

Spatiotemporal variation in phenology of the invasive brown macroalga *Sargassum muticum* (Yendo) Fensholt and the environmental parameters relationships along four different sites in the Atlantic coast of Morocco

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Abstract

The alien brown seaweed *Sargassum muticum* (Yendo) Fensholt is currently observed along the coasts of Morocco. The present study aimed to evaluate the impact of physicochemical parameters on the distribution of *S. muticum* at four sites on the Atlantic coast of Morocco harvested between 2019 and 2020. This study's results showed that the highest biomass, thalli length and fertility values were recorded in sampling sites characterized by optimal physicochemical (temperature, pH and salinity) and nutrient H₂PO₄ during summer. The highest biomass values were recorded in August for Sidi Bouzid and Moulay Abdellah sites, conversely, in Saada and Jorf Lasfar sites the highest values were observed in February and Mars respectively. The thallus length was slightly larger in Moulay Abdellah site with 77,30 ± 14.09 cm in compare with the three other sites during summer/spring periods. Minimum thalli length was recorded in September for all studied sites. The thalli of *S. muticum* were fertile earlier in Sidi Bouzid and Saada during spring and peaks during summer season for all studied sites showing a positive correlation with increasing temperature.

Finally, the collected data shows that indeed physicochemical parameters influence the bioecological parameters. Thus, contributed to a better understanding of the temporal variation of *S. muticum* phenology in Moroccan Atlantic coast, these data provide the necessary information for coastal marine management and biomonitoring program as well as sustainable utilization of this renewable marine resource.

Introduction

Harmful macroalgal blooms have become a global concern, causing ecological, economic and health problems (Liu, F et al. 2013). Among the most widely proliferating seaweeds, *Sargassum muticum* (Yendo) Fensholt (Phaeophyceae: Fucales) was described for the first time from Japan by Yendo (1907), as *Sargassum kjellmanianum* f. *muticum*. It is native to the Northwestern Pacific coasts where it has been described as a minor component of the Japanese *Sargassum* group (Critchley 1983; Critchley et al. 1986), and as "inconspicuous" according to Givernaud (1984). However, Engelen et al. (2015) have also considered it as one of the most successful introduced seaweed species and the most widespread invasive macroalgae.

This Japanese seaweed was accidentally introduced to Pacific North America in the 1940s and then to European coasts in the early 1970s, in both cases associated with the intentional transfer of the Pacific oyster *Crassostrea gigas* (Critchley 1983; Haroun et al. 1992). The species was first recorded as drift on the Belgian coasts in 1972 and established populations were observed on the Isle of Wight, southern England, in 1973 (Knoepffler-Peguy et al. 1985; Wonham et al. 2005). In the eastern Pacific, its current distribution extends now from south-eastern Alaska to Baja California (Critchley et al. 1983). It was observed in numerous locations around the Channel region and spread during the next 30 years along European shores, reaching Scandinavia and Portugal (Aguilar-Rosas et al. 1985; Rueness et al. 1989 and

Karlsson *et al.* 1999). It was also introduced into Mediterranean coastal lagoons: Thau (France) and Venice (Italy) (Monteiro *et al.* 2009).

After dispersing (by natural or non-natural means) into a new area, the colonization success of *S. muticum* first and foremost depends on the match between the recipient environmental regime and the species' physiological tolerances Givernaud (1984). Several studies show that temperature and salinity often considered two of the most important environmental abiotic drivers of the geographical distribution of marine algae, and tolerance to these factors often varies between different life stages (Curiel *et al.* 1998; Lalegerie *et al.* 2020). *S. muticum* is a monoecious species, generates a large number of propagules and is able to disperse into new areas by way of drifting mature fronds (Kopecky *et al.* 2006). *S. muticum* known to have a direct impact on the indigenous floral assemblages (Norton *et al.* 1981). This invader inhibits the recruitment and growth of indigenous floral assemblages, even leading to the eradication of many species e.g., *Gongolaria barbata* (Stackhouse) Kuntze in Venice (Knoepffler-Peguy *et al.* 1985). Moreover, the impacts of this invader on the native macroalgal associated epifauna are well documented (Salvaterra *et al.* 2013; Belattmania *et al.* 2018; Engelen *et al.* 2013 and Veiga *et al.* 2014). Fletcher in 1975 predict that *S. muticum* may spread to parts of the North African Atlantic coast as it presently occupies similar latitudes on the Mexican Pacific coast. Considering these predictions, it appears that this invader took 72 years from time outside its native region 1941 to the coast of Morocco in 2012. Thus, in winter of 2011–2012 a population of *Sargassum* different from native species of the genus was detected during a field trip along the shoreline of Doukkala (Atlantic coast of Morocco, Northwest Africa) (Sabour *et al.* 2013). Moreover, it has been identified in the lagoon of Oualidia in June 2012. In addition, it has been reported for the first time in the Algerian coasts in Cherchell and Sidi Fredj in 2015. Other Moroccan researchers work on the spectroscopic characterization and rheological properties of alginate from *S. muticum* find that this invasive species could be considered as a potential source of alginates, beside another published paper in 2019 studied the use of *S. muticum* as Low-Cost Biosorbent of Methylene Blue (El Atouani *et al.* 2016; 2019). Zahira Belattmania in 2016 studied the spatiotemporal variation of the epifaunal assemblages associated with *S. muticum* on the NW Atlantic coast of Morocco, in addition to this, she worked in 2018 on similar epiphytic macrofauna inhabiting the introduced *S. muticum* and native Furoids on the Atlantic Coast of Morocco and also how the introduction of *S. muticum* modifies epifaunal patterns in a Moroccan seagrass meadow (Belattmania *et al.* 2016; 2018) beside another published paper in 2022 studied the possible use of *S. muticum* as an alginophyte for commercial applications during the seasonal life cycle in order to identify the best harvesting time which is May-June (Belattmania *et al.* 2022). Recently, El Atouani *et al.* (2021) highlighted various aspects of the dynamics of *S. muticum* populations on the Atlantic coast of Morocco over a period of two years (2013 and 2014), making this study as recent and second report concerning the biomonitoring of this invader species for 13 months, between April 2019 and Mars 2020 in the Moroccan Atlantic coast.

This study aimed to provide a recent data into *S. muticum* phenology after seven years of invasion in the Moroccan context. For this purpose, a biomonitoring study was conducted to assess the spatiotemporal differences in growth, density and reproductive development of *S. muticum* and the environmental

parameters relationships in four different sites along the Moroccan Atlantic coast in order to establish a management plan for any future rational valorization, control or eradication strategies.

Material & methods

Study areas

This study was conducted between April 2019 and Mars 2020. To monitor temporal variation in *S. muticum* length, biomass, density and fertility, beside algal environmental conditions, four sites of the Moroccan Atlantic coast were selected within El Jadida, Saada (SA) (33°13'02.55",08°33'51.41"), Sidi Bouzid (SB) (33° 13' 52", 8° 32' 51"), Moulay Abdallah (MA) (33° 11' 52", 8° 35' 18") and Jorf Lasfar (J) (33° 07' 36", 8° 37' 13") (Fig. 1). These sites were chosen because this non-native species is often present as an extensive canopy.

Sampling design and Environmental parameters

A sampling program was designed to assess the dynamic population of *S. muticum*. Samples were collected monthly, at low tide and when waves were < 1 m, for ensuring a large area of sampling, from April 2019 to Mars 2020. Thus, at the four study sites, three 25x25 cm quadrats were randomly placed in each level of mediolitoral zone. All thalli inside the quadrats were carefully removed, bagged, and carefully transported to the laboratory. Care was taken to ensure that all the samples were scattered throughout the population and to avoid repeated sampling of the same area (Chopin *et al.*1997).

Once in the laboratory, thalli were cleaned of epiphytes and rinsed with freshwater. Then several biometrical measurements have been assessed for each thallus, indeed all the thalli were measured in length from the holdfast to the apex then weighted. Whereas the fertility, has been observed as the appearance of the fertile receptacles on the tertiary branches using a stereomicroscope (Olympus SZX7, USA), and density was considered as the total number of individuals per sampled area m² (ind/m²).

