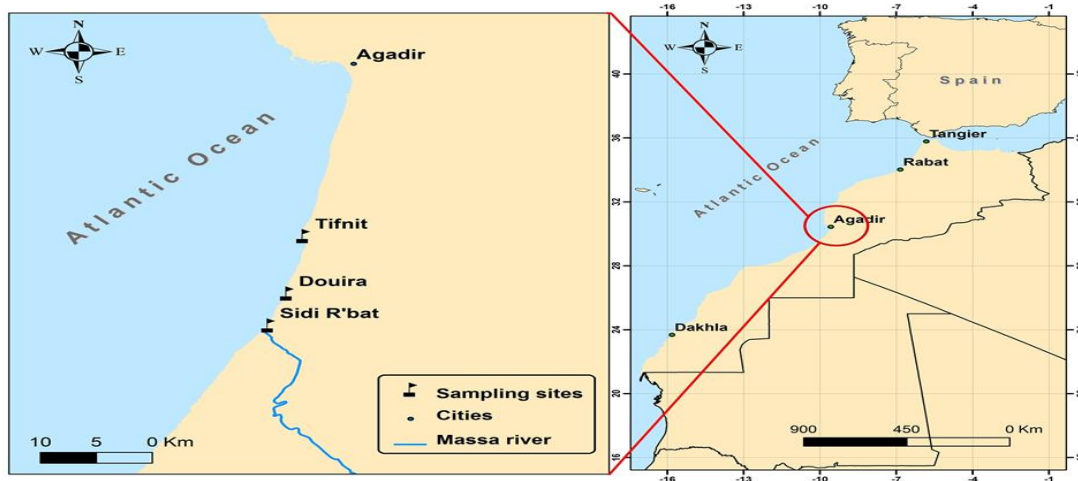

Fig. 1. Map of the three surveyed sites: Tifnit, Douira, and Sidi R'bat south of Agadir (Morocco)

1. Field sampling and analysis

1.1 Environmental parameters

Sampling was conducted over a two-year period (January 2018 to December 2019) at the three aforementioned sites. Surface water parameters, including temperature, pH, dissolved oxygen, and conductivity, were measured *in situ* during the sampling period. The temperature and conductivity were measured via a Thermo Scientific Orion StarTM A222 device, the dissolved oxygen content was measured via a Thermo Scientific Orion 3- Star plus apparatus, and the pH was measured via an HI-9024 Hanna pH meter.

1.2 Population dynamics and growth

M. galloprovincialis was collected monthly at low tide over an area of 0.25m² (4 quadrats of 25 × 25cm per survey) **(Menesguen, 1980)** and was randomly selected from the upper mediolittoral region. The animals harvested and transferred to the laboratory in tubs were first cleaned before measuring the anteroposterior length of the shell with a caliper (± 0.01mm). The animals were subsequently divided into size classes of 1mm each on the basis of their length (Lt) **(Moueza, 1971)**. This last measurement was used to study population dynamics and establish growth curves, given that the measurement (Lt) was a very suitable biometric variable for estimating the linear growth of mollusks **(Bayne, 1976)**. This study was completed by counting mollusks to determine their density (in ind/m^2) and by measuring their fresh weight with a precision balance to evaluate their biomass (g/m^2).

1.3 Condition index

In addition, 30 individuals per site were randomly sampled with a size class as close to 20 to 30mm as possible over the two cycles. These samples were used to determine the condition index **(Beninger, 1984)**. In the laboratory, after the mollusks were cleaned, the dry weights of the shell and flesh were measured after drying at 60°C for 48 hours. The condition index was calculated according to the following relationship:

CI= [(dry weight of meat/dry weight of shell) ×100]

2. Data processing growth

The individual values collected in the mussel growth study were processed with FISAT software **(Gayanilo *et al.*, 1996)**. This was achieved to plot size frequency histograms as a function of animal frequency and to perform a modal analysis on the basis of the algorithm according to the method of **Battacharya (1967)**. This comparison, with an application of the χ^2 test (at the 5% threshold), made it possible to distinguish the different age classes that made up the sample at each site and to plot the linear growth curves according to the growth function of **von Bertalanffy (1938)**: $Lt = L\infty (1 - e^{-K(t - t_0)})$.

Where, L∞ is the asymptotic mean length; Lt is the average length at time t; K is the growth coefficient (per year), and t is the time or age. For age t_0 at zero length, the value was calculated from the **Pauly (1979)** equation:

$$Log_{10} (-t_0) = - 0.392 - 0.275 \log_{10} (L\infty) - 1.038 \log_{10} (K)$$

The growth parameters, including the theoretical maximum length (L∞) and growth coefficient (K), were estimated from length frequency data via ELEFANT-I (Electronic Length-Frequency Analysis) software **(Pauly & David 1981)**. This method is widely used to estimate growth parameters for fish, crustaceans and bivalves **(Amin *et al.*, 2002)**.

2.1 Mortality

To assess total mortality Z, the length-converted catch curve method developed by **Pauly (1984)** was used. The natural mortality (M), which represents mortality without fishing involvement, was determined via the equation shown by **Pauly (1980)**. To specifically estimate fishing mortality (F), M was subtracted from Z, leaving mortality attributable solely to fishing activity. Finally, the level of exploitation (E), the intensity of fishing pressure on the mussel population, and the percentage survival of the samples (S) were determined using the empirical formula of **Gulland (1965)**: **E=F/Z** and **Gayanilo *et al.* (1996)**: **S=EXP(-Z)**.

2.2 The growth performance index

The linear growth performance index (Φ') was calculated according to the equation of **Pauly and Munro (1984)**: $\mathbf{\Phi' = \log_{10}(K) + 2\log_{10}(L\infty)}$

2.3   Recruitment

Recruitment can be described as the process by which a set of mussels of reduced size first join the stock of mussels of exploitable size. This recruitment phenomenon is assessed on the basis of the frequency distribution of mussel sizes **(Ahouansou, 2011)**.

2.4 Data analysis

STATISTICA (2006) software was used for the statistical analyses. Potential correlations between environmental parameters and biometric variables, including density, biomass, and condition indices, were evaluated using correlation analyses. One-way ANOVA tests were performed to assess whether significant differences existed in these variables, as well as in growth parameters, across study sites and seasons. Fisher's least significant difference (LSD) test was used for post hoc multiple comparisons to identify specific contrasts.

