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Spatiotemporal variation of seagrass meadow and associated bivalves in Mediterranean lagoon (El Mellah -Algeria)

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Abstract

This paper presents spatio-temporal variations of angiosperms, bivalves associated with them, to the environmental and conditions of the El Mellah lagoon in 2019 under continental and marine influences. Our results showed significant changes in their distribution, which appear to be linked to fluctuations in the environmental conditions and climatic change, between *Zostera noltei* and *Ruppia maritima*, while the seagrass beds are remarkably abundant, with a biomass that can reach 1313.32 ± 132.73 g DW.m -2 during the summer period. we have identified macrofauna made up of five species of bivalves: *Cerastoderma glaucum*, *Abra ovata, Ruditapes decussatus, Loripes orbiculatus,* and *Arcuatula senhousia*. Our results also highlight for the first time, an invasive species *A. senhousia*, the species dominates the bivalve community. and two threatened edible species in this area, *R. decussatus* and *C. glaucum*, probably due to the climat change, the reduced distribution of the *Ruppa maritima* meadow and silting of the channel.

Keywords

Coastal lagoon, Angiosperm, *Zostera noltei*, *Ruppia maritima*, bivalves, invasive species, climate change.

Introduction

Macrophytes are of great ecological value, providing a multitude of essential ecosystem services. They play a crucial role in enhancing biodiversity, carbon storage carbon storage, nutrient cycling and coastal protection (Hemminga and Duarte 2000). Because of their ability to modify their environment, to control the availability of resources for themselves and other organisms, these organisms are referred as engineering organisms (Bertrin et al. 2019). Seagrass beds are often used as biological indicators of ecosystem health due to their sensitivity and crucial ecological role (Mammeria. 2006, Mammeria and Djebar 2007, Montefalcone 2009). Coastal lagoons have been affected by the development of human activities in their catchment areas, resulting in increased inputs of nutrients and chemical contaminants such as urban wastewater, wastewater treatment plants and agricultural effluents (Munaron et al. (2012). This increase in nutrients has had an impact on Mediterranean lagoons since the middle of the 20th century, causing a phenomenon of eutrophication, which has led to significant changes in primary producers (Le Fur et al. 2019). In addition, the Mediterranean basin and shallow coastal ecosystems experience a wide variety of seasonal events, including significant variations in rainfall and high temperatures (Mammeria et al. 2019), makes them particularly vulnerable to global change (Anthony et al. 2009, De Wit 2011, Le Fur et al. 2019). Indeed, in coastal ecosystems, seagrass beds, have suffered an alarming decline in condition worldwide, resulting in a significant loss of biodiversity (Waycott et al. 2009, Van Der Heide et al. 2012). This deterioration is likely to be exacerbated by the increasing rate of global climate change observed this century and expected to accelerate in the future, which will have a significant impact on seagrass beds (Duarte et al. 2008, Mammeria et al. 2019).

The Algerian coastline spans a distance of 2,148 km. The absence of a lagoon ecosystem is a notable characteristic of this coastal area. In addition, since 1990, shellfish farming in the lagoon has remained unexploited, following the mass mortality of *Mytilus galloprovincialis* (Lamarck, 1819) mussel and *Crassostrea gigas* (Thunberg, 1793), Oyster populations (Benmarce 2012). However, recurrent fires lead to the reduction of vegetation and increase the risk of erosion, which can lead to the filling of the lagoon and promote sedimentation (Melouah et al. 2014, APS 2022). Due to these considerations our research aimed to evaluate the environmental condition of the El Mellah lagoon. As such, the objectives of our study were: i) to study the spatio-temporal evolution of the main physico-chemical factors affecting the life and distribution of macrobenthos in the Mellah lagoon. ii) to study the spatio-temporal variation in angiosperm biomass and associated fauna density.

Material and methods

Study site and location of stations

The only shallow brackish coastal lagoon in Algeria is El Mellah lagoon (36.89290N; 8.32623E), which has a maximum depth of 6.4 m and an average depth of 2.7 m. It is located in the far northeastern region of Algeria, inside the El-Kala National Park, which is recognized as a UNESCO biosphere reserve (Hamza et al. 2022). El Mellah is located on the Algerian sub-basin of the Mediterranean Sea's southern shore (Fig. 1). The lagoon, which occupies 865 hectares, has a single inlet in the north that is a natural channel that is

900 meters long and 10 to 20 meters wide. It is distinguished by its limited water exchange with the open sea (Cataudella et al. 2015).

El Mellah lagoon receives water from both marine sources, contributing to its brackish nature, and freshwater from three main seasonal rivers: R'Kibet in the Northwest, El Mellah in the Southwest, and Belaroug in the South. Additionally, rainfall also plays a role in replenishing the lagoon's water. These factors influence the salinity, which varies between 26 (polyhaline) and 35 PSU (mixoeuhaline). Comparatively, seawater salinity in the summer ranges between 37.1 and 37.4 PSU (Draredja et al. 2019).