Variation in environmental parameters was monitored monthly in situ in each site: pH, salinity (psu) and seawater temperature(°C) were measured with a pH meter (consort C931, 0.1% ± 1 digit), salinometer (consort C861, 0.5% f.s. of range) and liquid thermometer (± 1 scale division) respectively. The fixation of oxygen was done in situ using the chemical method of Winkler by the addition of reagents, manganese solution and potassium iodide solution (Winkler, 1888).

Over the period of the study Seawater was collected, and the nutrient analysis (Nitrates (NO⁻) and Orthophosphate (H⁺ PO⁻)) were determined by the colorimetric method (NF EN 12014-3, NF EN ISO 6878) according to the standards described by AFNOR, (2001). The measuring unit used for all nutrients is (μmol L⁻¹).

Data analysis

To evaluate relative similarities among different sampling sites and seasons depending on the biological indicators (biomass, thalli length, and fertility) and the physicochemical parameters, a statistical analysis was executed using Primer/ Permanova version 6.1.13 and XLSTAT. The normality of distribution data in *S. muticum* samples for all studied sites was checked based on the Shapiro-Wilk's test. Correlation matrix was used to determine the relation among all the studied parameters using Pearson (parametric) or Spearman (nonparametric) rank order correlations. Principal Component Analysis (PCA) was performed to identify data clusters among the sites, seasons and studied parameters. The differences between the amount of the studied parameters in *S. muticum* within sites and seasons were determined by analysis of variance (ANOVA) or Permanova tests. The p value ≤ 0.05 was identified as the significance level.

Results

Growth of *Sargassum muticum*: Biomass and thalli length

Over the monitoring period of *S. muticum*, the studied parameters varied significantly within seasons ($p < 0,05$), with no significant differences between sites (Figs. 1–2). In fact, the seasonal growth of *S. muticum* thalli in each studied site during 2019–2020 shows that:

In Saada, the average annual biomass was $1,2 \text{ Kg m}^{-2}$, with a seasonal variation ranging from $0,4 \text{ Kg m}^{-2}$, in April during mid-spring to $2,5 \text{ Kg m}^{-2}$, in February during late winter. The minimum and maximum thalli length varied clearly from 18,1 cm in September during autumn to 69,5 cm in August during summer.

In Sidi Bouzid, the average annual biomass was $1,03 \text{ Kg m}^{-2}$, with a seasonal variation ranging from $0,3 \text{ Kg m}^{-2}$, in November during mid-autumn to 2 Kg m^{-2} , in August during late summer. The minimum and maximum thalli length varied clearly from 15,4 cm in November during the autumn to 69,5 cm August during summer.

In Moulay Abdallah, the average annual biomass was $1,18 \text{ Kg m}^{-2}$, with a seasonal variation ranging from $0,36 \text{ Kg m}^{-2}$, in September and October during autumn to $1,94 \text{ Kg m}^{-2}$, in August during late summer. The minimum and maximum thalli length varied clearly from 16,25 cm in September, during autumn, to 77,30 cm in August, during summer.

In Jorf Lasfar, the average annual biomass was $1,66 \text{ Kg m}^{-2}$, with a seasonal variation ranging from $0,42 \text{ Kg m}^{-2}$ in September, during early-autumn, to $4,88 \text{ Kg m}^{-2}$ in Mars, during early spring. The minimum and maximum thalli length varied clearly from 24,4 cm in September, during autumn, to 75,6 cm in Mars, during spring.

Figure 2 Monthly variation in thalli length at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

Abdallah and Jorf Lasfar).

Density of *S. muticum*

The populations of *S. muticum* can be observed throughout the whole year, but their spatial variations of density varied significantly according to seasons ($p < 0,05$), with no significant differences between sites.

In Saada, Moulay Abdellah and Jorf Lasfar, *S. muticum* density peaks in May with 128, 176 and 112 ind m^{-2} respectively, remained high through to late summer then dropped to a low-density during winter with 48, 48 and 32 ind m^{-2} respectively (Fig. 4). However, in Sidi Bouzid, site a different pattern occurred, when the density of *S. muticum* showed a seasonal fluctuation, with abundances in April (112 ind m^{-2}) and lowest in July (32 ind m^{-2}) (Fig. 4).

Fertility

Regarding fertility during the biomonitoring period of our study, the individuals were checked for the presence of mature receptacles, hence the reproductive thalli show a significant variation within seasons ($p < 0, 05$), with no significant differences between sites.

In fact, in Sidi Bouzid and Jorf Lasfar, reproductive thalli first appeared during late spring then reached their maximum during summer, and then decreased and disappeared in the late summer for Jorf Lasfar, while in Sidi Bouzid a few reproductive thalli were still present till early autumn (September) then disappeared the next month (November) (Fig. 5). In contrast, *S. muticum* populations in Saada and Moulay Abdellah became fertile only in summer, then they were absent throughout the year (Fig. 5).

Environmental conditions at field sites

Two-way ANOVA or Premanova tests revealed no significant sampling site effect on the studied parameters. However, for the seasonal effect ANOVA or Premanova, only salinity and pH show no significant seasonal fluctuation ($p > 0, 05$), whereas seasonality was significantly demonstrated in the rest of the studied parameters with ($p < 0, 05$)

Physicochemical data

In Sidi Bouzid, sea water temperatures ranged from 13°C (January and December 2020) to 20°C (August 2019) (Fig. 6-a). Salinity oscillated between 35 psu (November 2019) and 37 psu (August 2019) (Fig. 6-b). Dissolved oxygen value ranged from 4,9 ppm in August to 16 ppm in March (Fig. 6-c), while maximum pH value was 8.5 (September 2019) and the minimum was 7 (April 2019) (Fig. 6-d).

In Saada, sea water temperatures ranged from 12°C (December 2019) to 19,5°C (August 2019) (Fig. 6-a). Salinity oscillated between 34 psu (January 2020) and 37 psu (August 2019) (Fig. 6-b). Dissolved oxygen value ranged from 5,8 ppm in August to 20,8 ppm in March (Fig. 6-c), while maximum pH value was 8,7 (August 2019) and the minimum was 7,5 (March 2019) (Fig. 6-d).

In Moulay Abdallah, sea water temperatures ranged from 16°C (March 2019) to 19.81°C (August 2019) (Fig. 6-a). Salinity oscillated between 35.9 psu (February 2020) and 37 psu (November 2019) (Fig. 6-b). Dissolved oxygen value ranged from 5.1 ppm in August to 18 ppm in March (Fig. 6-c), while maximum pH value was 8.33 (August 2019) and the minimum was 7 (March 2019) (Fig. 6-d).

In Jorf Lasfar, sea water temperatures ranged from 12.6°C (March 2019) to 19.9°C (August 2019) (Fig. 6-a). Salinity oscillated between 34.9 psu (February 2020) and 37.3 psu (November 2019) (Fig. 6-b). Dissolved oxygen value ranged from 5 ppm in August to 17 ppm in March (Fig. 6-c), while maximum pH value was 8.27 (April 2019) and the minimum was 7.65 (March 2019) (Fig. 6-d).

Nutrients

The results revealed that nutrient levels (NO_3^- and H_2PO_4^-) varied within site and seasons (Fig. 7).