RESULTS

1. Environmental parameters

The monthly values of the different water parameters measured at the three study stations are presented in Fig. (2).

The environmental parameters monitored monthly showed distinct seasonal trends at the study sites, but no significant differences ($P = 0.05$) were observed according to the fisher smallest significant difference test. The water temperature followed a typical annual cycle, reaching a peak of 24–25°C in summer (August 2018 and 2019) and a minimum of 16–17°C in winter (January 2018 and 2019). The pH values were alkaline in

spring, ranging from 8.4-8.75 in April-May but decreased to slightly acidic levels of 7.3-7.4 in winter and autumn 2018. Dissolved oxygen concentrations were inversely related to temperature, with a maximum of 8.45–8.62mg/ L in winter and a minimum of 4.14–4.66mg/ L in late summer/early autumn. The electrical conductivity showed an annual fluctuation, ranging from 42–48.71ms/ cm during the winter/spring period to maximum levels of 65–66.58ms/ cm in autumn.
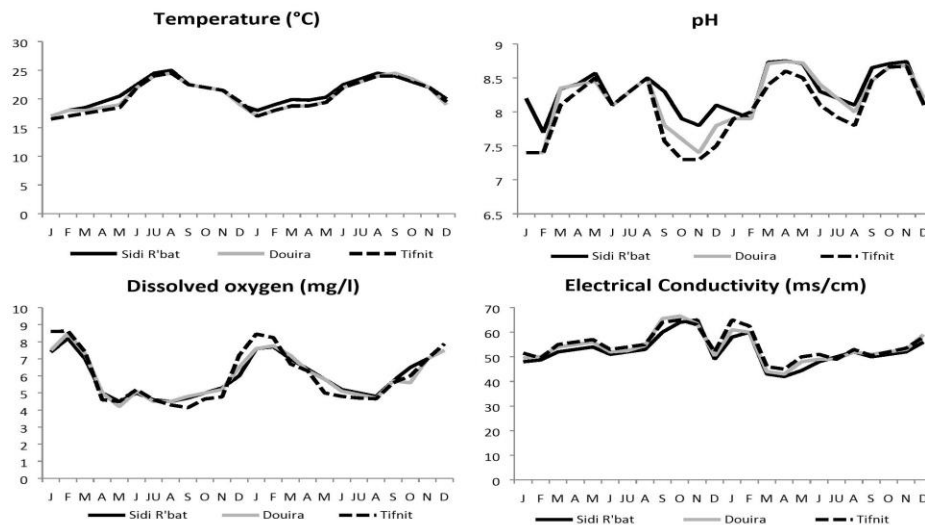

Fig. 2. Monthly variations in water temperature, pH, dissolved oxygen, and conductivity at the three stations throughout the study period (2018-2019)