Nutrient concentrations are like for most lagoon systems they depend mainly on rainfall events and watershed runoff, this last contains only soil leaching products as the area is poorly urbanized and is occupied by a greatly sparse population in dwellings identified by the presence of houses mostly of traditional type (Draredja et al. 2019).From February to December 2019, the examined lagoon was visited monthly. Three representative sampling stations were chosen based on hydrological features (Fig. 1: Station 1 (S.1) is situated in the southern region of El Mellah, near Wadi El-Mellah and Wadi El Aroug. It is affected by various pollutants believed to originate from urban and industrial discharges. Station 2 (S. 2) is located between Wadi el-Mellah and Wadi El Aroug, influenced by continental factors. Station 3 (S.3) is positioned in the northern region, near the channel separating El Mellah from the Mediterranean Sea.

Sampling of benthic assemblages

Triplicate sediments cores were collected manually in the shallow subtidal (0.3 m to 0.5 m depth) at three different or representative stations colonized by heterogeneous seagrass meadows. Benthic sampling was destructive using manual cores (N=3) of 0.028 m^2 (diameter 19 cm) which were vertically pushed through the vegetation and sediment. Physico-chemical parameters such as salinity, pH, temperature, and dissolved oxygen) were measured monthly in situ in all sampling sites, using the appropriate multi-parameter HANA HI9829 (Hamza et al. 2022).

Samples were immediately transferred to the laboratory and carefully washed in tap water, removing remaining organic debris and sediment. Macrophytes and bivalves were then carefully sorted and identified to functional group level and species level. macrophytes separated into leaves and root-rhizomes fractions and then they were dried at 60 during 24 h in order to estimate dry biomasses. Each species density was estimated separately, by counting individuals. The seagrass beds where sampling was performed were heterogeneous in terms of density, therefore bivalves density and macrophyte biomass were calculated per sample (0.028 m^2) and not par m^2. Specimens were identified such as *Cerastoderma glaucum* (Bruguière, 1789), *Ruditapes decussatus* (Linnaeus, 1758), *Loripes orbiculatus* (Poli, 1795), *Abra ovate* (Philippi, 1836) and *Arcuatula senhousia* (Benson, 1842) by shell observation at the MARBEC laboratory (Marine Biodiversity, Exploitation and Conservation) at the University of Montpellier.

Results

Physicochemical characteristics

The physicochemical parameters of the waters in El Mellah Lagoon displayed variations throughout the year 2019 (Fig. 2). Surface temperature measurements taken at the three surveyed stations reveal a slight variation between the stations. The minimum temperature recorded was 13.8 °C in February at station 1, located north of the lagoon. In contrast, the maximum temperature was 30.8 °C, recorded in July at station 3, located south of the lagoon (Fig. 1, Fig. 2). The spatiotemporal variations in salinity across the surveyed stations indicate a certain homogeneity of the lagoon water mass. The extreme haline values were observed in the northern region of the lagoon (station 3) during the months of May (10.7 PSU) and November (29 PSU) (Fig. 2). Additionally, dissolved oxygen levels exhibit fluctuations, ranging from a minimum of 4.50 $mg.L^{-1}$ in July (station 2) to a maximum of 11.13 $mg.L^{-1}$ in April (station 1). Overall, the waters near the channel tend to be less oxygenated compared to those within the lagoon itself (Fig. 1, Fig. 2). The pH of the water remains relatively constant and slightly alkaline across the three stations. Spatiotemporal pH fluctuations range from 7.4 in December at the westernmost station to 8.7 in September at the northernmost station (Fig. 2).

Angiosperms and their associated bivalves

During this study, the inventory of the benthic macroflora "angiosperms" of the El Mellah lagoon allowed the identification of 3 species of Magnoliopsida. These are *Zostera noltei* Hornemann, 1832, *Ruppia maritima* (Linnaeus, 1753) and *Ruppia cirrhosa* (Petagna) Grande 1918. The biomass of the seagrass community varied significantly across the three stations and throughout the year (Fig. 3). The minimum biomass was recorded at station 2 in March, with a value of 129.55 ± 65.36 g $DW.m^{-2}$. In contrast, the maximum biomass was observed at station 3 in September, reaching 1313.32 ± 132.73 g $DW.m^{-2}$. Moreover, two distinct biomass peaks were observed at all three stations during 2019. The first peak occurred at the beginning of the summer season (June), with biomass values ranging from 559.51 ± 231.50 g $DW.m^{-2}$ to 673.42 ± 97.78 g $DW.m^{-2}$ (Fig. 3). The second significant peak emerged at the start of the autumn season (September), with biomass values of 865.94 ± 179.35 g $DW.m^{-2}$, 515.59 ± 152.64 g $DW.m^{-2}$, and 1313.32 ± 132.73 g $DW.m^{-2}$ at stations 1, 2, and 3, respectively. Furthermore, *Z. noltei*, was found to be the dominant seagrass species at stations 1 and 2, located farther away from the channel, while *R. maritima* dominated the seagrass community at station 3, situated closer to the channel (Fig. 4). Additionally, the presence of *R. cirrhosa* was observed in deeper waters (beyond one meter) within the El Mellah lagoon.

