SEASONAL VARIATION OF CYMODOCEA NODOSA IN THE GHAR EL MELH LAGOON (TUNISIA), WITH REFERENCE TO INSOLATION, TEMPERATURE AND SALINITY EFFECTS

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ملخص

متابعة نمومعشبة السيمودوسيا خلال دورتها السنوية في بحيرة غار الملح : تمت المتابعة الشهرية للإنتاج الأولي ولدورة الكتلة الحيوية لمعشبة السيمودوسيا *Cymodocea nodosa* (Ucria) Ascherson في بحيرة غار الملح (شمال شرق تونس) من نوفمبر 2006 أكتوبر2007. وقد تم اختيار محطتين لأخذ العينات من أجل تقييم مدى استجابة الأعشاب البحرية لظروف البحيرة .وقدر نمو الأوراق باستخدام طريقة Zieman وتم تقييم إنتاج الجذمور بواسطة الوسم. لوحظ اختلاف في نمو أوراق معشبة السيمودوسيا قرب نقطة الاتصال بالبحر و داخل البحيرة وكذلك في كثافة حزمها حيث انخفضت من 915إلى 500 حزمة في المتر المربع الواحد. بينت متابعة نمومعشبة السيمودوسيا خلال دورتها السنوية منوالا واحدا في كلتا المحطتين وسجل أقصى نمو الأوراق في فصل الصيف. تباينت الكتلة الحيوية الإجمالية بين 34 ± 241.6 و ± 413.8 46غ وزن جاف في المتر المربع الواحد. وتفاوتت فترات plastochrone Interval الأوراق بمتوسط سنوي يبلغ ما بين 23 و 28 يوما. كما انخفض متوسط إنتاجية السيمودوسيا من 1.42 غ وزن جاف في المتر المربع الواحد إلى 0.15 داخل البحيرة . أما بالنسبة إلى الإنتاج السنوي للأوراق، فقد كان أكثر بعشر مرات قرب نقطة الاتصال بالبحر (518.6 غ وزن جاف في المترالمربع الواحد وفي السنة) مقابل 54غ وزن جاف في المتر المربع الواحد وفي السنة داخل البحيرة . وقد بينت نتائجنا أيضا أن الخصائص البيولوجية لمعشبة السيمودوسيا في حدود توزيعها داخل البحيرة أكثر حساسية لتقلب المعايير البيئية (تشمس، ودرجة حرارة المياه والملوحة).

كلمات مفاتيح : *Cymodocea nodosa*، بحيرة ساحلية، الإنتاج الأولي، الكتلة الحيوية، والملوحة.

ABSTRACT

The primary production and the biomass cycle of *Cymodocea nodosa* (Ucria) Ascherson were calculated monthly from November 2006 to October 2007 in Ghar El Melh lagoon (N-E of Tunisia) : Two sampling stations were selected in order to assess the response of the seagrass to lagoon conditions. Leaf growth was estimated using Zieman method and rhizome production was evaluated by marking rhizome terminals. The vegetative development of *C. nodosa* inside the lagoon at the limit of its distribution is different from that observed close to the communication channel with the sea. The growth of *C. nodosa* show a clear unimodal cycle in the two stations reaching maximum leaf development in summer. Shoot density decreased from 915 to 500 shoot m^{-2} from the communication channel toward the lagoon. The average total biomass varied between 241.6 ± 34 g DW m^{-2} and 413.8 ± 46 g DW m^{-2}. Leaf plastochrone interval varied seasonally with an annual average of about 23 and 28 days. The average leaf productivity decreased from 1.42 to 0.15 g DW m^{-2} d^{-1} inside the lagoon. As for the annual leaf production, it was approximately ten times higher near to communication channel (518.6 g. DW m^{-2} $year^{-1}$) than inside the lagoon (54 g. DW m^{-2} $year^{-1}$). Our results show also that the biological characteristics of *C. nodosa* at this limit of its distribution in the lagoon were more sensitive to the variability of environmental parameters (insolation, water temperature and salinity).

Keywords: *Cymodocea nodosa*, coastal lagoon, primary production, biomass, salinity.