2. Size frequency distribution of *Mytilus galloprovincialis*

The evolution of the size frequency distribution of *M. galloprovincialis* (Fig. 3.) across the three study sites over the period from 2018-2019 showed monthly variations in the population's size structure. This is a multimodal distribution and therefore heterogeneous population were derived from several cohorts.
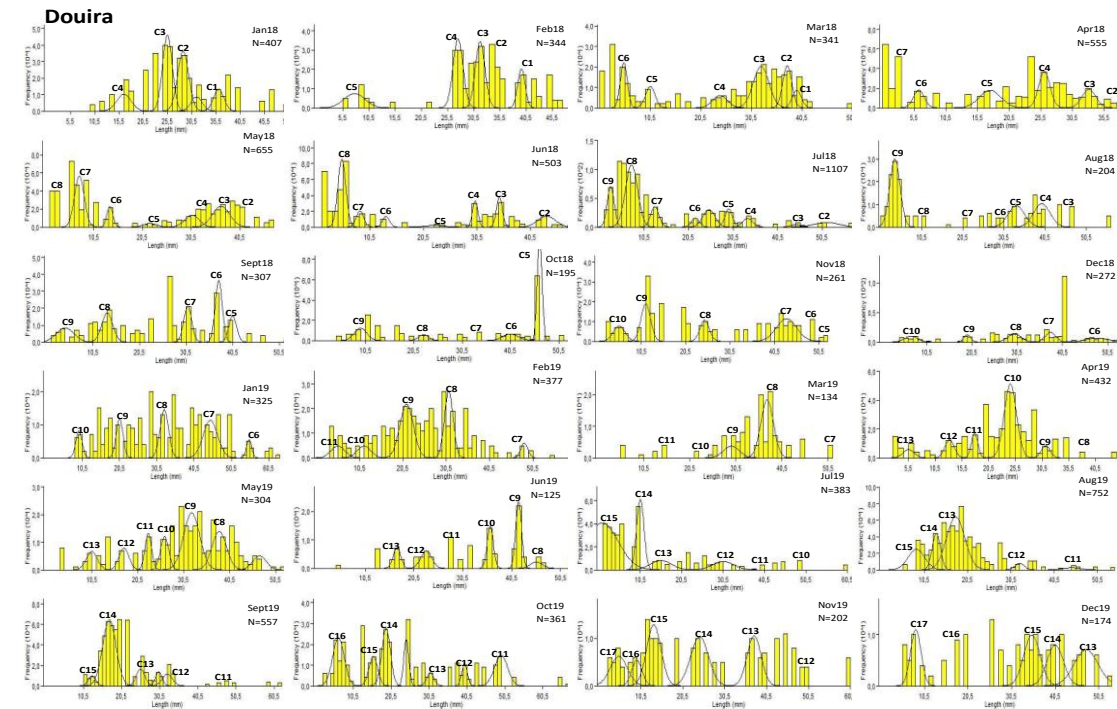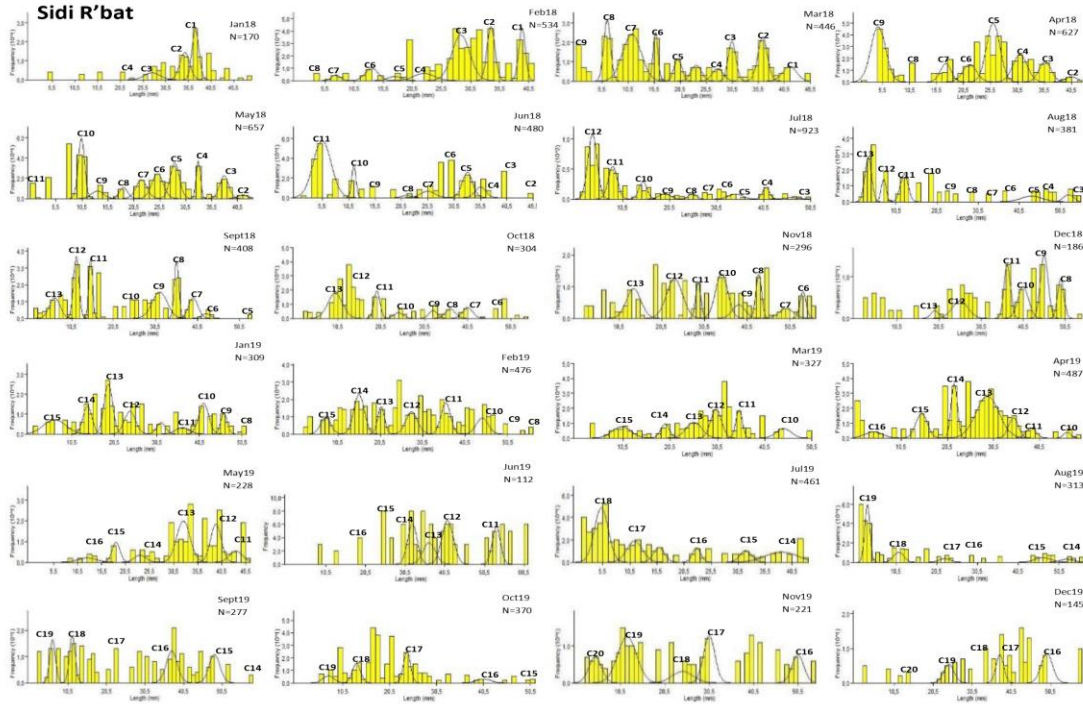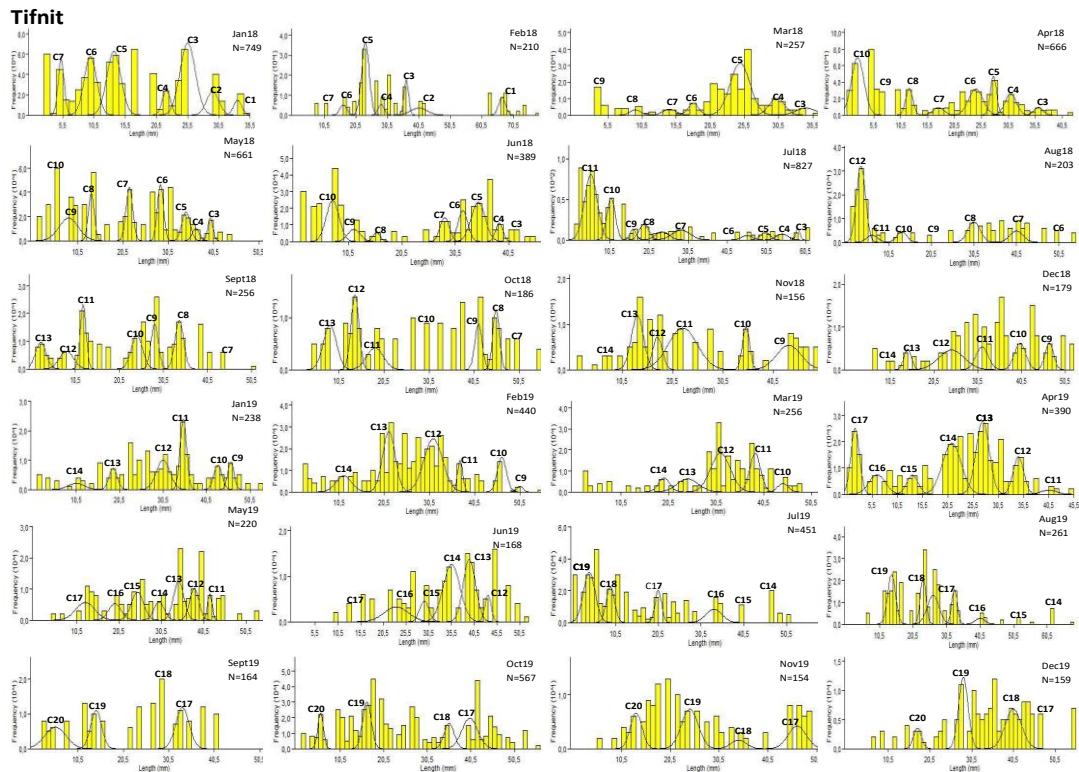
Fig. 3. Size frequency distribution of *M. galloprovincialis* at the three stations throughout the study period (2018-2019)

The evolution of *M. galloprovincialis* size frequencies for the three sites presented several modes per histogram, with an average of approximately twenty cohorts during the period from January 2018 to December 2019; however, tracking the evolution of all cohorts was not possible because of the effects of harvesting and predation.

Young mussels appear almost year-round, with two major periods: winter–spring and summer, allowing the population to renew itself. The size of these young mussels varies between 1 and 9mm. The cohorts corresponding to young individuals are as follows:

-In Sidi R'bat, in spring, C9 (March 2018) and C16 (April 2019) and in summer, C12 (July 2018) and C18 (August 2019);

-In Douira, in April (C7, 2018), (C13, 2019) and July (C9, 2018), (C15, 2019);

-In Tifnit, in April (C10, 2018) and (C17, 2019), and in summer, in C12 (August 2018) and C19 (July 2019).

3. Recruitment

The recruitment of the studied species is widespread throughout the year at the three study sites. The intensity of this process fluctuates over time. Fig. (4) shows the average size of the recently recruited juvenile mussel class by month, as well as the percentage of this class in the total population, which varies between 1 and 18%. Analysis of this overall recruitment pattern revealed two intense periods of juvenile mussel recruitment: one in winter–spring and the other in summer.
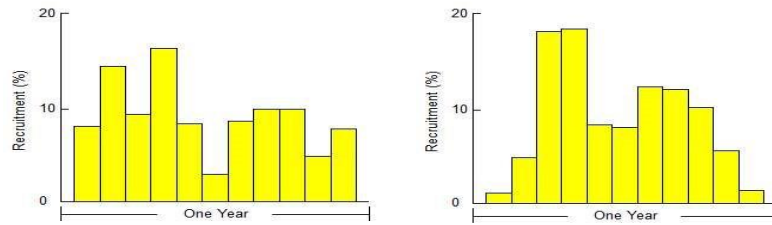
Fig. 4. Percentage class of recruited juveniles of *M. galloprovincialis* as a function of sampling month (2018-2019) at the three surveyed sites

4. Density, biomass and condition index of *M. galloprovincialis*

The monthly variation in *M. galloprovincialis* densities at the three study stations is shown in Fig. (5).