Zostera noltei Hornemann, 1832, emerged as the dominant seagrass species in the southern region of the lagoon (station 1), exhibiting an aboveground biomass ranging between 65.47 ± 9.96 g $DW.m^{-2}$ in November and 304.16 ± 131.98 g $DW.m^{-2}$ in June (Fig. 4). The belowground biomass of *Z. noltei* fluctuated between 80.88 ± 45.42 g $DW.m^{-2}$ in

February and 710.71 ± 127.86 g DW.m^{-2} in September. The highest biomass values were observed between June and September for both aboveground and belowground biomasses. *Ruppia maritima*, the secondary angiosperm species in El Mellah, was not consistently present throughout the study period and exhibited a lower biomass compared to *Z. noltei* (Fig. 4). However, In the western part of the lagoon (station 2), we observed a prevalence of *Z. noltei.* The aboveground biomass exhibited fluctuations, ranging from 34.52 ± 8.98 g DW.m^{-2} in December to 341.76 ± 71.40 g DW.m^{-2} in June. Belowground biomass values showed variability, ranging from 72.00 ± 38.48 g DW.m^{-2} in March to 390.00± 109.19 g DW.m^{-2} in September (Fig. 4). In the northern part of El Mellah (station 3), *R. maritima* is the most dominant species. We observed an increase in both aboveground and belowground biomass from February (45.71 ± 45.71 g DW.m^{-2}; 31.78 ± 31.78 g DW.m^{-2}) to July (403.68 ± 130.46 g DW.m^{-2}; 360.94 ± 140.22 g DW.m^{-2}), followed by a remarkable decline in August (145.94 ± 35.48 g DW.m^{-2}; 105.59 ± 16.84 g DW.m^{-2}). Starting from September, a sharp rise in biomass becomes noticeable (786.19 ± 58.06 g DW.m^{-2}; 510.23 ± 62.05 g DW.m^{-2}). Indeed, the biomass is higher during the autumn period (Fig. 4).

At station 1, we observed a dominanceof the Asian mussel *A. senhousia* from its initial detection, with a density ranging between 262 ± 106 ind.m^{-2} in December and 1321 ± 475.6 ind.m^{-2} in June. Furthermore, the arrival of the latter species coincided with the peak density of *Loripes orbiculatus,* and the appearance of *A. ovata*. Additionally, *Loripes orbiculatus* was consistently present throughout the study period, with a density varying between 36 ± 21 ind.m^{-2} in February and May, and 238 ± 104 ind.m^{-2} in June (Fig. 5). At station 2, we similarly observed a dominance of the Asian mussel *A. senhousia* since its first appearance, with a minimum density of 416 ± 117 ind.m^{-2} in August and a maximum density of 1440 ± 36 ind.m^{-2} in July. *L. orbiculatus,* was present throughout the sampling period, except in April, and exhibited a notable increase in density during the summer months, ranging from 0 ± 0 ind.m^{-2} in April to 202.38 ± 36 ind.m^{-2} in September. In contrast, *A. ovata* was only collected during the summer period, with a density not exceeding 59.52 ± 59.52 ind.m^{-2} in August (Fig. 5). The invasive mussel *A. senhousia* was exclusively observed in the months of June and July, reaching a peak density of 893 ± 119 ind.m-2 in June at station 3. We noted an augmentation in the density of *L. orbiculatus,* from February (12 ± 12 ind.m^{-2}) until August (268 ± 72 ind.m^{-2}), followed by a subsequent decline in density and complete disappearance during the months of October and November (Fig. 5).

Discussion

Our results show the existence of a community of marine angiosperms at El Mellah belonging mainly to the families Zosteraceae and Ruppiaceae. These are *Zostera noltei*, *Ruppia maritima* and *Ruppia cirrhosa*. However, the literature lacks comprehensive studies providing a detailed overview of the composition of macrophyte populations in El Mellah, particularly with regard to marine angiosperms. although they are of enormous ecological importance as they provide valuable services (Orth et al. 2006). adding their major ecological role as biological indicators of ecosystem health (Mammeria. 2006, Mammeria and Djebar 2007, Montefalcone 2009). According to Costanza et al. (1997), the economic value of one hectare of seagrass meadow is USD 19,004 per year. This estimate places this habitat among the most expensive on the planet in terms of services and goods (Bargain 2012).