Résumé

La production primaire et le cycle de la biomasse de *Cymodocea nodosa* (Ucria) Ascherson ont été calculés mensuellement à partir de novembre 2006 à octobre 2007 au niveau de la lagune de Ghar El Melh (NE de la Tunisie). Deux stations d'échantillonnage ont été sélectionnées afin d'évaluer la réponse des herbiers aux conditions lagunaires. La croissance des feuilles a été estimée en utilisant la méthode Zieman et la production du rhizome a été évaluée par le marquage des rhizomes. Le développement végétatif de *C. nodosa* l'intérieur de la lagune à la limite de sa répartition est différent de cellui observé à proximité du canal de communication avec la mer. La croissance de *C. nodosa* montre un cycle unimodal dans les deux stations atteignant un développement maximal des feuilles en été. La densité des faisceaux diminue de 915 à 500 faisceaux par m^{-2} du canal de communication vers l'intérieur de la lagune. La biomasse totale varie entre 241,6 ± 34 g sec m^{-2} et 413,8 ± 46 g sec m^{-2}. Le plastochrone intervalle des feuilles variait de façon saisonnière, avec une moyenne annuelle d'environ 23-28 jours. La productivité moyenne des feuilles diminue de 1,42 à 0,15 g sec m^{-2} j^{-1} à l'intérieur de la lagune. Quant à la production annuelle de feuilles, elle est dix fois plus importante près du canal de communication

(518,6 g. sec m^{-2} an^{-1}) qu'à l'intérieur de la lagune (54 g. sec m^{-2} an^{-1}). Nos résultats montrent également que les caractéristiques biologiques de *C. nodosa* à la limite de sa distribution dans la lagune étaient plus sensibles à la variabilité des paramètres environnementaux (ensoleillement, la température et la salinité).

Mots-clés: *Cymodocea nodosa*, lagune côtière, production primaire, biomasse, salinité…

INTRODUCTION

The ecological characteristics of organisms living in coastal lagoons are related to high environmental stress due to the alternating inputs of marine and freshwaters, in addition to the increased nutrient inputs due to human activities that have impacted on coastal lagoons world-wide (Nixon, 1982; Masini & Manning, 1997).

Seagrasses are keystone species in many shallow lagoons and estuaries providing a complex habitat and high rates of primary production for ecologically and economically important higher consumers (Duarte & Cebrián, 1996; Short & Wyllie-Echeverria, 1996; Buia et al., 2000; Hemminga & Duarte, 2000; Short & Duarte, 2001; Duarte, 2002). Studies on seagrasses have documented that seagrass distribution and growth are strongly related to physiological tolerances and other growth restrictions including water temperature, light attenuation and salinity zonation (Torquemada et al., 2005).

Although most seagrasses can tolerate short-term salinity fluctuations, salinity variations will significantly affect some of the biochemical processes involved in photosynthesis and growth, determining the biomass, distribution and productivity of these species (Montague & Ley, 1993; Hillman et al., 1995; Chesnes & Montague, 2001). Along with salinity levels, other important environmental factors can vary, such as temperature or insolation, also affecting the distribution and growth of several seagrass species (Ogata & Matsui, 1965; Hillman et al., 1995). Temperature can alter the metabolism or cause mortality at extreme values (Biebl & McRoy, 1971; Drysdale & Barbour, 1975; Drew, 1979; Marsh et al., 1986).

Cymodocea nodosa (Ucria) Ascherson is a common seagrass species in the Mediterranean Sea, the North-Atlantic coasts of Africa and South-Atlantic coast of Europe and colonising also coastal areas of the Canary Islands (Den Hartog, 1970; Reyes et al., 1995; Cunha & Duarte, 2007). This species may be considered euryhaline, as it forms healthy stands under a wide range of salinities (Pérez & Romero, 1994), and this suggests it has a higher tolerance to elevated salinities than other Mediterranean seagrass species (e.g. *P. oceanica*).

However, only few studies are available on salinity effect on biomass, growth and primary production of *C. nodosa* (Fernández-Torquemada & Sánchez-Lizaso, 2006; 2011; Pagès et al., 2010). Some preliminary experimental evidence indicates that shoots may suffer deterioration or mortality under hypersaline conditions (Fernández Torquemada & Sánchez-Lizaso, 2006), while no significant changes were detected in a field study carried out by Pérez Talavera & Quesada Ruiz (2001) in a meadow close to the brine discharge from a desalination plant.