Fig. 5. Density and monthly biomass of *M. galloprovincialis* from January 2018 to December 2019 for the populations of Sidi R'bat, Douira and Tifnit

During the study, the mean annual densities of *M. galloprovincialis* in Sidi R'bat, Douira and Tifnit were 6092 ± 2968.05, 6184.66 ± 3546, and 5471.33 ± 3322.10 ind/m², respectively. Peaks were generally observed in summer, mainly in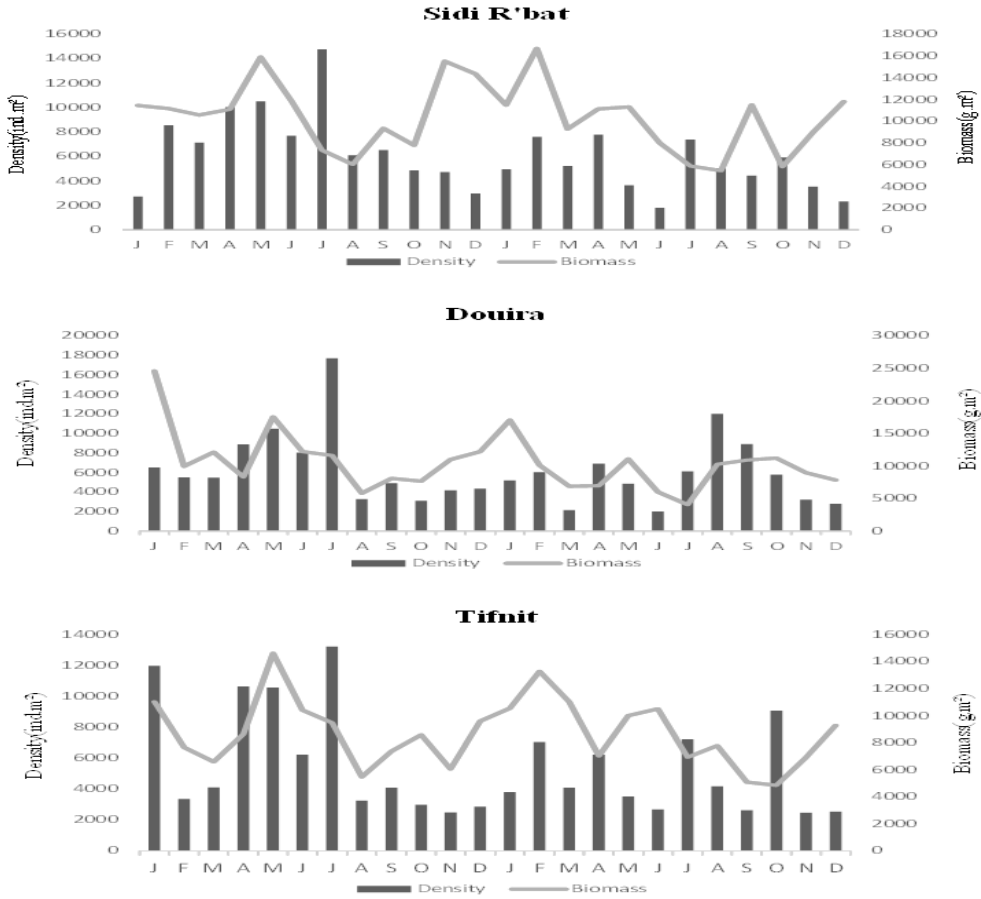 July and early spring, such as in July 2018 in Douira with 17712 ind/m² and in April 2018 in Tifnit with 10656 ind/m², whereas the minimum peak was recorded in November with 2000 ind/m² in Douira. The average annual biomasses of *M. galloprovincialis* were recorded at 10,396.38 ± 3,183.10g/ m² in Sidi R'bat, 10,524.03 ± 4,382.65g/ m² in Douira, and 8,701.65 ± 2,492.32g/ m² in Tifnit. The maximum biomass was observed in winter, reaching 24,638.944g/ m² in January 2018 in Douira. There were two significant declines in biomass: one in spring, with 6,586.68g/ m² in March 2018 in Tifnit, and another in summer, with 4,052.448g/ m² in July 2018 in Douira.

Analysis of density and biomass variations for the *M. galloprovincialis* mussel via ANOVA and Student (LSD) tests revealed no significant differences in density among the three sites ($P>0.05$) or between seasons. However, for biomass, a significant difference was observed between seasons ($P<0.05$), notably at Sidi R'bat in winter 2019 and at Tifnit in autumn 2019.
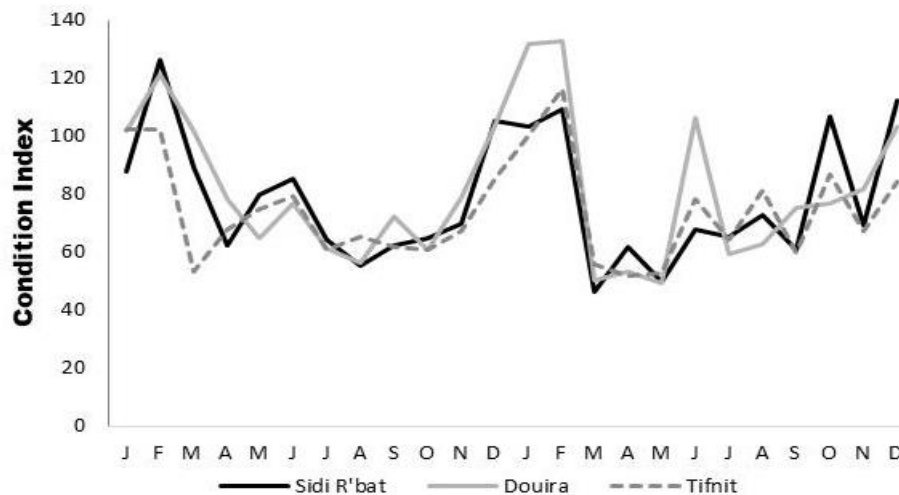
Fig. 6. Monthly variations in condition index (CI) of *M. galloprovincialis* at Sidi R'bat, Douira and Tifnit during the study period (2018/2019)