Our study found the presence of *Z. noltei*, in all the investigated stations, with a total dominance in the stations far from the inlet. In contrast, *R. maritima* was only dominant in the northern part of the lagoon (Fig. 4). Various studies conducted worldwide have observed changes in the distribution and abundance of seagrasses (Adams et al. 1992). Hence, the results of our study indicate a considerable change in the distribution of herbaceous mats compared to the studies of Guelorget et al. (1989), who reported the dominance of *Z. noltei*, in the pre-channel areas to the north of the lagoon and the colonization of *R. maritima* in the southernmost stations far away from the adjacent sea; research by Draredja et al. (2019) showed that the angiosperm *Ruppia* sp. encroaching the shore to a depth of 1.50 m, especially in the East, South and West of the lagoon. In Mediterranean lagoons, the distribution of benthic macrophytes is mainly structured by two key factors: salinity and the trophic state index present in the water column (Le Fur et al. 2017). The significant change in the distribution of seagrass beds compared to previous studies is probably linked to the fluctuation of salinity during the last decades. *R. cirrhosa*, with the presence of several invertebrates, including annelids in the sediments, can provide an important food resource for diving ducks, which exploit it extensively (Tyler-Walters and d'Avack 2015). During our study, we observed the presence of *R. cirrhosa* at depths greater than one meter, which can probably be attributed to its morphology, including its length, which can reach up to 100 cm.

Marine angiosperms colonize almost all intertidal and subtidal coastal environments around the world, they generally have a high biomass in the environment they colonize (Auby 1991). In recent decades, coastal ecosystems, and seagrass beds in particular, have suffered an alarming decline in condition on a global scale, leading to a significant loss of biodiversity (Waycott et al. 2009, Van Der Heide et al. 2012). In El Mellah the biomass of this community can reach up to 1313.32 ± 132.73 g DW.m^{-2} during August (Fig. 3). Our results are quite similar to those reported by Falace et al. (2009) in the Marano-Grado lagoon (Italy), where a maximum biomass of 900 g DW.m^{-2} of seagrass beds was reported. Seagrass growth rates undergo distinct seasonal variations, with accelerated growth observed during spring and summer, and a decline in growth during the fall and winter seasons d'hiver (Lee et al. 2007). Indeed, we observed an increase in El Mellah seagrass bed biomass during the perinatal and summer periods, reaching a peak in September (865.94 ± 179.35 g DW.m^{-2}; 515.59 ± 152.64 g DW.m^{-2}; 1313.32 ± 132.73 g DW.m^{-2}, respectively, for stations 1, 2, and 3) (Fig. 3). These findings are likely attributable to light and temperature, which are the two primary factors regulating seagrass photosynthesis. However, as temperature directly influences physiological processes through the acceleration of biochemical reactions, the impact of light is not solely dependent on photosynthetic capacities but also on the morphology of the seagrass bed (Dennison and Alberte 1982, Plus et al. 2003). Furthermore, a significant regression in the biomass seagrass beds during the month of August is likely attributed to the presence of epiphytes observed on leaf surfaces. According to Short et al. (2001), the frequent occurrence of epiphytes on leaf surfaces reduces the transmission of light to the chloroplasts of epidermal cells, where photosynthesis takes place (Bargain 2012).

Healthy *Zostera noltei* seagrass beds have been recognized for their stabilizing effect in shallow coastal bays (De Wit et al. 2001, Delgard et al. 2013). To the south of the lagoon, influenced by continental factors such as Wadi el-Mellah and Wadi El R'Kibet, we observed the complete dominance of *Z. noltei*, Additionally, we documented seasonal variations in its biomass, both in aboveground and belowground components (Fig. 4). In El Mellah, *Z. noltei*, exhibits significant biomass, reaching up to 846 g $DW.m^{-2}$ south of the lagoon, surpassing observations by Laugier et al. (1999), in the Thau pond (with a maximum of 215 to 226 g $DW.m^{-2}$). The shoots of *Z. noltei*, exhibit minimal lengths at the beginning of spring, reaching their maximum lengths by the end of summer (Auby 1991). During winter, the leaves of *Z. noltei*, are either lost or removed through grazing or wave action (Nacken and Reise 2000, Tyler-Walters and d'Avack 2015). Indeed, a peak aboveground biomass of 304.16 ± 131.98 g $DW.m^{-2}$ (station 1) and 341.76 ± 71.40 g $DW.m^{-2}$ (station 2) was recorded in June (Fig. 4). In comparison with other studies conducted on Mediterranean lagoons, the aboveground biomass is notably higher. Pergent-Martini et al. (2005) recorded a maximum above-ground biomass value of 92 g $DW.m^{-2}$ in July 1998 at the Pond of Urbino, while Plus et al. (2001), reported a maximum above-ground biomass of 173.8 g $DW.m^{-2}$ in 1998 at the Thau lagoon. According to Auby (1991) in the Arcachon Basin, the development of the rhizomes of *Z. noltei,* like that of the leaves, is very slowed down at the start of winter. The hypogeal biomass at El Mellah gradually increases from the month of May and reaches its maximum in the month of September with a maximum hypogeal biomass of 710.71 ± 127.86 g $DW.m^{-2}$ recorded south of the lagoon (Fig. 4). Our results are significantly higher than those reported in Mediterranean lagoons by Pérez and Camp (1986) in the Ebro Delta, where a maximum hypogeal biomass of 370 g $DW.m^{-2}$ was reported in July; by Pergent-Martini et al. (2005), who indicated a maximum hypogeal biomass of 368 g $DW.m^{-2}$ at the Étang d'Urbino in January 1999 and does not exceed 100 at the Étang de Biguglia in April 1999.