With the aim of expanding knowledge of the effects of lagoons conditions on key organisms, (1) we assess the growth and the vitality of *C. nodosa* meadow (density, phenology, biomass and primary production during the annual cycle (2006–2007), (2) we analyze the influence of lagoon conditions (insolation, water temperature and salinity) on seagrass morphology and production and (3) we compare the results obtained in the same period and the same lagoon given by Sghaier et al. (2011) in order to evaluate if the vegetative development of *C. nodosa* meadows inside the lagoon was different from those under marine influence.

MATERIAL AND METHODS

Study site

The Ghar El Melh lagoon is a Mediterranean water body, situated in Northern Tunisia, on the Northwestern side of the Gulf of Tunis (Fig. 1). The lagoon has an elliptical shape of approximately 34 km2 and an average depth of 0.8 m with a flat and muddy bottom (Kock Rasmussen et al., 2009). A single channel connects the lagoon to the Mediterranean Sea with a 10-70 m wide.

Due to human activities (industry, agriculture and population increases) within the lagoon itself and in the surrounding area, the lagoon ecosystem has suffered a progressive deterioration. This deterioration has led to reduction in biodiversity resulting mainly in a decrease in fish resources and production (Romdhane, 1985).

According to Ben Alaya (1972), large monospecific beds of *C. nodosa* constituted the main marine plant community in the lagoon in the early 1970s. *C. nodosa* declined considerably and persisted only in the eastern part of the lagoon by the early 1980s (Romdhane & Ktari-Chakroun, 1986). Between 1981 and 1983, most of the lagoon was covered by beds of *Zostera noltii* and *Z. marina* (Romdhane, 1985, Romdhane & Ktari-Chakroun, 1986) and *Ruppia maritima* occurred mainly along the northern shorelines (Shili et al., 2002). In the last decade, *Ruppia cirrhosa* and *Cladophora* spp. were the most dominant macrophytes while *C. nodosa* occupied a limited area exposed to marine influence (Shili et al., 2002).

In order to assess the response of the seagrass to lagoon conditions, we compare our results to those of

Sghaier et al. (2011) assessed close to the communication channel with the sea. [Station I (37°09’22”N/10°13’14”E) within a dense monospecific beds of *C. nodosa*]. The Station II located inside the lagoon at the limit of *C. nodosa* distribution (37°09’52”N/10°13’22”E). The meadows were located in the subtidal zone, 50 m from shore and at 50 cm depth (Fig. 1).

Physico-chemical parameters

Monthly insolation was obtained from Bizerte regional meteorology office. Water temperature and salinity were measured monthly from November 2006 to October 2007 using a salinometer (WTW Cond 315i, SUNTEX, Weilheim, Germany).

Morphometrics, density, biomass and phenology

Monthly sampling was performed by snorkel from November 2006 to October 2007 except for June, July and August when two samplings per month were performed. Shoot density of *Cymodocea nodosa* was measured in plots of 20x20 cm (10 replicates at each sampling event). The plant biomass (above and belowground) was measured using a 15 cm diameter metal core sampler (5 random replicates at each sampling event). Replicates were taken about 1 m apart. Twenty shoots were collected randomly at the sampling station to measure plant morphometrics.

In the laboratory, the number of leaves in the 20 collected shoots was counted and separated into differentiated leaves (with sheath) and undifferentiated leaves (without sheath). Leaf length (from the meristem to the tip of the leaf), and leaf width were measured. For each sample, the presence of male or female flowers was noted and the flowering percentage (no. of flowering shoots/total no. of shoots x 100) was calculated (Pergent & Pergent-Martini 1988). Shoots, rhizomes and roots were dried separately at 60°C to a constant weight.

Leaf and rhizome production

Twenty shoots of *Cymodocea nodosa* were marked monthly 1 cm above the sheath of the oldest leaf according to Zieman (1974) method to estimate its leaf production; in the laboratory, the newly formed tissue was measured by the shift of the marking hole along each leaf. The leaf growth rate (g DW shoot-1 d-1) and elongation (mm shoot-1 d-1) were estimated by dividing the dry weight and the length of the new leaf tissue by the number of days in the experimental period. An estimate of areal production (g DW m-2 d-1) was obtained as follows: mean leaf growth x mean shoot density.