The monthly evolution of the CI for the species studied at the three sites across the two study cycles is depicted in Fig. (6). The index values exhibit consistent fluctuations: they peak during winter, gradually declining in the spring, reaching a minimum in April–May, and then rising in June before decreasing again in August–September. Notably, the CI increased to 126.62% in February 2018 in Sidi R'bat, 116.21% in February 2019 in Tifnit, and 133.08% in February 2019 in Douira. Significant discrepancies ($P=0.011$) were observed during spring, with the index registering at 46.23% in March 2019 in Sidi R'bat and increasing to 51.74% in April 2019 in Tifnit. Upon analyzing the seasonal variations,

a notable divergence (*P*<0.05) was discerned across all three sites during both periods. However, no significant distinctions were noted between the sites (*P*>0.05).

5. Relationships between density, biomass and condition index and environmental parameters

The correlations between the density, biomass and CI of *M. galloprovincialis* and environmental parameters (temperature, pH, conductivity and dissolved oxygen) are presented in Table (1).

Table. 1. Correlations between density, biomass and condition index with environmental parameters for *M. galloprovincialis*

		pH	T (°C)	DO (mg/l)	EC (ms/cm)
Sidi R'bat	Density	0.009 p=0.965	0.480 **p=0.018**	-0.297 p=0.157	0.036 p=0.866
	Biomass	-0.257 p=0.225	-0.609 **p=0.002**	0.297 p=0.158	0.217 p=0.309
	Condition index	-0.542 **p=0.006**	-0.496 **p=0.014**	0.631 **p=0.001**	0.186 p=0.384
Douira	Density	0.046 p=0.830	0.534 **p=0.007**	-0.342 p=0.102	-0.056 p=0.794
	Biomass	-0.354 p=0.090	-0.430 **p=0.036**	0.290 p=0.169	0.090 p=0.675
	Condition index	-0.482 **p=0.017**	-0.534 **p=0.007**	0.644 **p=0.001**	0.209 p=0.327
Tifnit	Density	0.174 p=0.416	0.620 **p=0.001**	-0.089 p=0.680	-0.109 p=0.613
	Biomass	-0.065 p=0.760	-0.512 **p=0.011**	0.205 p=0.335	0.145 p=0.500
	Condition index	-0.365 p=0.080	-0.385 p=0.063	0.620 **p=0.001**	0.246 p=0.247

Density was positively correlated with temperature at all three sites. In contrast, biomass was significantly negatively correlated with temperature at all three sites: Sidi R'bat (r=-0.6092 p=0.002), Tifnit (r=-0.5119 p=0.011), and Douira (r=-0.4296 p=0.036). The condition index was negatively correlated with pH in Sidi R'bat (r=-0.5425 p=0.006) and Douira (r=-0.4817 p=0.017) and negatively correlated with temperature in Sidi R'bat (r=-0.4961 p=0.014) and Douira (r=-0.5345 p=0.007). Finally, CI was highly significantly positively correlated with dissolved oxygen at Sidi R'bat, Douira and Tifnit (r=0.6306, *P*=0.001; r=0.6442, *P*=0.001; r=0.6197, *P*=0.001, respectively).

6. Age and linear growth

A comparison of the parameters of the von Bertalanffy equation obtained for *M. galloprovincialis* from the three sites studied (Table 2) revealed a non significant difference depending on the site. The highest value for asymptotic length (L∞) was recorded at Tifnit (112mm), followed by Douira (95mm) and Sidi R'bat (70mm). The growth coefficient (K) is on the order of 0.5 yr^{-1}, regardless of the sampling site. The growth performance index in length is 3.38 for Sidi R'bat, 3.65 for Douira and 3.79 for Tifnit.

Analysis of the linear growth curves calculated using these parameters at the three study sites (Fig. 7) revealed that growth increased during the first years of the species' life but slowed thereafter. The growth rates achieved during the three years of life of the species were 32.68, 14.68 and 8.91mm at Sidi R'bat; 43.81, 20.14 and 12.22mm at Douira; and 51.35, 23.86 and 14.48mm at Tifnit, with the best growth potential at Tifnit.

Table 2. Comparison of growth parameters for the *M. galloprovincialis* population at Sidi R'bat, Douira and Tifnit during 2018 and 2019

	Sidi R'bat	Douira	Tifnit
Asymptotic length L∞ (mm)	70	95	112
Growth coefficient K (yr^{-1})	0.5		
Recruitment time t_0 (s)	-0.258	-0.237	-0.227
The length at time t Lt (mm)	32.68	43.81	51.35
The length growth performance index Φ'	3.38	3.65	3.79
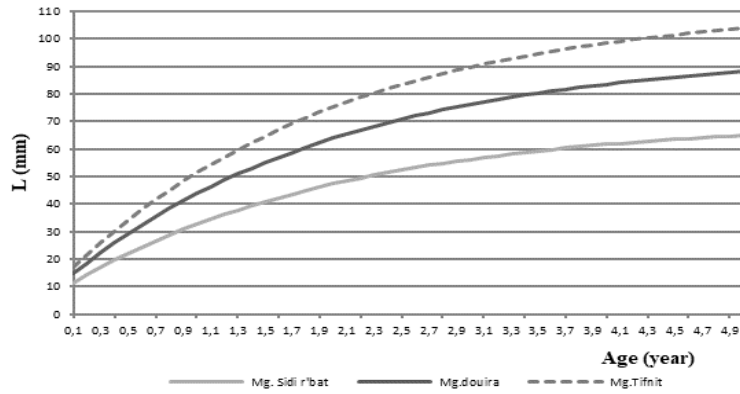
Fig. 7. Linear growth curves of *Mytilus galloprovincialis* in Sidi R'bat, Douira and Tifnit

7. Mortality and exploitation

The total mortality (Z) and natural mortality (M) were 4.25 and 0.80 yr^{-1}, respectively, at Douira; 2.84 and 0.87 yr^{-1}, respectively, at Sidi R'bat; and 2.41 and 0.76 yr^{-1}, respectively, at Tifnit (Fig. 8). The fishing mortality (F) based on the mean habitat temperature (26.2 °C) was 3.45 yr^{-1} in Douira, 1.97 yr^{-1} in Sidi R'bat and 1.65 yr^{-1} in Tifnit.