Ruppia spp. is of great ecological importance, as many macrozoobenthic species use it as a refuge and shelter area for their eggs and juveniles (Melouah et al. 2014). In El Mellah, the majority of young clams and young cockles are observed mainly within this herbarium. In the Mediterranean region, three species of *Ruppia* spp. have been recognized, such as *R. maritima, R. cirrhosa,* and *R. drepanensis* (Mannino et al. 2015). However, according to current knowledge, *R. drepanensis* (Mannino et al. 2015) is present only in the southwest of the Mediterranean (Comín et al. 1993, Mannino et al. 2015). During our study, we unequivocally documented the presence of *R. maritima* and *R. cirrhosa*. Moreover, in regions beyond the Mediterranean, *R. maritima* appears to be more prevalent than *R. cirrhosa* (Mannino et al. 2015). Conversely, we observed a notable predominance of *R. maritima* compared to *R. cirrhosa*. Since 2007, *R. maritima* has been listed on the IUCN Red List for certain wetlands (Short et al. 2001). In comparison with the earlier study by Guelorget et al. (1989), we observed a decline in distribution and an almost complete absence of *R. maritima* in areas distant from the channel. The populations of *R. maritima* in the Mediterranean are poorly documented, while those in regions outside the Mediterranean have been extensively studied (Mannino et al. 2015). In winter, *R. maritima* undergoes complete dieback, primarily overwintering in the form of seeds (druplets), which germinate in early spring (April). From April onwards, the plant undergoes rapid growth, reaching its peak biomass in August-September (Tyler-Walters and d'Avack 2015). To the north of the lagoon, near the adjacent sea, we observed a seasonal variation in *R. maritima* similar in the Netherlands at 'De Bol.' The maximum aboveground and belowground biomass (786.19 ± 58.06 g $DW.m^{-2}$; 510.23 ± 62.05 g $DW.m^{-2}$) was recorded in September at El Mellah (Fig. 4). These values are notably higher compared to the study by Verhoeven (1980) on temporary brackish habitats, where a maximum biomass of 290 g $DW.m^{-2}$ was reported (Mannino et al. 2015). In addition, The reduction in *R. maritima* biomass in El Mellah may also be attributed to the presence of wild bird species, such as the tufted duck *Aythya fuligula* (Linnaeus, 1758), the coot *Fulica atra* (Linnaeus, 1758), and the *Anas penelope* duck (Linnaeus, 1758), (Mammeria and Rutger 2022). These birds have the potential to directly feed on *Ruppia* sp. during the winter months (Tyler-Walters and d'Avack 2015).

Bivalves are marine organisms intricately linked with seagrasses, playing a significant role in tropical ecosystems, including the formation of food chains (Sousa et al. 2009, Syukur et al. 2021). During our study, we documented a total of 1310 individuals belonging to five species of bivalves in the Mellah lagoon: *C. glaucum*, *A. ovate, R. decussatus*, *L, orbiculatus*, and the newly identified invasive species *A. senhousia* (Fig. 5). Since 1979, the qualitative composition of bivalves has exhibited a degree of stability, consistently ranging between 5 and 6 species (Bakalem and Romano 1979, Benmarce 2012). However, we observe that the diversity of bivalve species appears relatively low when compared to other Mediterranean lagoons, such as the Berre pond with 34 species (Febvre 1968), in Lake Tunis with 14 species, and the two lagoons of Albufeira and Obidos with 36 species. According to Melouah et al. (2014), El Mellah stands out as the least diverse site among Mediterranean lagoons. This distinctiveness is attributed, as mentioned earlier, to the physicochemical characteristics of the environment. The channel connecting the lagoon to the sea is winding and narrow, leading to rapid clogging and significantly restricting water exchanges between the lagoon and the adjacent coast. As a result, the EL Mellah lagoon experiences high confinement, contributing to its low biological diversity (Benmarce 2012).