The number of new leaves produced per shoot between consecutive samplings and the leaf Plastochrone Interval (PI: the number of days since marking divided by the number of new leaves produced, i.e., the time interval between initiation of new leaves on a shoot) (Short & Duarte, 2001) were also calculated. The leaf life span was derived from the formulation of a spreadsheet in which each leaf, numbered according to its position in the shoot, was monitored monthly, taking into account both the mean number of leaves for each month and that of new leaves which appeared in the same period.

Every three months, 20 plagiotropic rhizomes were tagged with a plastic string before the last rhizome node and collected three months later. Their length increase (mm day-1) was measured to estimate the seasonal rhizome growth (Short & Duarte, 2001).

Rhizome and root production (below-ground production) was estimated according to the difference between the maximal and minimal biomass recorded during the year studied (De la Cruz & Hackney, 1977).

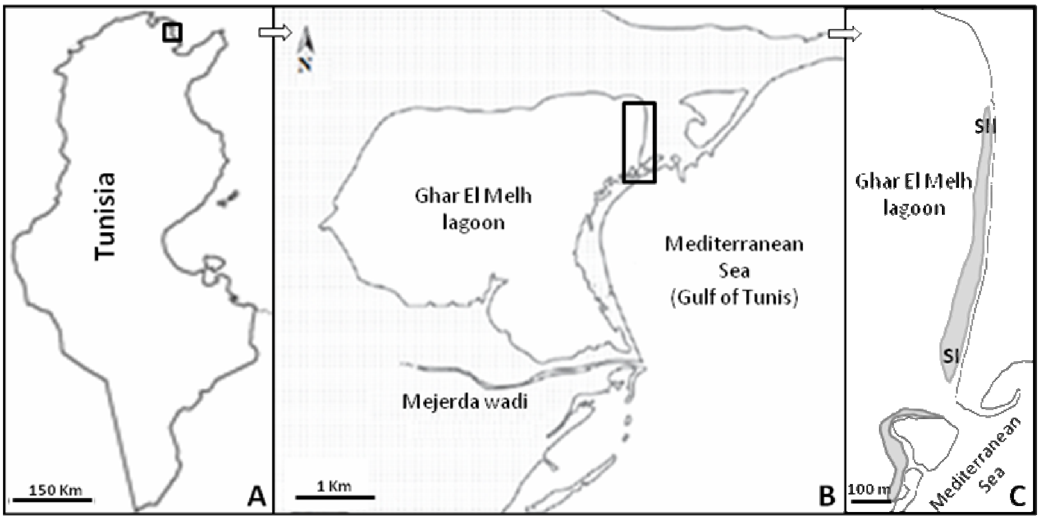

Fig. 1. Study site located in Ghar El Melh lagoon (A, B), *Cymodocea nodosa* meadows in grey color and sampling sites SI (Sghaier et al., 2011) and SII (C).

Data analysis

Seasonal variation in insolation was analyzed with a one-way ANOVA. Differences in water temperature, salinity, morphometrics, shoot density, biomass and leaf productivity were analyzed using two-way ANOVA with the main effect of site and time. When a significant difference among variables was observed, means were analyzed with Tukey's multiple comparison test to determine which variables were significantly different. Data were tested for normality and homogeneity of variance to meet the assumptions for parametric statistics. Simple linear regression analysis was used to examine the relationships between physicochemical parameters (water temperature, salinity and insolation) and biological characteristics (shoot density, leaf length, leaf width, number of leave per shoot, total biomass, plastochrone interval, leaf growth rate, leaf growth elongation, leaf life span, rhizome production and rhizome growth). For all tests, the statistical significance was set at $p < 0.05$.

RESULTS

Environmental parameters

Water temperature displayed a clear annual pattern, with the lowest values (14°C) in February, and the highest ones in September (31°C) for the station I and in August (34°C) for the station II (Fig. 2A). Salinity generally ranged from 37 to 39 psu for the station I and to 45 psu for the station II with an important increase in summer (Fig. 2B). Monthly insolation showed typical seasonal variation (Fig. 2C). The maximum monthly insolation was 396.3 hours in July; the minimum was 144.6 hours in January. All three parameters were highly correlated (Water temperature and salinity ($p < 0.001$, r2 = 0. 91), water temperature and insolation ($p < 0.001$, r2 = 0.74)).