The exploitation level (E) was generally higher than the expected exploitation level of 0.5 at all sites, with 0.81 at Douira. The mussel survival rate (S) was lower at Douira (0.014) than at Sidi R'bat (0.058) and Tifnit (0.089).

Fig. 8. Estimated mortality of *M. galloprovincialis* using the length converted catch curve method and estimated exploitation

DISCUSSION

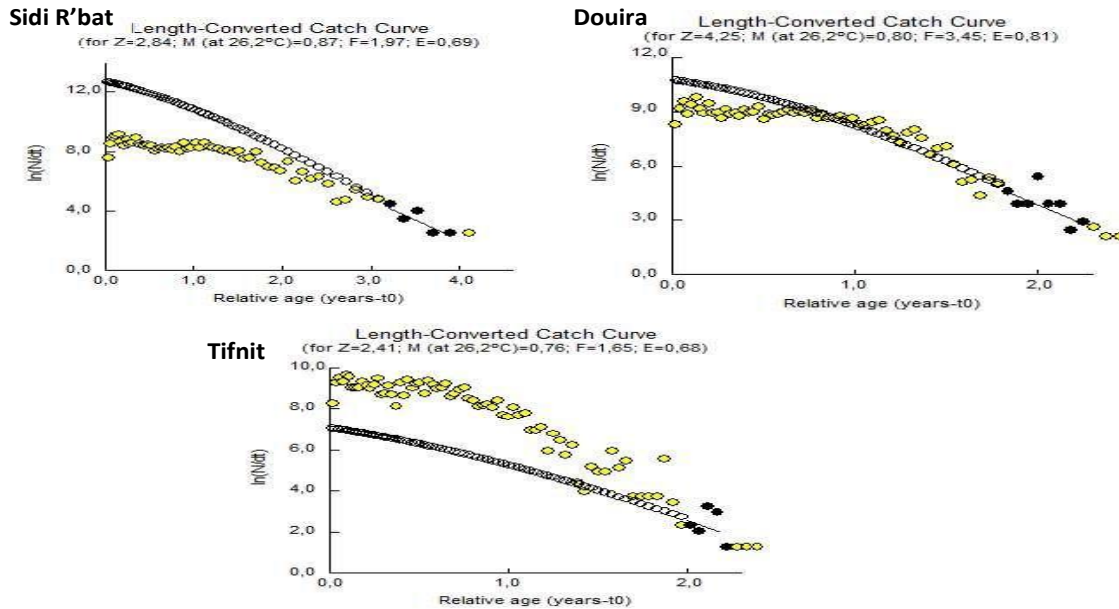The data collected in this study provide a scientific basis for the spatial distribution of the mussel *Mytilus galloprovincialis* and its exploitable characteristics. This analysis is based on monitoring population dynamics and growth at three sites, Sidi R'bat, Douira and Tifnit, which are known for their intensive mussel harvesting by coastal communities. This study revealed that the physicochemical parameters of seawater measured in this study fluctuated seasonally at all three sites.

The temperature of the seawater collected at the three sites shows a similar pattern, with a minimum in winter and a maximum in summer. The seasonal variation in water surface temperature is linked to changes in the climate of the region, which is characterized by a hot summer and a cold winter, with marine waters responding sensitively to climate change **(Berthome *et al.*, 1982)**. These results corroborate those of previous studies in Agadir Bay **(Chaouay, 2016; Kaaya, 2002; Agnaou, 2014)** as well as on the Moroccan Atlantic coastline.

pH is slightly acidic in winter because of heavy precipitation or rainwater, which acidifies seawater and is alkaline in summer. The DO concentration has maximum values in winter and minimum values in summer and early autumn. Similar results have been reported in several studies conducted in Agadir Bay **(Id Halla, 1997; Chaouay, 2016; Lamine, 2020)**. However, the values were notably higher at Tifnit, a discrepancy that can likely be attributed to the diminished pollution levels at this particular site. The electrical conductivity of seawater decreased in all three studied locations during the rainy periods, which was a consequence of the dilution effect caused by rainwater. Conversely, the observed increase in conductivity during the early autumn months could be explained by the increase in atmospheric temperature, which precipitated the evaporation of seawater **(Abbassi *et al.*, 2017)**.

The density values of *M. galloprovincialis* fluctuated over time. The maximum densities occur in spring and summer, generally following periods of mass sedentarization of spat, which are the main sources of renewal for these populations at the three sites studied during these two periods of the year, thus confirming the two recruitment peaks. These variations are positively correlated with seawater temperature. Indeed, **Lubet (1973)** reported that density varies according to the recruitment rate, edaphic factors and action of predators. A decrease in density indicates high adult mortality, which is caused not only by predation but also by harvesting. **Abada-Boudjema and Dauvin (1995)** conducted a comprehensive study spanning five years (1985-1989) along the North African coast, east of Algiers, elucidating a substantial summer sedentarization phenomenon among two bivalve species, *M. galloprovincialis* and *Perna perna*. These findings underscore notable density fluctuations, with *P. perna* exhibiting peak densities during winter and autumn, a pattern that is consistent with the observations of **Taounza (2021)** at Figuier Bay in Boumerdes. Similarly, research by

Lamine (2020) on *Donax trunculus* in Agadir Bay revealed two distinct density peaks occurring in spring and autumn, further elucidating the seasonal dynamics of bivalve populations in these coastal ecosystems.

The densities recorded at our survey sites reveal a fluctuating trend in the total annual average across the three locations. In 2018, a peak density of 6800.88 ind/m² was observed, driven primarily by a substantial influx of juveniles settling during early summer and winter-spring. However, in 2019, this density decreased to 5031.11 ind/m² because of the absence of significant spat deposits and the harvesting of adult animals. Despite this decline, these densities exceed those reported by **Bitar and El Hannach (1987)** at Sidi R'bat and by **Naciri (1998)** for the Temara mussel beds, which recorded densities of 1342 ind/m². Such variations may be attributed to the favorable nutrient conditions facilitated by upwellings in the region and other environmental factors. **Shafee (1992)** noted a comparatively lower average density of 3000 ind/m², excluding juveniles under 10mm from consideration. Conversely, **Id Halla (1997)** highlighted the notably high density at Cap Ghir, contrasting with the pollution-affected Anza site. Our results corroborate those reported by **Lagbouri (1997)** for *D. trunculus* at Aghroud, southern Agadir. The maximum densities were observed between April and July 1995, and the lowest densities were observed in autumn and winter 1996.