Since 2005, the harvesting of *C. glaucum*, and *R. decussatus*, has been discontinued, attributed to the disappearance of the clam and a decline in the natural stock of the cockle (Draredja et al. 2019). In our study, the maximum density of *C. glaucum*, did not exceed 71 ± 11 $ind.m^{-2}$ in February, and it completely disappeared during the summer and autumn at station 1 et 2 (Fig. 5). We observed a decline in the density of this species when compared with the earlier study by de (Melouah et al. 2014), which documented a density ranging from 22 $ind.m^{-2}$ (January) to 176 $ind.m^{-2}$ (April). In this context, it is justifiable to characterize the presence of the clam as threatened in El Mellah. During our study, a maximum density of 48 ± 12 $ind.m^{-2}$ was reported for the European clam, *Ruditapes* *decussatus*. Nevertheless, it is noteworthy that there has been a decline in the stock of this species compared to the study by Draredja et al. (2019), which documented a density of 250 ind. m^{-2}. The development of seagrass beds has influenced the health of the cockle population, impacting their growth, abundance, and recruitment (Do et al. 2011). Hence, we propose that this decline is likely associated with the regression of *R. maritima* at the lagoon level, given its acknowledged ecological significance. In line with observations indicate that the primary habitat for most young clams and juvenile cockles is within this seagrass bed. This decline can also be attributed to multiple factors, including intense predation by predators such as crabs and sea breams, trophic competition between clams and cockles for access to food resources in the environment, as well as challenges in adapting to fluctuations in the physicochemical conditions of the environment (Melouah et al. 2014),

Excluding the new invasive mussel *A. senhousia*, the Lucinidae *L. orbiculatus*, emerges as the primary dominant bivalve, showcasing its characteristic presence in Mediterranean lagoon environments. This dominance has been consistently reported by (Melouah et al. 2014), in the same ecosystem. A maximum density, not exceeding (238 ± 104 ind.m^{-2}; 202.38 ± 36 ind.m^{-2}; 268 ± 72 ind.m^{-2}) respectively for stations 1, 2, and 3, was observed during the summer period (Fig. 5). The density reported is comparatively lower than that documented by Geest et al. (2020) in the Thau pond, which recorded 1771 ind.m^{-2}, as well as the density reported by Sanmartí et al. (2018) in the Ebro delta, reaching 1981 ind.m^{-2}. The observed low density could be directly attributed to the physicochemical conditions and trophic state of the lagoon. This is likely a consequence of the clogging state of the communication channel with the sea, disrupting the optimal development of the benthic fauna in general, as suggested by (Melouah et al. 2014).

The widespread acknowledgment of invasive species stands as a key driver behind the diminishing biodiversity in the Mediterranean region. These intruders possess the capacity to disturb not only various facets of marine ecosystems but also other aquatic environments (Galil 2007). In June 2019, the Asian mussel *A. senhousia* was documented in the El Mellah lagoon for the first time, displaying a maximum density of 1321 ± 475.6 ind.m^{-2} at station 1, 1071.428 ± 36 ind.m^{-2} at station 2, and 893 ± 119 ind.m^{-2} at station 3 (Fig. 5). These findings reveal relatively modest densities in comparison to the high densities observed in San Diego Bay, where numbers reached as high as 15,000 ind.m^{-2} (Reusch and Williams 1998). Nonetheless, in regions where *A. senhousia* has been introduced, its presence can exert a notable impact on native communities of benthic macrophytes and invertebrates (Crooks and Khim 1999, Allen and Williams 2003, Hamza et al. 2022). Indeed, since its introduction, this species has dominated the bivalve community (Fig. 5). Crooks (2001) observed a similar situation in the eastern Pacific Ocean (Mission Bay, San Diego), noting that *A. senhousia* is now 100 times more abundant than any native bivalve, resulting in a decrease in the richness of native species (disappearance of *Chionista fluctifraga* and decrease in the density of *Solen rostriformis*). According to Cohen 2005, *A. senhousia* causes direct mortality of cultivated oysters in Japan by smothering them with dense mats of byssal threads on the sediment surface. In the El Mellah lagoon, the presence of *A. senhousia* can lead to the complete disappearance of the threatened cockle *C. glaucum*, as during our sampling, we observed aggregates of *A. senhousia* attached to empty shells of C. glaucum. Similarly, in the Atlantic Ocean (the Solent), *A. senhousia* has been observed attached to dead oysters, *Ostrea edulis* (Hamza et al. 2022). This findings highlights the critical role of continued research and monitoring to evaluate the full impact of invasive species and environmental changes on the El Mellah entire benthic community.