In Saada, nitrate (NO_3^-) levels varied from 0.6 $\mu\text{mol L}^{-1}$ in October to 3.18 $\mu\text{mol L}^{-1}$ in March, (Fig. 7-a), whereas Orthophosphate level (H_2PO_4^-) ranged between 0.107 $\mu\text{mol L}^{-1}$ in December and 0.384 $\mu\text{mol L}^{-1}$ in August (Fig. 7-b). In Sidi Bouzid, nitrate (NO_3^-) levels varied from 0.1 $\mu\text{mol L}^{-1}$ in October to 5.91 $\mu\text{mol L}^{-1}$ in April (Fig. 7-a), whereas Orthophosphate level (H_2PO_4^-) ranged between 0.106 $\mu\text{mol L}^{-1}$ in December and 0.334 $\mu\text{mol L}^{-1}$ in September (Fig. 7-b). In, Moulay Abdallah, nitrate (NO_3^-) levels varied from 0.075 $\mu\text{mol L}^{-1}$ in October to 4.54 $\mu\text{mol L}^{-1}$ in April (Fig. 7-a), whereas Orthophosphate level (H_2PO_4^-) ranged between 0.112 $\mu\text{mol L}^{-1}$ in December and 0.395 $\mu\text{mol L}^{-1}$ in August (Fig. 7-b). In Jorf Lasfar, nitrate (NO_3^-) levels varied from 0.2 $\mu\text{mol L}^{-1}$ in August to 4.55 $\mu\text{mol L}^{-1}$ in May (Fig. 7-a), whereas Orthophosphate level (H_2PO_4^-) ranged between 0.106 $\mu\text{mol L}^{-1}$ in October and 0.380 $\mu\text{mol L}^{-1}$ in September (Fig. 7-b).

(Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

Multivariate analysis of the bioecology of *Sargassum muticum* and environmental parameters within sites and seasons

We used Principal Component Analysis (PCA) to determine the influence of site/season on the phenology of *S. muticum* harvested from four different sites along Moroccan Atlantic coast and its relationship with the environmental parameters (Fig. 8).

By applying the principal component analysis (PCA) on the bioecological parameters and environmental parameters, two principal components have been extracted by covering 54,4% of the cumulative variance (Fig. 8). We focused on the first two dimensions of PCA for the interpretation. The first principal component (PC1) revealed 35% of the total variance and the second, (PC2) of the total variance.

The PCA analysis between each bioecological parameter (used as a particular variable of interest) and the other variables of *S. muticum* by the sites showed an absence of any tendency for spatial preference, as sites are grouped independently of their geographical origins. Whereas the months are separated from

one to other and grouped as seasons, hence it is more influenced on phenology of *S. muticum*. Thus, the PCA analysis showed that biomass, thalli length and fertility were significantly higher in June, July and August (summer) warm period compared to other seasons, hence those parameters are significantly positively associated with temperature, pH, salinity and HPO_4^{2-} , whereas December, January, February March (winter) cold period was more characterized only by higher dissolved oxygen and NO_3^- . In contrast Spring and Autumn were characterized by higher thalli density (this parameter was not correlated to any of the other bioecological parameters), whereas the dominant season is autumn over spring for this cluster.

Discussion

Growth of *Sargassum muticum*: Biomass and thalli length

The biomass, density, thalli length and fertility of *S. muticum* differed among sites and seasons. To our knowledge, this study provides a recent data on the population dynamic of *S. muticum* in Moroccan Atlantic coast based on the previous works by El Atouani biomonitoring study of this invader in 2014 published in 2021, we have added other biomonitoring indicators namely (biomass and fertility) beside thalli length and physicochemical parameters.

The average biomass and thalli length generally show a seasonal fluctuation. The biomass showed low values in spring in Saada and during autumn in the three remained sites Sidi Bouzid, Moulay Abdellah and Jorf Lasfar, whereas the highest values were recorded in summer for Sidi Bouzid and Moulay Abdellah sites, in contrast, in Saada and Jorf Lasfar sites the highest values were observed in late winter and early spring respectively.

Similar results were reported by (Wernberg *et al.* 2000) that highest and lowest mean biomass of *S. muticum* collected from Denmark found in July and January respectively.

In the same context (Baer and Stengel 2010) studied *S. muticum* in two sites in Ireland found that maximum biomass with 25.48 Kg m^{-2} at Letterard, in May. Similar results were reported by Mattio *et al.* (2009), that studying three *Sargassum sp.* in four different sites, in the Southwest lagoon of New Caledonia. For *Sargassum spinuligerum* Sonder, the highest biomass was measured, during summer 2006 ($686 \text{ g m}^{-2} \text{ dw}$), whereas the lowest was measured during Autumn 2006 ($6 \text{ g m}^{-2} \text{ dw}$).

For *Sargassum howeanum* A.H.S. Lucas, biomass was maximal during autumn 2006 and minimal during summer 2007, at the first site, whereas the tendency was inverted at another studied site, with the highest values observed in summer 2007 and the lowest in autumn 2006. Regarding *Sargassopsis decurrens* (formerly known as *Sargassum decurrens*) was found to have its highest biomass recorded in spring 2006, while the lowest biomass was observed in summer 2007. As an overall, *Sargassum sp.* biomass shows a different seasonal trend among sites worldwide.

Regarding the thalli length analysis, Sidi Bouzid, Moulay Abdellah and Saada share the same period of a maximum thalli length, which is the summer, precisely in August, while maximum thalli length was monitored in Jorf Lasfar in April during spring. Nevertheless, the four sites recorded a minimum length value during the autumn.

In Morocco at Each studied site *S. muticum* population characterized by a period of increasing length specially in summer followed with a marked decrease in autumn, whereas biomass increased from late winter to summer and decreased in autumn. Therefore, after the end of the reproductive period, the growth rate declines rapidly and the laterals start to degenerate, and that explains the decrease in thalli length and biomass during autumn.

Similar results were reported for *S. muticum* length by (El Atouani *et al.* 2021) documenting a clear variation of thalli length according to site, season and depths (varying from 0.5 to 1 m) in three different sites at Moroccan Atlantic coast between 2013–2014 including two sites we are studying (Saada and Sidi Bouzid) revealing that thalli length was the highest during summer. In Deauville Beach site in El Jadida, maximum length of 498.14 cm and 643.33 cm in June 2013 and July 2014, respectively, whereas for Saada and Sidi Bouzid sites the lengths of thalli reached the highest values of 188 cm and 95 cm in June 2014 respectively.

The same growth pattern has been demonstrated in the south- western coast of Ireland (54°N), individuals reach their maximum length in summer (Baer and Stengel 2010). In Strangford Lough, Northern Ireland (54°N) either, maximum length achieved in August (Summer) (Kraan 2009). In the same context, (Jephson and Gray 1977) found that length of the population was at a maximum during the early part of July (summer). According to some researchers, *S. muticum* may grow as fast as 4 cm/day and reach up to 10 m of length, if given optimal environmental conditions (Jephson and Gray 1977; Nicholson *et al.* 1981; Abbott & Hollenberg 1976; Belsher and Boyen 1983).

Other authors 'studying *S. muticum* along the coasts of Brittany (France) recorded that, thalli were generally longer in summer up to 73.2 ± 2.7 cm that confirm our results (Plouguerne *et al.* 2006).

As in previous study the Moroccan Atlantic coasts presents the largest range of ecological conditions and the influence of upwelling on the abundance and distribution of many species (Lourenço *et al.* 2020), it may correspond to the seasonal variation in the growth of *S. muticum*. (Wernberg- Møller *et al.* 1998) demonstrate a highly specialized adaptation of *S. muticum* to life in a seasonal environment. (Arenas *et al.* 1995) subdivide the growth rhythm of this species into two phases: one of moderate growth in autumn-winter with a slow increase in thalli length, and one of strong growth during the spring-summer period. The timing of the different phases of the annual life cycle varies geographically. Whereas in the Lagoon of Venice, Italy (45°N) the growth rate of individual *S. muticum* increases in March, with maximum length 485 cm reached in April (Sfriso and Facca 2013).

(Incera *et al.* 2011) mentioned that the length of thalli varied significantly among the ten studied sites (from March 2008 to August 2008) reaching max at Vigo site located along the Galician coast (NW

Spain).

Seasonal variations are thought to be related to the combined effect of biotic (i.e., seaweed growth cycle, the age of the algal tissue) and abiotic factors (i.e., seawater temperature) (Bengtsson et al. 2010 and Mancuso et al. 2016).

Nevertheless, our study confirmed by other studies world wide suggesting that *S. muticum* population growth at the Moroccan Atlantic coast has the same biological behavior comparing to other localization worldwide.