The highest values of the biomass and condition index were recorded in winter. In contrast, the lowest biomass values were observed in spring and summer. **Taounza (2021)** reported a peak in dry weight biomass for *P. perna* in February 2017 (182 g/m²), followed by a fall during spring and autumn (108g/ m²). The decrease in dry weight in early spring could correspond to a spawning period in mytilids **(Seed, 1976; Boukroufa, 1987; Widdows, 1991; Taounza, 2021)**, whereas the second decrease in dry weight in late summer **(Taounza, 2021)** in September for *P. perna* could result from continued gamete emissions after gonad restoration, as already known in mollusks **(Lubet & Mann, 1988)**. The biomass values observed by various authors for certain bivalve populations therefore differ from one locality to another and from one species to another **(Abada-Boudjema, 1983)**.

The condition index is subject to fluctuations that can be attributed to various factors. These include the processes of flesh and shell growth, gamete formation and spawning, the utilization of energy reserves during certain phases of the life cycle, and the availability of food resources in the environment **(Taounza, 2021)**. Notably, previous studies have corroborated that variations in the condition index occur in tandem with changes in biomass and are intrinsically linked to the sexual cycle of the organism **(Djediat, 1982; Abada-Boudjema, 1983; Bougride & Atmani, 2001)**. These findings underscore the interplay between the physiological state of mussels, as reflected by the condition index, and factors such as reproductive processes, energy allocation, and environmental resource availability. Furthermore, research conducted in various regions, such as southwest England and the Italian coast, has revealed seasonal variations in the

condition index of *M. galloprovincialis* (**Orban *et al.*, 2002; Ivankovic *et al.*, 2005**). Studies on the seasonality of benthic assemblages in northern Portugal, specifically in tide pools, have shown significant seasonal differences, with macroalgae being the dominant organisms (**Rubal *et al.*, 2011; Bertocci *et al.*, 2012**).

At our study sites, histograms revealed that the recruitment of *M. galloprovincialis* was continuous throughout the year, with a major intense recruitment occurring in both winter & spring and in summer. In previous studies, **El Khou *et al.* (2017)** reported that recruitment lasts throughout the year, with a major peak in summer for *M. galloprovincialis* and *P. perna* in Mirleft Bay. **Bouhaimi *et al.* (2000)** reported that the recruitment of two mussel species, *M. galloprovincialis* and *P. perna*, took place between January and May in Agadir Bay. Further north, in Temara, **Naciri (1998)** reported that the main recruitment is in June and February for the *M. galloprovincialis* population. Moreover, **Shafee (1992)** reported that recruitment takes place between May and September for *P. pecta* in the same area. **Zaouali (1973)**, along with, **Abada-Boudjema and Mouëza (1981)**, documented recruitment patterns extending from May to September and in autumn for *M. galloprovincialis* in Algiers and Tunisia, respectively. This bimodal recruitment trend is emblematic of Mediterranean populations, a consensus echoed by **Moueza and Frenkiel Renault (1973)**, **Ansell and Bodoy (1979)**, and **Ramon *et al.* (1995)**. Further evidence is provided by the *D. trunculs* population at Mehdia, as observed by **Bayed and Guillou (1985)**. However, contrasting findings emerged from various studies indicating unimodal recruitment in the Mediterranean. **Lubet *et al.* (1981)** revealed a singular recruitment period from March to April in Bizerte. Similarly, in the Atlantic, unimodal recruitment was noted for the *D. trunculus* population by **Ansell and Lagardère (1980)** and **Guillou and Le Moal (1980)**. **Essedaoui *et al.* (2017)** reaffirmed this with their observations of unimodal recruitment for *M. galloprovincialis* at Jorflasfar in the El Jadida coastal region of Morocco.

Recruitment timing and intensity can vary widely depending on the year, location, and species. These fluctuations are often due to differences in the timing and synchronization of reproductive cycles, which are influenced by geographic location and specific environmental conditions such as temperature, nutrient availability, and the presence of predators or prey. These environmental factors play critical roles in shaping the survival and growth of young individuals, thereby influencing their recruitment patterns. As a result, population dynamics are closely tied to environmental conditions. At the three natural sites surveyed, for example, favorable conditions for the attachment of young individuals were observed primarily in spring and summer (**Abada-Boudjema, 1995; Lagbouri, 1997; Lamine *et al.*, 2021**).

The timing and intensity of recruitment can vary between years, between study sites, and even between species. These variations can be explained by differences in the timing and synchronization of the different phases of each species' reproductive cycle, which are influenced by factors such as geographic location and site-specific environmental

conditions such as temperature, nutrient availability and the presence of predators or prey, which can affect the timing and intensity of recruitment by influencing the survival and growth of young individuals. Thus, variations in the population are strongly influenced by environmental conditions: at the three natural sites surveyed, conditions for the attachment of young individuals seemed to be favorable only in spring and summer, as was the case in the study of **Abada-boudjema (1995)**.

The number of cohorts is relatively high, reaching up to 7 per month. However, monitoring these cohorts presents difficulties in most cases, which could be due to predation, the harvesting of large mussels and adult mortality. Monitoring of new spring recruits (spring 2018) revealed a short lifespan of approximately 12 months and a maximum recorded length of 78mm at Tifnit, whereas the work of **Abada-boudjema (1995)** east of Algiers confirmed a maximum observed length of 49mm and a lifespan of 11–28 months. This lifespan of mussels on the Massa-Tifnit coast seems shorter than that observed for *P. viridis* in Hong Kong by **Lee (1985)**, who recorded life expectancies of approximately three years. Similarly, **Berry (1978)** reported that the maximum lifespan of *P. perna* on the South African coast was around three years. However, **Seed (1969)** reported that mussels rarely survived beyond their second or third year in areas where mortality was mainly due to predation by gastropods such as cynoglossus. **Lubet (1973)** noted that *M. galloprovincialis* could live for more than 8 years under favorable environmental conditions.

However, we know from observations that these individuals are mature from 15 to 35mm in size, according to **Lubet (1959)**. In our case, these lengths are reached between 5 and 8 months after attachment, enabling these individuals to participate in two breeding periods (summer 2018, winter 2019).