Conclusions

This finding highlights the critical role of continued research and monitoring to evaluate the full impact of invasive species and environmental changes on the El Mellah entire benthic community.

The increasing rate of global climate change observed over the course of this century, and expected to accelerate in the next, will have a potentially significant impact on flora and fauna. This concern is particularly relevant for Mediterranean coastal lagoons, which are exposed to Mediterranean seasonal fluctuations and anthropogenic activities, making them particularly vulnerable to global change. Our results on the spatio-temporal evolution of benthic organisms have shown the relationship between angiosperms, their associated macrofauna and environmental conditions to be closely linked. It is possible to assess the overall health of Algeria's only lagoon ecosystem and to take appropriate measures for its preservation. Analysis of the spatio-temporal variation in angiosperms reveals a significant change in their distribution compared with previous observations. This highlights the impact of fluctuations in environmental and climatic conditions on the benthic community. For the first time, a quantitative analysis of the lagoon's seagrass beds was conducted, allowing us to compare them to other Mediterranean lagoons and estimate their distinctive richness, natural stock, and biomass. The decline in the dispersal of the *R. maritima* seagrass iand the clogging of the channel has disrupted the functioning of this ecosystem, leading to a massive reduction in the natural stock of the European clam *R. decussatus* and the cockle *C. glaucum*, two edible species that could potentially be exploited in the El Mellah coastal lagoon. The invasive species *A. senhousia*, which was first observed in June 2019, has the potential to cause changes in the structure and functioning of this ecosystem. This phenomenon may lead to a decline in the lagoon's biodiversity, particularly of the *Z. noltei* and the threatened cockle *C. glaucum*. Seagrass beds are being significantly reduced due to the accumulation of toxic sulphur in the sediments. This situation is likely to occur more frequently in the future due to ongoing global warming and the increase in the organic load in coastal ecosystems around the world.

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Conflicts of interest

The authors have declared that no competing interests exist.

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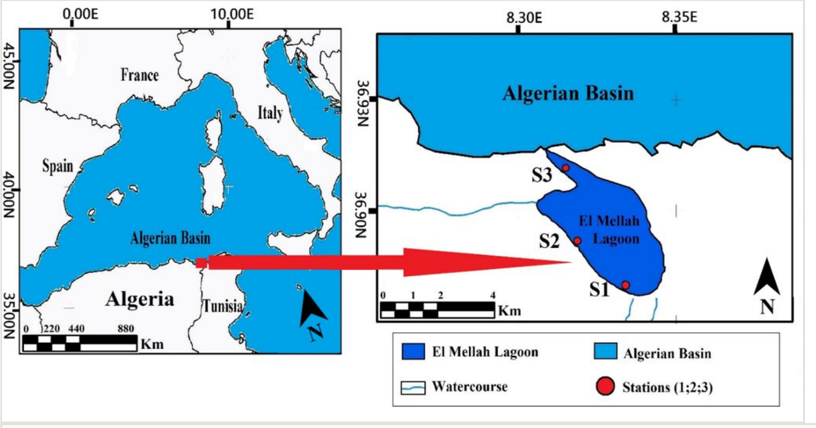

Figure 1.

The study area is situated in the Mediterranean Sea, and the sampling stations are situated in El Mellah Lagoon (Southern Coast of the Algerian Basin, Algeria) (Station 1: 36.87722N; 8.33083E; Station 2: 36.88722N; 8.31444E; Station 3: 36.90944N; 8.31444E) (Hamza et al. 2022).

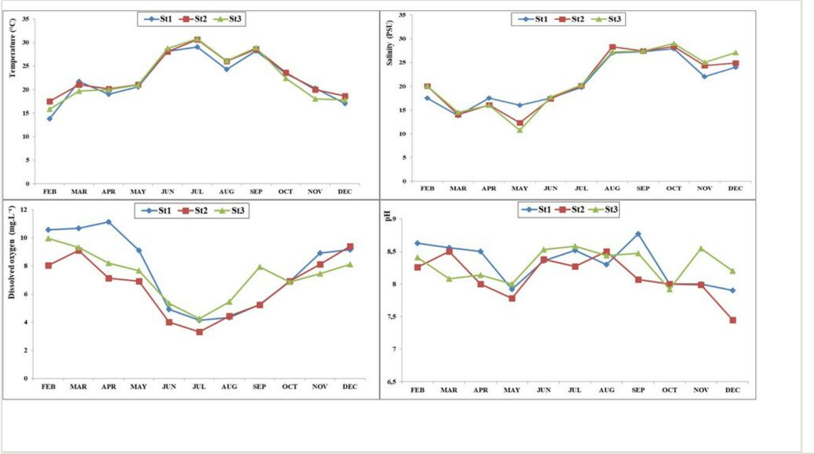

Figure 2.