Density of *S. muticum*

The thallus density was relatively abundant during spring for the four sites and scarcity in July during summer for Sidi Bouzid site and during winter in the three remained sites.

Our results were in concordance with those of El Atouani *et al*/2021, recorded spatiotemporal distribution of *S. muticum* density in 3 sites including Saada and Sidi Bouzid sites between 2013–2014. The average densities from winter to early summer (23–39 ind m⁻² in 2013, 43–46 ind m⁻² in 2014) for Saada and Sidi Bouzid sites respectively, with significant differences in thalli density between hot and the cold months, when the species naturally degenerates after the reproductive period (El Atouani *et al*/2021). These finding revealed an expansion of *S. muticum* density from three to four times in Saada and Sidi Bouzid sites respectively, in fact density increased from 43 to 128 ind m⁻² and from 46 to 176 ind m⁻² between 2014 and 2020 respectively.

According to our observations one of the key elements that can explain the success of *S. muticum* in Moroccan Atlantic coasts, is the great amount of free space available such as: rockpools and the Substratum of the four sites is a mixture of small stones, pebbles and shingle, most of the time covered by sand or embedded in mud.

Moreover, some authors confirm that *S. muticum* densities depending on seasonal changes in water motion, grazing pressure (Plouguerné et al., 2006), seabed topography, substrate type (El Atouani *et al.* 2021 and Harries et al., 2007), and exposure (Viejo 1997), thus those factors highlighted as potential determinants of ecological success.

Fertility

S. muticum is a pseudo-perennial species with strong seasonality in its life cycle (Wernberg et al. 2001). In fact, the period of the reproductive cycle of *S. muticum* varies among regions according to the geographical latitude (Engelen et al. 2015). Some authors as Hales and Fletcher 1989 suggest that fertility, cessation of growth, and senescence are almost simultaneous processes in *S. muticum*.

In this study, we have noted a local scale difference in the timing and rate of fertility occurrence between sites and seasons. The reproductive periods of *S. muticum* populations in Sidi Bouzid and Jorf Lasfar

were significantly earlier than in Saada and Moulay Abdellah sites. In all studied sites, the fertile season peaks in summer, but small fertile individuals are also present only at Sidi Bouzid in early autumn. In addition, different authors suggest that throughout the reproductive season *S. muticum* releases gametes intermittently at intervals of 14 days following a semilunar periodicity (Norton 1981, May and Clayton 1991; Engelen et al. 2008). In the North-Western coast of Baja California, Mexico (32°N) and in Southern California, USA (33°N) where, fertile individuals can be found throughout the year (Aguilar and Galindo 1990). A similar situation as in the Moroccan Atlantic coast, observed along the north coast of Spain (43°N), with a spring-summer reproductive period (Arenas and Fernández 1998), whereas in its native area Japan (34–39°N), fertile thallus of *S. muticum* are found from winter to early summer (Yoshida 1983, 1985). Other authors found that, on southern Portugal (37°N) the reproductive period occurs between January and September, depending on the location (Engelen et al. 2008). (Cheang *et al.* 2010) personal observation in China (39°N), confirm that fertile individuals are recorded in spring. While in the Northern coast of Portugal (42°N), can last from April to August (Engelen et al. 2008). On the Western coast of Brittany, France (48°N), mature individuals are observed until autumn, when fragmentation begins (Le Lann et al. 2012). On the southern England (49°N), receptacle development begins in June, and zygotes are released during August (Norton 1981). Populations growing in the British Isles (50°N) are only fertile in summer (Gorham and Lewey 1984; Norton and Deysner 1989). Whereas in the Strangford Lough, Northern Ireland (54°N) the reproductive season is short and is restricted to summer (Boaden, 1995). Although this synchronization might be affected by the onset of senescence at the end of the reproductive season (Monteiro et al. 2009). Those results from various locations suggest a latitudinal dependency in the phenology of *S. muticum*.

The seasonal pattern of *S. muticum* annual life cycle in the Moroccan Atlantic Coast can be summarized as follows: initial growth begins (maximum biomass and accompanied with increasing in length) from late winter to summer depending on sites, following by elongation (maximum growth in length), reproduction phase during summer and ends with quiescence, degeneration from late summer to autumn.

Conclusion

we have noted during this biomonitoring study of the invasive macroalgae *S. muticum* along the four different sites in the Moroccan Atlantic coast, that growth occurs gradually from late winter to summer, with some variation from one site to another. Nevertheless, fertility occurs in late spring and peaks in summer with releasing of embryos from receptacles or the newly branch with vesicles detach from older perennial parts carrying fertile propagules and float away at the end of the summer season. Whereas from late summer to autumn we have noticed dormancy and degeneration of individuals except the holdfast and with some old primary laterals, which means that senescence occurs abruptly (with rapid decrease in length and biomass) after peak of growth and fertility. Thus, it remains from autumn to early winter with the appearance of recruits in mid-autumn that grows in transversely and longitudinally by ramification of branches and that explains the peak growth in biomass, the elongation during summer is notable with the prevalence of large individuals, which explains the peak growth in length. Thus, these

results highlight the clear seasonal variations of the bioecological parameters which could be related to environmental factors. Thus, efficient colonization by *Sargassum muticum* could represent a major risk for native benthic algae. It would be interesting to investigate the potential valorization of this alien seaweeds to avoid its pressure on coastal areas and limit its economic problems.

Declarations

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Competing interests

The authors declare that they have no competing interests of a financial or personal nature which could have influenced the design, conduct, analysis or interpretation of this scientific study.

Authors' contributions

A.A., N.R and T.O.B wrote the manuscript. They contributed equally to the development of the research concept, data collection, analysis, and interpretation of results. H.Z provision of field equipment, including GPS devices, monitoring instruments, administration facilities and data collection. B.B provided help in the physicochemical analysis. L.P provided valuable feedback on the manuscript and helped to deepen our understanding of the data. His insightful suggestions and critical review contributed to the overall clarity and coherence of the manuscript.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author or reasonable request.