The application of the von Bertallanfy equation enabled us to determine the characteristics of each site. A comparison of the growth parameters recorded for *M. galloprovincialis* at the three sites revealed different maximum lengths L∞, with the greatest value (112mm) occurring at Tifnit. These differences between sites are linked to physicochemical parameters and possibly to environmental stress. The growth coefficient is identical at all three sites K (0.5 yr^{-1}). However, the K value found is lower than that reported by **Vakyli (1992)** in Korea for the species *C. gigas* K (2.35 yr^{-1}), by **AL-Barwani *et al.* (2006)** in Malaysia for the *mussel P. viridis* (*P. perna*) K (1.5 yr^{-1}), and by **Essedaoui *et al.* (2017)** K (2.01 yr^{-1}) at Jorf-Lasfar in the El Jadida region. In contrast, several authors **(Id halla, 1997; Bouhaimi, 2002; Benomar *et al.*, 2006)** reported low growth rates in mussels from the polluted Anza area north of Agadir. Additionally, in Italy, **Fabi *et al.* (1985)** reported a K value of 0.1 yr^{-1}. Several factors influence the growth rate, including physical factors such as available space and the degree of aggregation tolerated by the species. In addition, environmental factors such as temperature, food abundance, colony density, immersion time, currents and pollution have been identified **(Vakyli, 1989; Cheung, 1993; Hicks *et al.*, 2001)**.

Shafee (1992) reported that the low growth rate of *Perna* observed in Hong Kong was attributed to environmental pollution **(Lee, 1985)**. In contrast, at unpolluted sites, the growth rates were higher **(Shafee, 1992; Bouhaimi *et al.,* 2000)**.

The annual growth rate of *M. galloprovincialis* decreased during the first two years: 32.68, 14.68mm at Sidi R'bat; 43.81, 20.14mm at Douira; and 51.35, 23.86mm at Tifnit. Indeed, **Bownes (2006**) confirmed that the growth rate begins to decrease with the increase in size. The decrease in the growth rate obtained could be explained by the fact that the samples reached their threshold size, beyond which growth slowed **(Etim *et al.,* 1999)**. The growth patterns observed in this study align with similar findings reported for *M. edulis* by **Dare (1976)**, who reported sizes ranging from 34.5 to 37.5mm after one year and 49.5 to 51mm after two years. Notably, the size growth performance index reached its highest value of 3.79 at the Tifnit site. These superior biological performances in terms of growth and size could be attributed to underlying physiological and hormonal factors, as suggested by **Kouassi *et al.* (2012)**. The variations in growth parameters can be attributed to environmental conditions and the experimental period, as noted by **Sidibé (2003)**. The disparities observed in size growth rates appear to be influenced by the species' diets **(Lorenzoni *et al.,* 2007)**. On the other hand, **Reichert (2003)** noted that optimal growth rates appear to be associated with the quality of nutrients consumed and the assimilation of the proteins they contain **(Audic, 2006)**.

Mussel growth is typically assessed by size, which generally correlates with age but is also influenced by environmental conditions **(Seed, 1976)**. According to **Peharda *et al.* (2007)**, *M. galloprovincialis* experiences slow growth at temperatures above 21°C and below 10°C, with food availability also playing a crucial role in its growth. The lack of a seasonal pattern in the abundance of different size classes may result from continuous recruitment and growth due to the favorable environmental conditions in the studied area.

The mortality Z of the *M. galloprovincialis* species is high at all three sites, and this finding is similar to natural mortality (M). This finding could be ascribed to several factors, such as sand dynamics and movements, which sometimes completely cover mussel beds, leading to total extermination. In addition, the development of toxic phytoplankton along the coasts of the regions studied can influence mussel mortality **(Abouabdellah, 2012)**. The investigations conducted by **Benabdelmouna *et al.* (2018)** further substantiated these observations, documenting multiple mortality outbreaks affecting both adult and juvenile mussels across various temperature ranges. In addition, a very high fishing mortality rate (F) (3.45 yr^{-1}) was observed, with a low survival rate (S) (0.014) at Douira. Indeed, **Seed (1969)** mentioned that, in the absence of unfavorable ecological conditions, mussel mortality is mainly due to high predation. At our three sites, natural predation as well as other factors, such as intense harvesting activity, particularly for large samples at Douira, where a woman's cooperative operates, contributed to this mortality. In addition, the harvesting techniques and periods used also resulted in high mortality.

The ion rate E>0.50 indicated the overexploitation of bivalves at all three sites, particularly Douira, where E>0.80.

A recent study by **Lamine *et al.* (2023)** reported a high total mortality rate (3.30 years^{-1}) in *Donax trunculus* compared with the values previously recorded in Agadir Bay, Morocco **(Lagbouri, 1997)**. This increased mortality was traced back to the prevalence of parasitism by the trematode *Bacciger bacciger*, as detected through histological studies **(Lamine *et al.*, 2021)**. Additionally, other parasites, such as the protozoan *Mikrocytos* sp., have recently been identified as potential causes of mass mortality in mussels along the French Atlantic coast **(IFREMER, 2011)**.

CONCLUSION

This comprehensive two-year study addresses various aspects of the population dynamics, growth patterns, size frequency distributions, and mortality rates of the mussel species *Mytilus galloprovincialis* across three natural beds along the Moroccan Atlantic coast. The results revealed that this bivalve is characterized by lower density, biomass, and growth rates than previously reported, coupled with abundant recruitment events occurring throughout the year. Notably, the findings indicate overexploitation, with exploitation rates exceeding sustainable levels (E>0.50) across all three surveyed sites.

Despite the challenges posed by overexploitation, this study highlights the exploitable potential of *M. galloprovincialis,* presenting an opportunity for local communities and cooperatives to engage in sustainable management practices. Crucially, engaging local communities in decision-making processes and ensuring an equitable distribution of benefits derived from these initiatives is paramount. This inclusive approach can foster support and cooperation from local stakeholders, thereby increasing the likelihood of successful implementation and long-term sustainability of mussel resource management efforts. Overall, this research provides a comprehensive baseline for informed ecological management, highlighting the need for concerted efforts involving all relevant stakeholders to address overexploitation and promote sustainable practices in the mussel fishery along the Moroccan Atlantic coast.

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