Mean values (± SE) of temperature, salinity, dissolved oxygen and pH measured in the surface waters at the sampling stations in El Mellah Lagoon (Algeria, south-western Mediterranean Sea) in 2019. T = temperature (°C), Sal = salinity (PSU), DO = dissolved oxygen (mg.L^{-1}). N = 9 replicate measurements per month.

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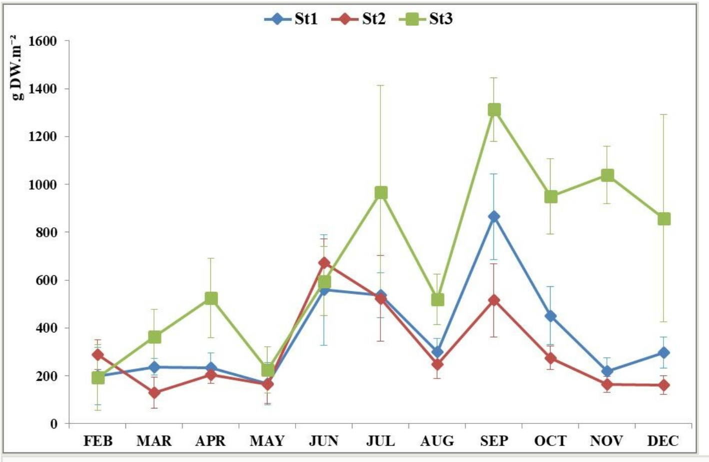

Figure 3.

Spatiotemporal variations in angiosperm biomass (g DW.m^{-2}) (mean ± SEM) in the El Mellah lagoon during 2019.

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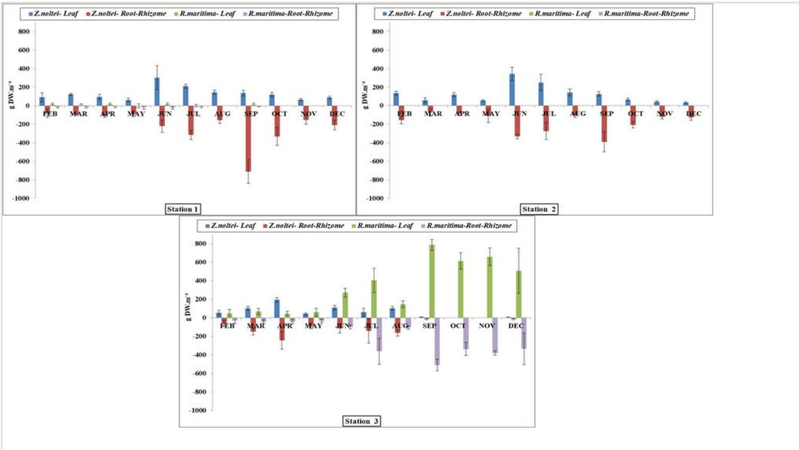

Figure 4.

Spatial and temporal variations of aboveground and belowground biomasses (g $DW.m^{-2}$) (mean ± SEM) of different benthic angiosperm species collected at the three surveyed stations in the El Mellah Lagoon during 2019.

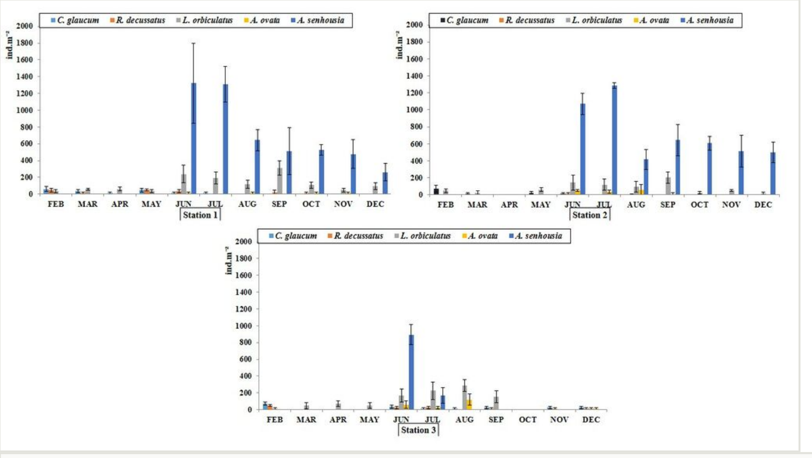

Figure 5.

Spatial and temporal variations of density (ind.m^{-2}) (mean ± SEM) of different benthic bivalves assosited species collected at the three surveyed stations in the El Mellah Lagoon during 2019.