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Figures

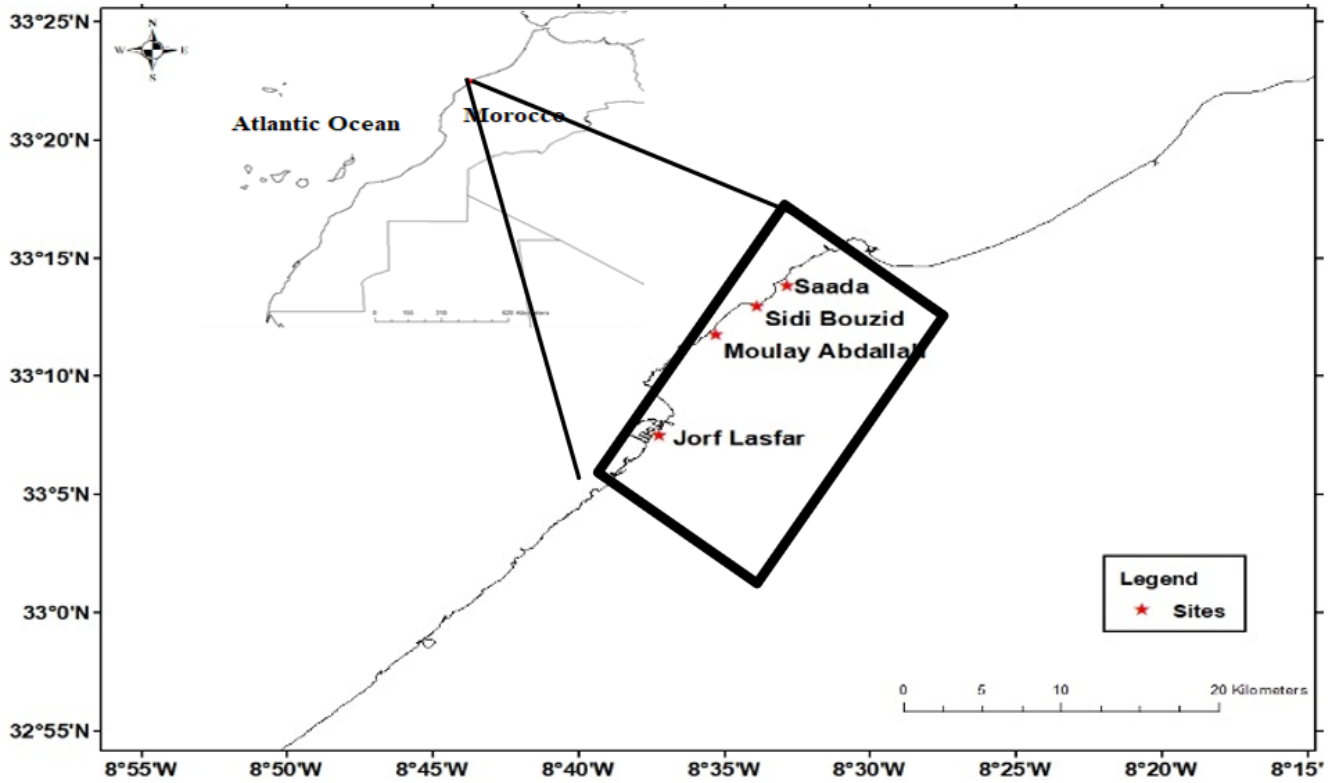


Figure 1

Location of the four sampling sites of *Sargassum muticum* along the Atlantic coast of Morocco using Arc GIS10.8.

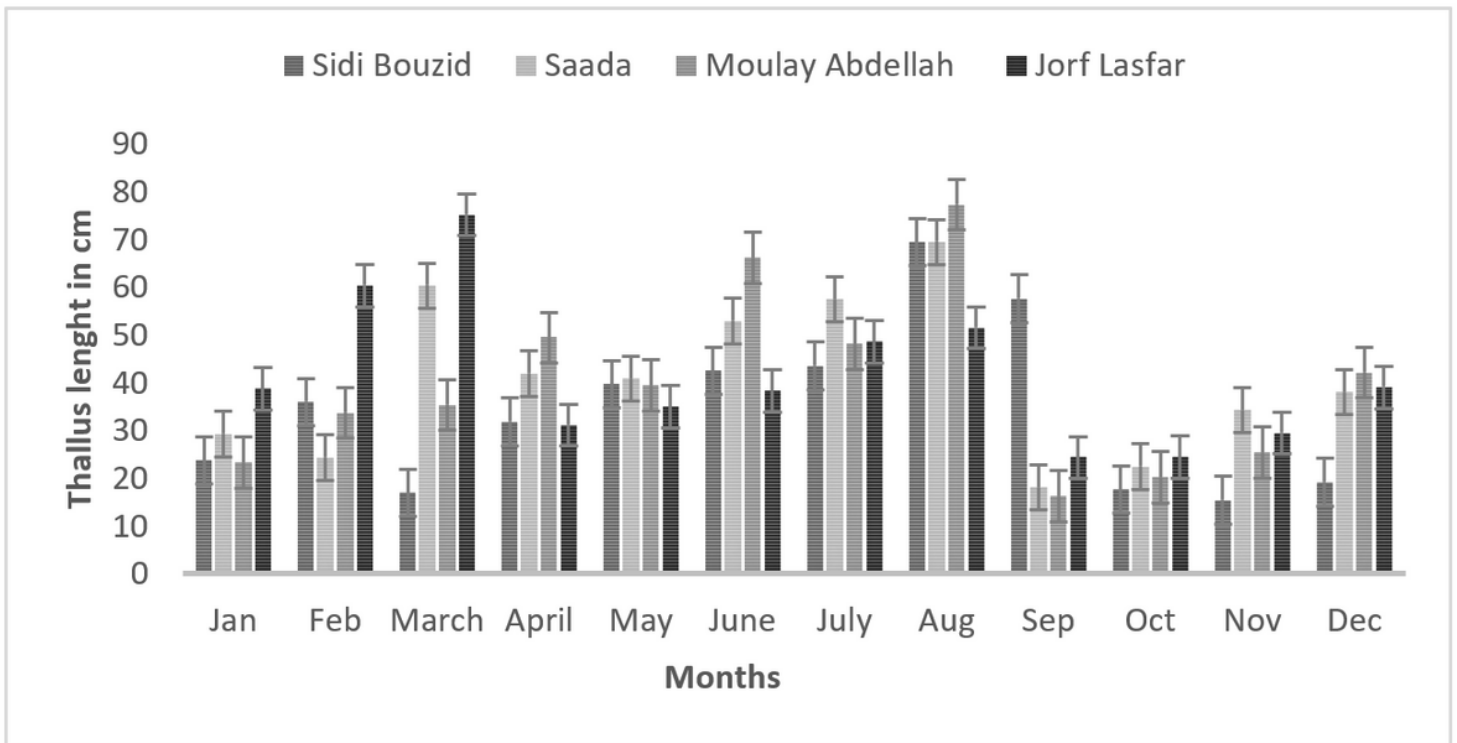


Figure 2

Monthly variation in thalli length at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

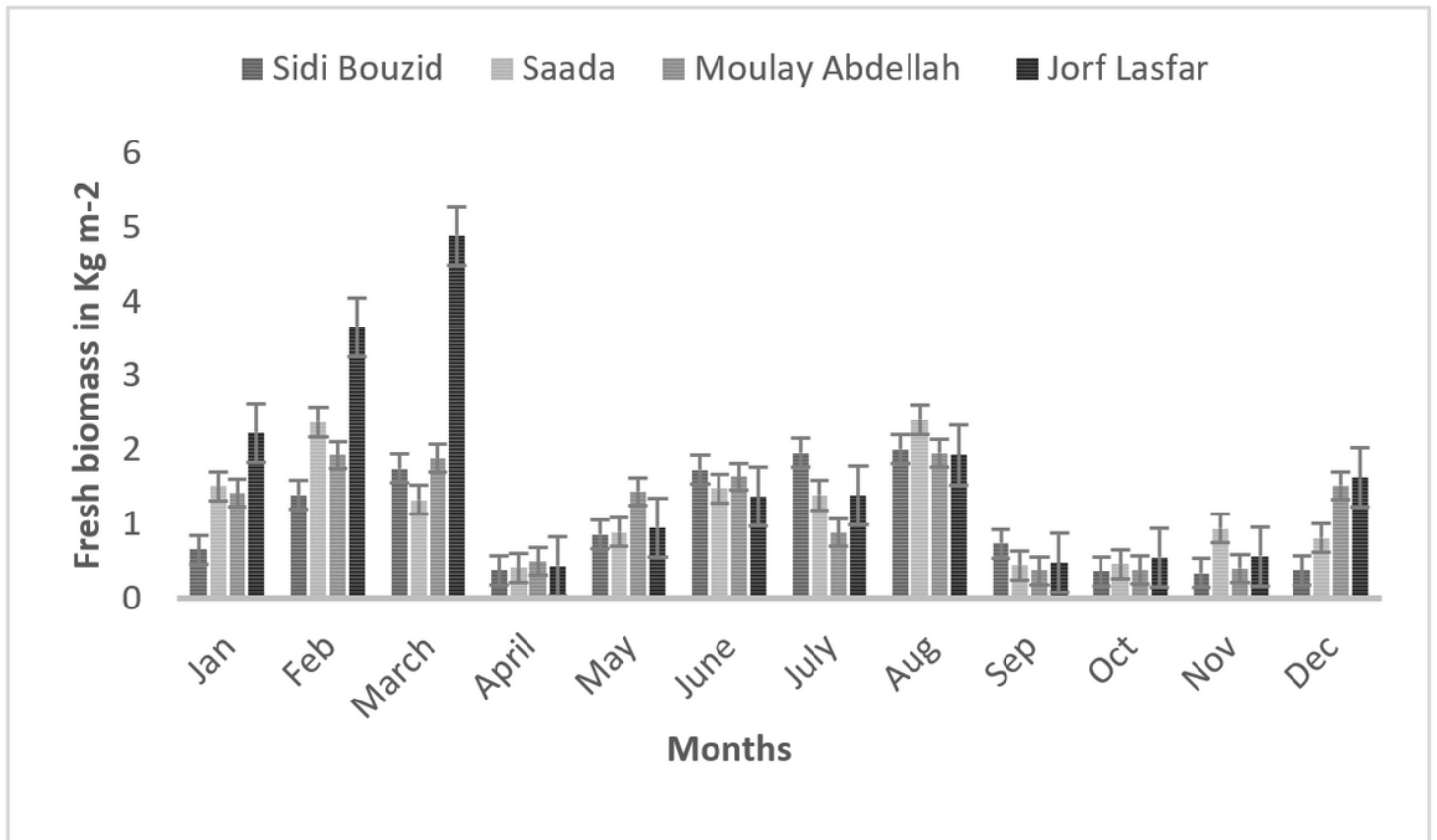


Figure 3

Monthly variation in the biomass of *S. muticum* at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