Seagrass density and phenology

The distribution of *Cymodocea nodosa* in the study area is similar to that reported by Shili et al., (2002), showing that the population distribution in Ghar El Melh is stable. In this area (Fig. 1), *C. nodosa* colonizes 100 ha of pure population and a few m2 of mixed, mainly with *Zostera noltii*.

The mean shoot density was significantly different among the two stations (Table 1; Fig. 3A). It reached 915 ± 166 shoots m-^{2} in SI and decreased to 500 ± 65 shoots m^{-2} inside the lagoon (SII). Shoot density showed a clear seasonal pattern, increasing during summer and autumn and decreasing during spring and winter (Fig. 3A). The mean annual number of leaves per shoot was 3.7 ± 0.3 at SI and 3.3 ± 0.3 at SII (Fig. 3B). The number of leaves per shoot showed a significant seasonal and spatial variation.

Both leaf length and width showed a regular seasonal fluctuations (Table 1, p < 0.001), with a maximum values reached in July for SI and in June for SII. The leaf length was significantly (p < 0.001) higher at SI than SII (Fig. 3C).

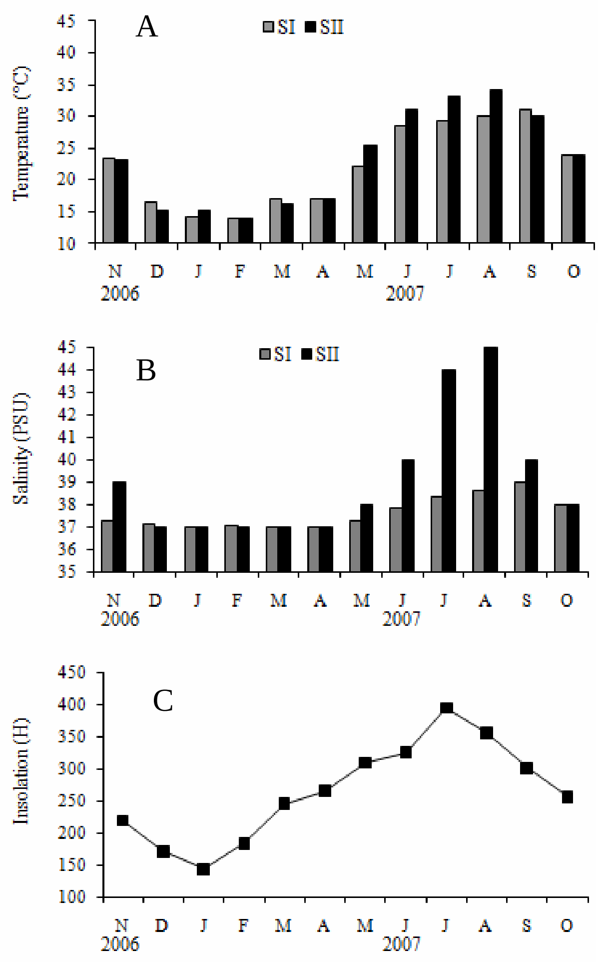

Fig. 2. Water temperature (A), salinity (B) and hours of daylight (C) at the study sites (SI and SII) from November 2006 to October 2007.

Regarding the total biomass, SI and SII showed opposite trends (Fig. 4) with a lowest value at SII in April and the highest one in May at SI. The average total biomass varied between 241.6 ± 34 g DW m^{-2} at SI and 413.8 ± 46 g DW m^{-2} at SII. The above-ground biomass exhibited a clear seasonal pattern with a period of rapid increase in April–May, reaching maximum value in June for SII and in September for SI. Annual average aboveground biomass was lowest in January-February at the two stations. Annual average aboveground biomass was significantly (Table1, p < 0.001) higher at SI (148.6 ± 20.6 g DW m^{-2}) than at SII (45.9 ± 9.6 g DW m^{-2}). Belowground biomass was significantly (Table 1, p < 0.001) higer at SI (333.9 ± 49.4 g DW m^{-2}) than at SII (195.5 ± 26.8 DW m^{-2}). The total aboveground biomass component accounted for 21% of the total biomass at SI and 19 % at SII.