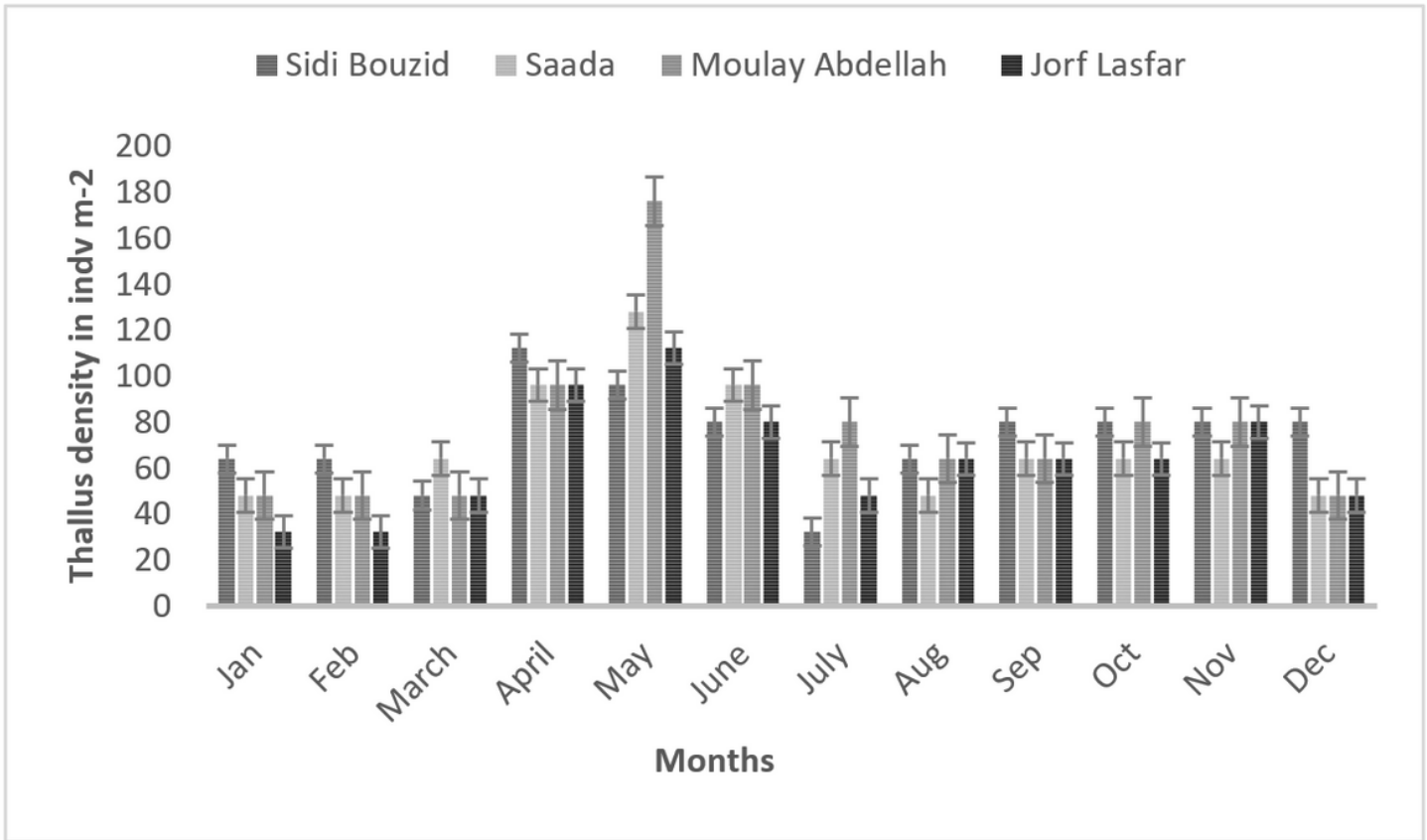


Figure 4

Monthly variation in thalli density of *S. muticum* at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

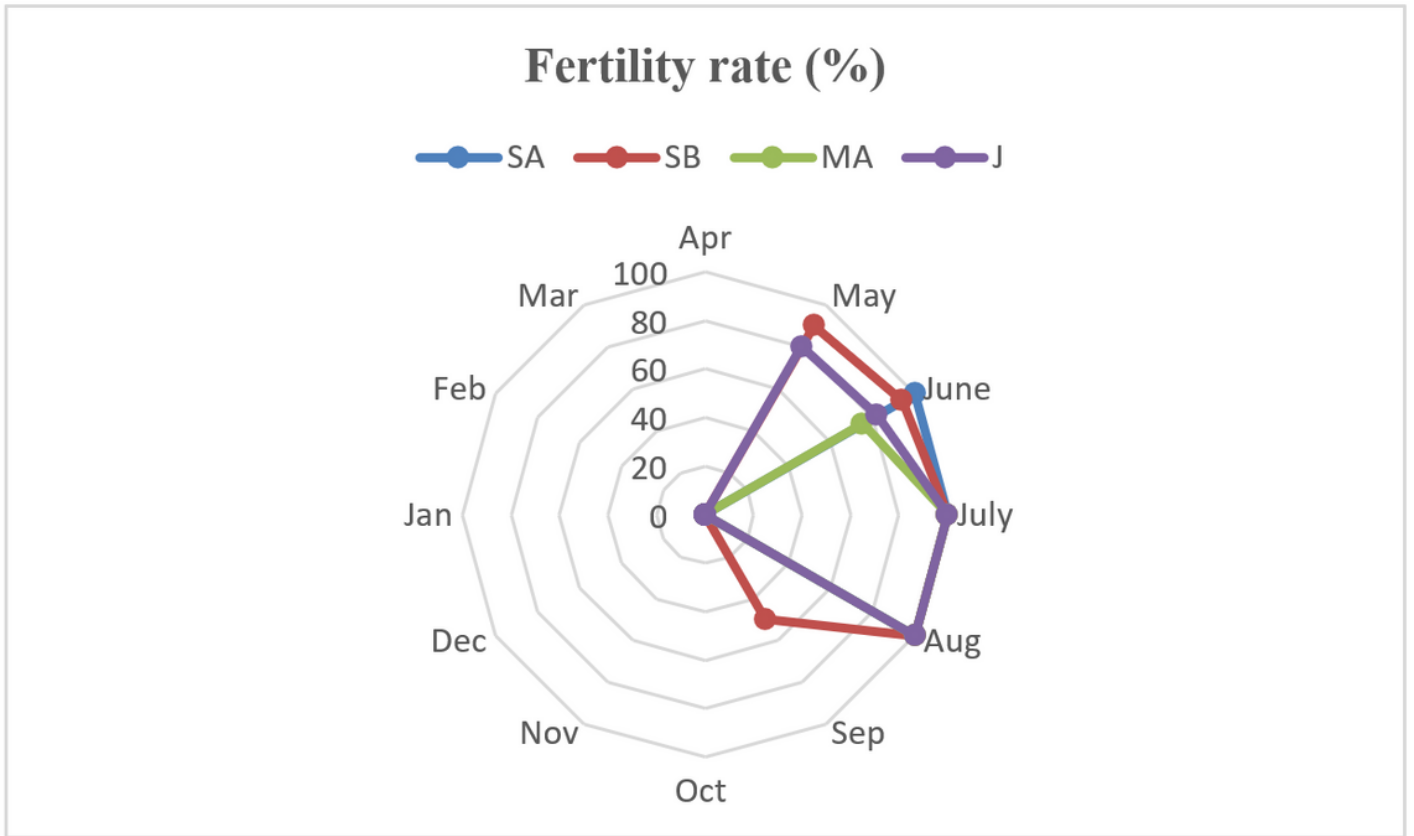


Figure 5

Monthly variation in *S. muticum* fertility at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

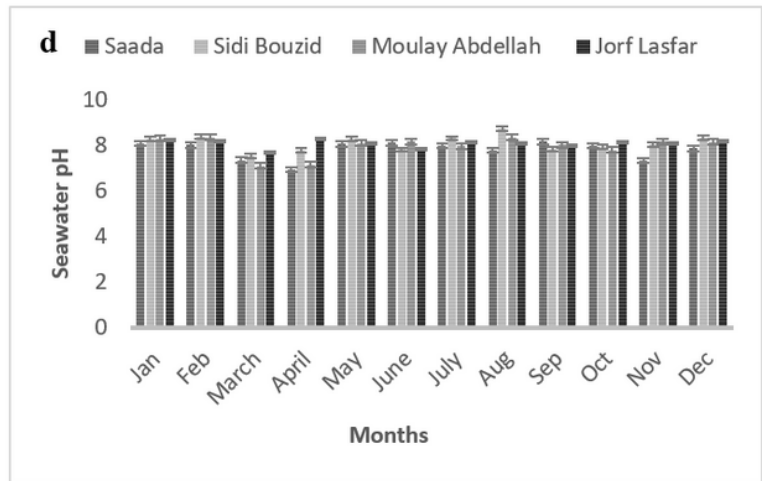
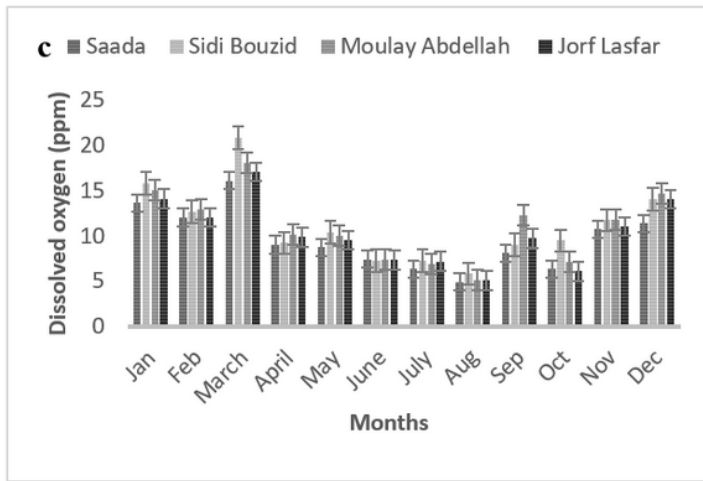
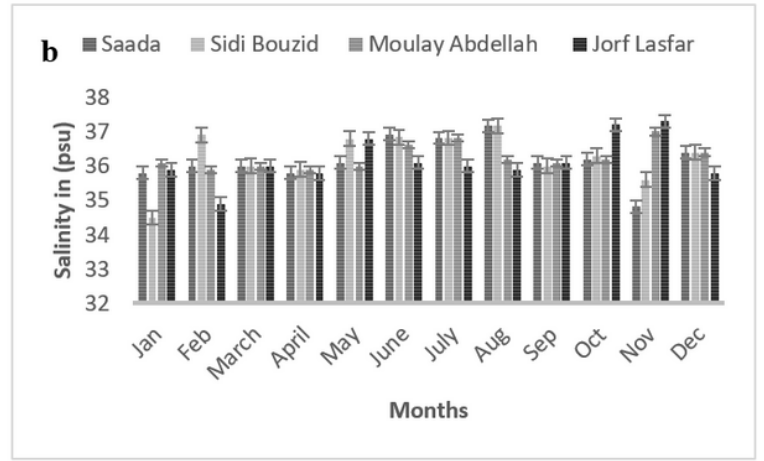
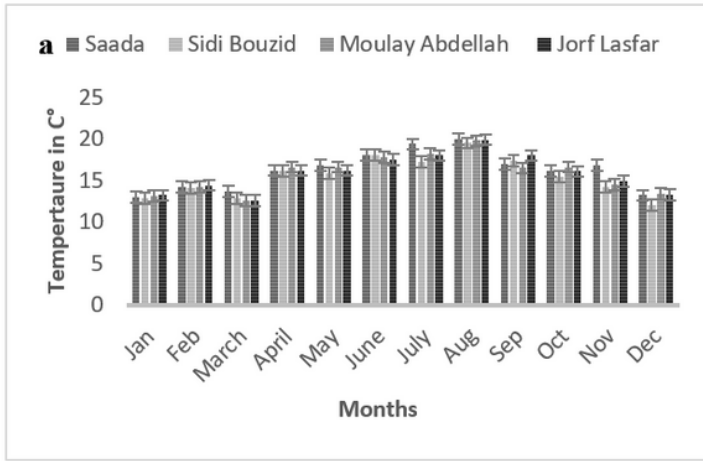


Figure 6

Monthly variation in the physicochemical parameters: Sea water Temperature (a), Salinity (b) dissolved Oxygen (c) and pH (d) at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