The occurrence of reproductive shoots was observed only at SI during April, May and June, and represented approximately 50% of the total shoot density at the sampling site in those months (539 flowers m^{-2} in June) with a significant effect of time (Table 1, $p < 0.001$).

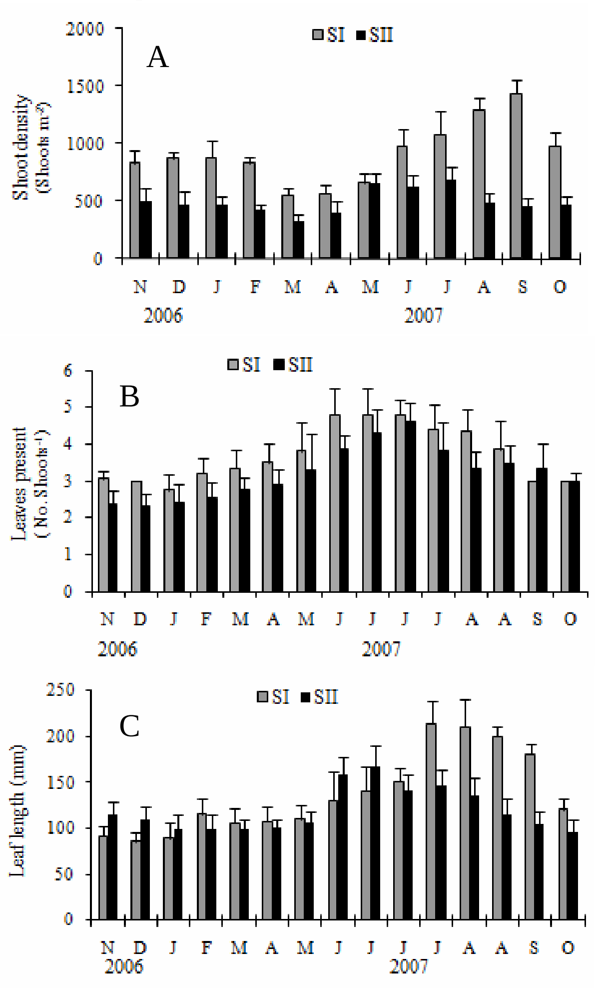

Fig. 3. Monthly mean and standard error of *C. nodosa* shoot density (A), leaves number per shoot of *C. nodosa* shoot in the different ranks (B) and length of the leaves excluding sheath (C).

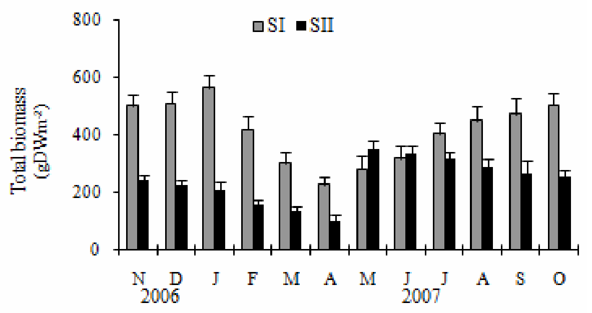

Fig. 4. Monthly mean and standard error of total biomass, above and below-ground (A) and below-ground biomass (B).

Leaf and rhizome production

Leaf plastochrone interval (PI) varied seasonally ($p < 0.001$) with an annual average of about 23 days at SI and 28 days at SII. The maximum PI occurred in November at SI and December at SII. The annual avrege PI varied significantly among stations (Table 1, $p < 0.001$). the leaf lifetime varied with sampling time, and the difference between stations was statistically insignificant (ANOVA, $p = 0.207$). The mean leaf lifetime was longest in February (200 days at SI and SII) and shortest in June (41 days at SII and 56 days at SI).