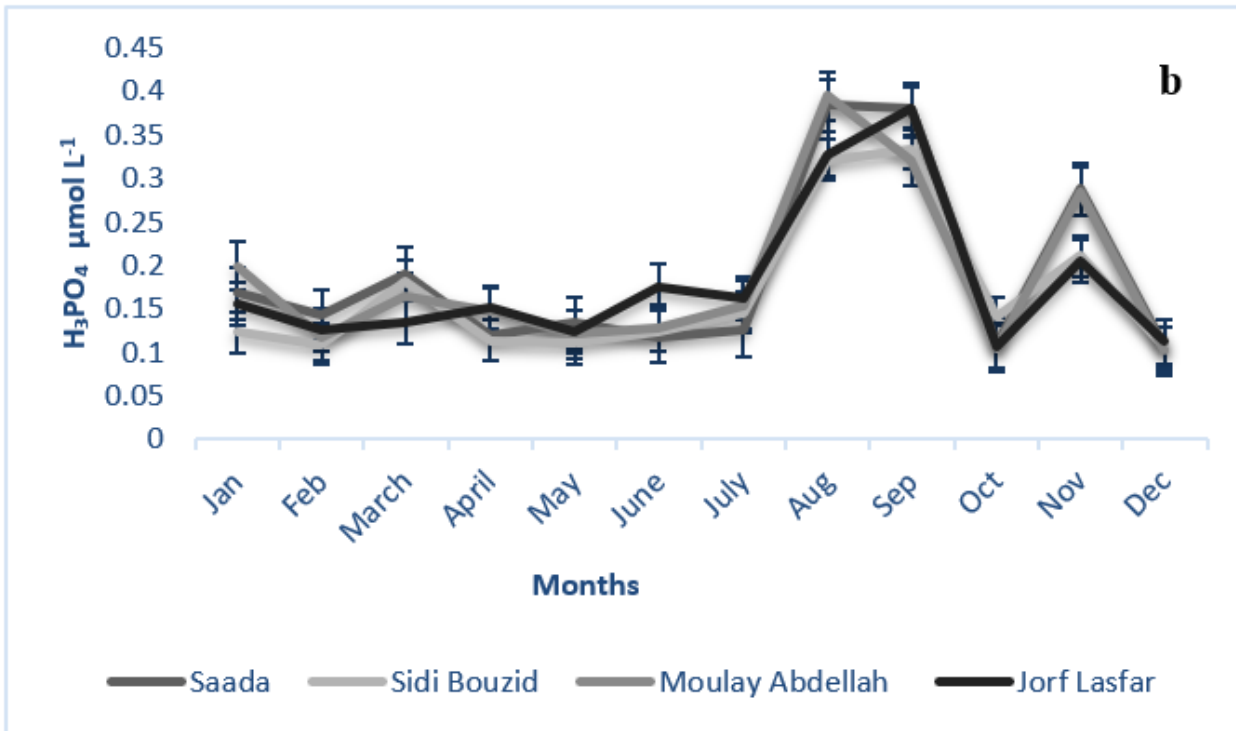
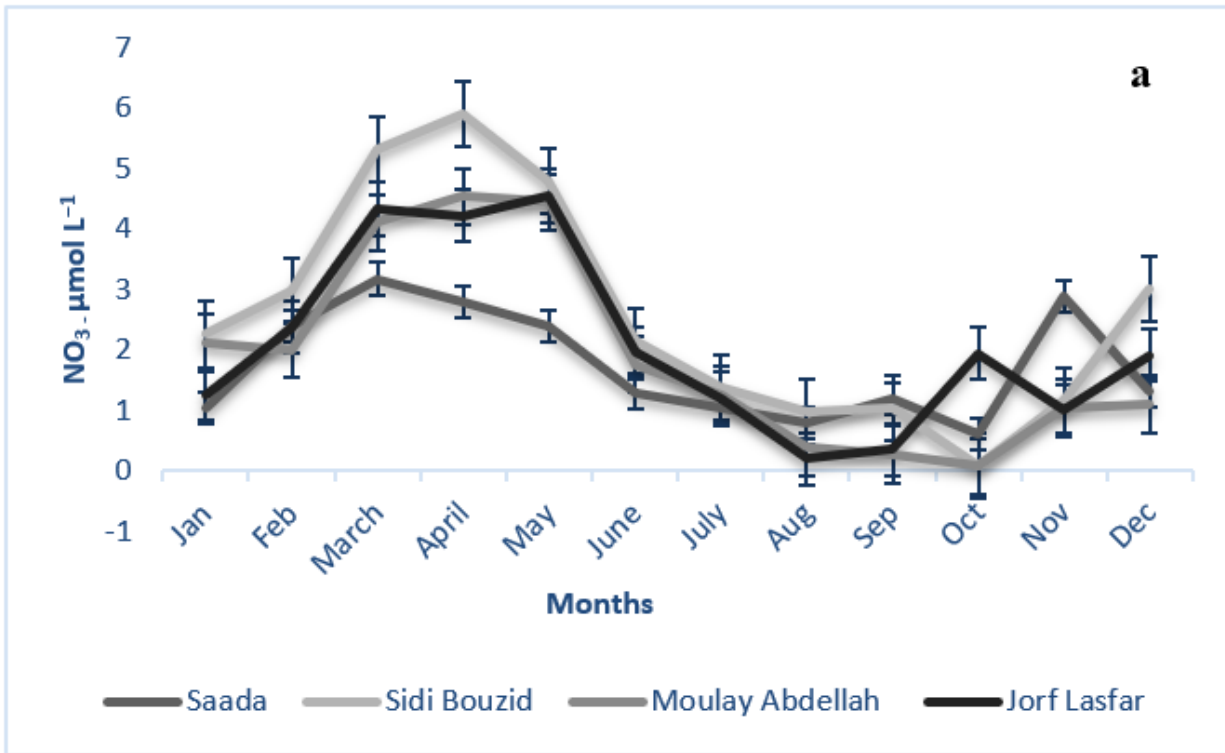


Figure 7

Monthly variation of nutrients (nitrate (NO⁻) (a) and Orthophosphate (H₃PO₄) (b) at the four sites (Saada, Sidi Bouzid, Moulay Abdallah and Jorf Lasfar).

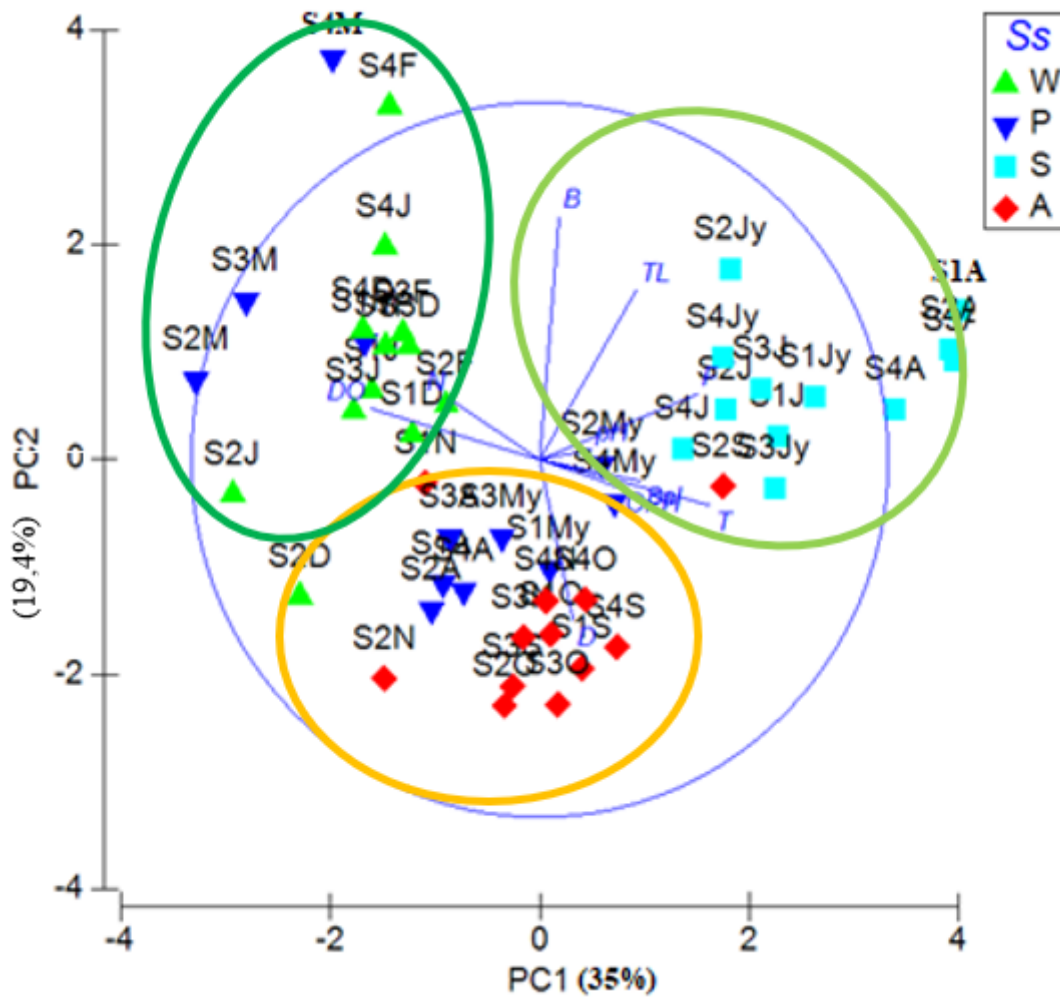


Figure 8

Principal component analysis scatter plot representing the scores for the bioecological data (Biomass, Thalli length, Fertility and Density) and environmental parameters (Temperature, Salinity, pH, Dissolved oxygen, Nitrate and Orthophosphate) in *Sargassum muticum* and their variation within site and seasons. Abbreviations in the figure are as follows: B (Biomass), TL (Thalli length), F (Fertility), D (Density), T (Temperature), Sal (Salinity), DO (Dissolved oxygen), N (Nitrate), OPH (Orthophosphate), S1 (Saada site), S2 (Sidi Bouzid site), S3 (Moulay Abdellah site), S4 (Jorf lasfar site), S (Summer), P (Spring), A (Autumn), W (Winter), months J (January), F (February).