The daily leaf elongation followed a clearly unimodal seasonal diagram (Fig. 5A), increased significantly (Table1, $p < 0.001$) between May to July and reached its higest value in the begin of July. Moreover, an important decraase was observed in the second part of July at SII. The averge leaf elongation varied significantly among stations ($p < 0.001$) and time ($p < 0.001$). The leaf productivity showed a clear seasonal pattern with the peak in July (0.207 g DW m-2 d-1) at SII and in September (3.356 g DW m-2 d-1) at SI. The average leaf productivity was approximately ten times higher ($p < 0.001$) at SI (1.42 g DW m-2 d-1) than at SII (0.15 g DW m-2 d-1). The leaf productivity varied significantly among stations ($p < 0.001$) and time ($p < 0.001$).

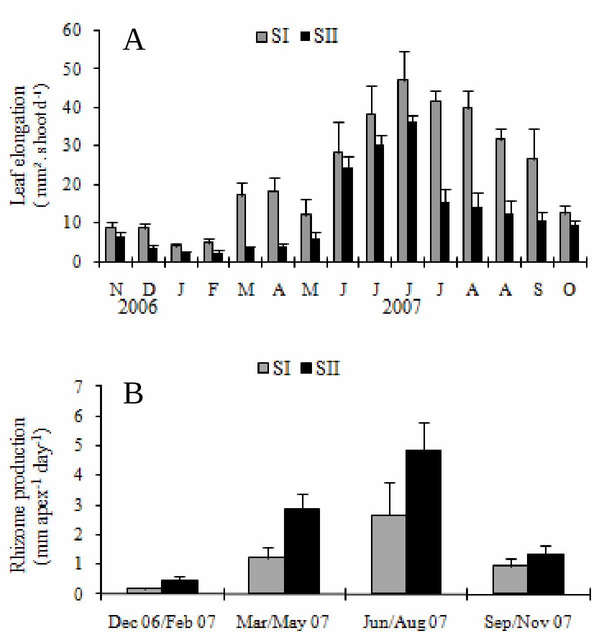

Fig. 5. Monthly mean and standard error of daily leaf growth as leaf elongation rate (A) and daily rhizome production rate (B).

The daily rhizome elongation (Fig. 5B) showed a clear seasonal pattern ($P < 0.001$) with the lowest rates in winter (0.18 mm apex d^{-1} at SI and 0.48 mm apex d^{-1} at SII) and the highest ones in summer (2.65 mm apex d^{-1} at SI and 4.8 mm apex d^{-1} at SII) for the both stations. The average daily rhizome elongation varied significantly among stations ($p <0.001$). The annual growth rate was 795 mg rhizome apex^{-1} at SI and 1037.4 mg rhizome apex^{-1} at SII.

The Annual belowground primary production was 200 g DW m^{-2} year-1 at SII and 368 g DW m^{-2} year^{-1} SI. As for the annual leaf production, it was approximately ten times higher at SI (518.6 g. DW m^{-2} year^{-1}) than at SII (54 g. DW m^{-2} year^{-1}).

Correlation between biological characteristics and environmental parameters

In a linear regression of biological characteristics to environmental parameters monitored, the three environmental parameters (insolation, water temperature and salinity) were significant factors (Table 2). The biological characteristics of *C. nodosa* seem to be more sensitive to the environmental parameters variation at SII than at SI. Indeed, the environmental parameters were significantly correlated to 10 biological characteristics at SI and to 12 at SII. The water temperature variation will be the determinant factor influencing the annual growth and production variability of *C. nodosa* in the Ghar El Melh lagoon. This variation in water temperature explained the annual variability of eight biological characteristics at SI and all biological characteristics at SII, except those of rhizome growth and production. The insolation variation was significantly correlated to 9 biological characteristics at SI and 10 at SII, while the salinity was only correlated to 7 biological characteristics at SI and eight at SII. Changes in rhizome growth were independent of the seasonal variation in insolation and water temperature, and salinity did not exhibit significant relationships with biological characteristics.

DISCUSSION

The vegetative development of *C. nodosa* inside the lagoon at the limit of its distribution is different from that observed by Sghaier et al. (2011) close to the communication channel with the sea. The values of the studied morphological variables were significantly low from those recorded in the station near to the communication channel (Sghaier et al., 2011). Furthermore, our results show also that biological characteristics of *C. nodosa* at the limit of its distribution in the lagoon were more sensitive to the variability of environmental parameters (insolation, water temperature and salinity).

Shoot density, number of leaves per shoot, leaf production and elongation and total biomass were strongly reduced in warm months (July and August) at SII. The decrease of the *C. nodosa* productivity in this area could be related to the salinity stress (hyper salinity recorded in summer up to 45 psu).

In fact, experimental studies on seagrass tolerance to salinity changes have shown that most species have optimum productivity at around oceanic salinity (33-37 psu) (Ogata & Matsui, 1965; McMillan & Moseley, 1967; Biebl & McRoy, 1971; Drysdale & Barbour, 1975; Hillman et al., 1995; Doering & Chamberlain, 1998; Chesnes & Montague, 2001). These investigations have demonstrated that extreme or suboptimal salinities can produce negative alterations of their photosynthetic rate (Biebl & McRoy, 1971; Kerr & Strother, 1985; Dawes et al., 1987, 1989), metabolism (van Katwijk et al., 1999), reproduction (Ramage & Schiel, 1998), growth (McMillan & Moseley, 1967; Walker, 1985; Walker & McComb, 1990) and survival (Vermaat et al., 2000). According to Pagès et al. (2010), salinity should never exceed 44 psu inside the meadows, to prevent deterioration of *C. nodosa* habitats.

Seasonal variations in seagrass characteristics have been attributed to seasonal changes in irradiance and in water temperature (Duarte, 1989). *C. nodosa* productivity, biomass and shoot size usually increase with water temperature and light availability during spring and summer, and decrease during autumn and winter (Terrados & Rós, 1992; Reyes et al., 1995; Cancemi et al., 2002; Agostini et al., 2003; Cunha & Duarte, 2007).

The shoot densities recorded were lower than those recorded in the Atlantic (Reyes et al., 1995; Cunha & Duarte, 2007; Terrados & Rós, 1992), as well as those reported from Mediterranean Sea (Pérez, 1989; Cancemi et al., 2002; Rismondo et al., 1997; Agostini et al., 2003), with the exception of those reported by Mostafa (1996), Van Lent et al. (1991), Terrados et al. (2006) and Barberá et al. (2005).

Leaf phenology of *C. nodosa* at Ghar El Melh lagoon showed a seasonal behaviour with its highest leafiness in spring-summer, when the mean highest values in the number of leaves per shoot, the length and width of the leaves were recorded. The number of leaves per shoot recorded is of the same order of magnitude than those found in other localities (Table 3).

The biomass cycle of *C. nodosa* showed a seasonal model similar to that observed for the same seagrass species in marine Mediterranean and Atlantic environments (Terrados & Rós, 1992; Reyes et al., 1995; Cancemi et al., 2002; Agostini et al., 2003). The total biomass was lower than recorded in Ebro Delta, Spain (Pérez, 1989), in Ria Formosa, Portugal (Cunha & Duarte, 2007), in the lagoon of Venice, Italy (Rismondo et al., 1997), in Urbinu lagoon, France (Agostini et al., 2003) and in the Golf of Trieste, Italy (Peduzzi & Vukovič, 1990). These variations mainly reflect the seasonality observed in the above-ground biomass as well as in the density of the shoots.

In the Ghar El Melh lagoon, *Cymodocea nodosa* produced between 13 to 16 leaves shoot^{-1} year^{-1}, the same annual value calculated by Pérez (1989), Reyes et al. (1995) and Cancemi et al. (2002) and slightly higher than that reported by Terrados & Rós (1992) and Peduzzi & Vukovič (1990) of 11-12 and 10 leaves shoot^{-1} year^{-1}, respectively. The leaf life span and the rhizome growth values estimated in the Ghar El Melh lagoon were consistent with the data reported by other authors (Table 3).

Leaf production and the annual leaf production at the limit of the distribution of *C. nodosa* in Ghar El Melh were the lowest values estimated in both Mediterranean Sea and Atlantic Ocean.

To conclude, despite the high adaptation capacity to environmental variability of *C. nodosa*, the distribution of this species in Ghar El Melh is limited by the poor growth conditions and the higher salinity inside the lagoon. Our study could be very useful for further restoration of the Ghar El Melh lagoon.

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