

Leaf Phenology, Growth and Production of the Seagrass *Cymodocea nodosa* at El Médano (South of Tenerife, Canary Islands)

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Data on density, biometry, growth and biomass of *Cymodocea nodosa* (Ucria) Ascherson at El Médano (South of Tenerife, Canary Islands) are presented. Monthly data of all these parameters showed regular seasonal variations, with their mean highest values in spring–summer and their mean lowest ones in autumn–winter. The mean number of leaves per shoot varied from 2.4 to 3.4 leaves shoot⁻¹, the oldest leaf length varied from 14.7 to 31 cm and the leaf width from 1.7 to 3.4 mm, with the shoot density varying from 934 to 1928 shoots m⁻². Leaf growth measurements were estimated by a slightly modified hole punching method. The leaf growth was between 0.8 and 1.9 mg dw shoot⁻¹ day⁻¹, the shoot production/biomass (P/B) ratio varied from 0.012 to 0.018 day⁻¹ and the leaf appearance rate from 0.025 to 0.056 leaves shoot⁻¹ day⁻¹, with the leaf production varying from 0.9 to 3.6 g dw m⁻² of meadow day⁻¹. The above-ground biomass was between 55 and 249 g dw m⁻² and the below-ground one varied from 181 to 385 g dw m⁻². The annual leaf production was 752 g dw m⁻² year⁻¹, with a P/B ratio of 3.5 year⁻¹. The annual rhizome production was 30–37 g dw m⁻² year⁻¹, with a P/B ratio of 0.14–0.16 year⁻¹ and an annual growth of 2.2 m of rhizomes per m² of meadow. In general, *Cymodocea nodosa* presented a similar behaviour to that known for this seagrass species from the Mediterranean Sea.

Introduction

Cymodocea nodosa (Ucria) Ascherson is widely distributed in the Mediterranean Sea and along the Atlantic coasts of North Africa (den Hartog 1970), being the most common and abundant seagrass species in the Canaries (Afonso-Carrillo and Gil-Rodríguez 1980, Reyes 1993). This seagrass forms submarine monospecific meadows or mixed populations with *Caulerpa prolifera* (Forsskål) Lamouroux, generally located along the southeastern coasts of these islands (Reyes 1993). In recent papers, aspects of the morphology and anatomy of *Cymodocea nodosa* (Reyes and Sansón 1994) and its reproductive phenology and distribution in the Canary Islands (Reyes *et al.* 1995) were discussed.

Seagrasses contribute significantly to the productivity of coastal areas of both temperate and tropical waters (Phillips and McRoy 1980). At present, information on the growth and production of *Cymodocea nodosa* has been obtained basically from different coastal areas of the Mediterranean Sea: Gessner and Hammer (1960) and Caye and Meinesz (1985) on the French coasts; Pérez (1989) in the Ebro River delta; Peduzzi and Vuković (1990) in the Gulf of Trieste; and Terrados and Ros (1992) in the Mar Menor. The only data known along the subtropical Atlantic coasts were obtained in short period researches by Johnston (1969) in Lanzarote, Canary Islands (referred to as *Zostera marina* Linnaeus) and those by

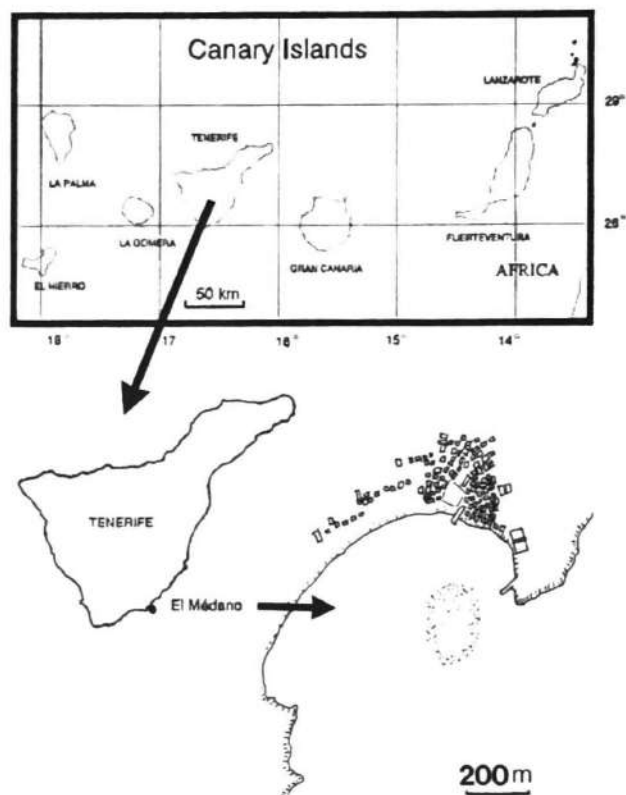


Fig. 1. Geographical location of the study area. Stippled surface represents the situation of the meadows studied.

Pergent *et al.* (1988), van Lent *et al.* (1991) and Vermaat *et al.* (1993) in meadows at Banc of Arguin, Mauritania. Until now, no study of the effect of seasonal changes on the growth and production of *Cymodocea nodosa* in meadows on the Canary Islands had been made.

The aim of this paper is to show some data on leaf and rhizome growth and estimate the production of the meadows studied during an annual cycle, as part of a study to attempt to interpret simultaneous studies on the epiphytic community of *Cymodocea nodosa*.

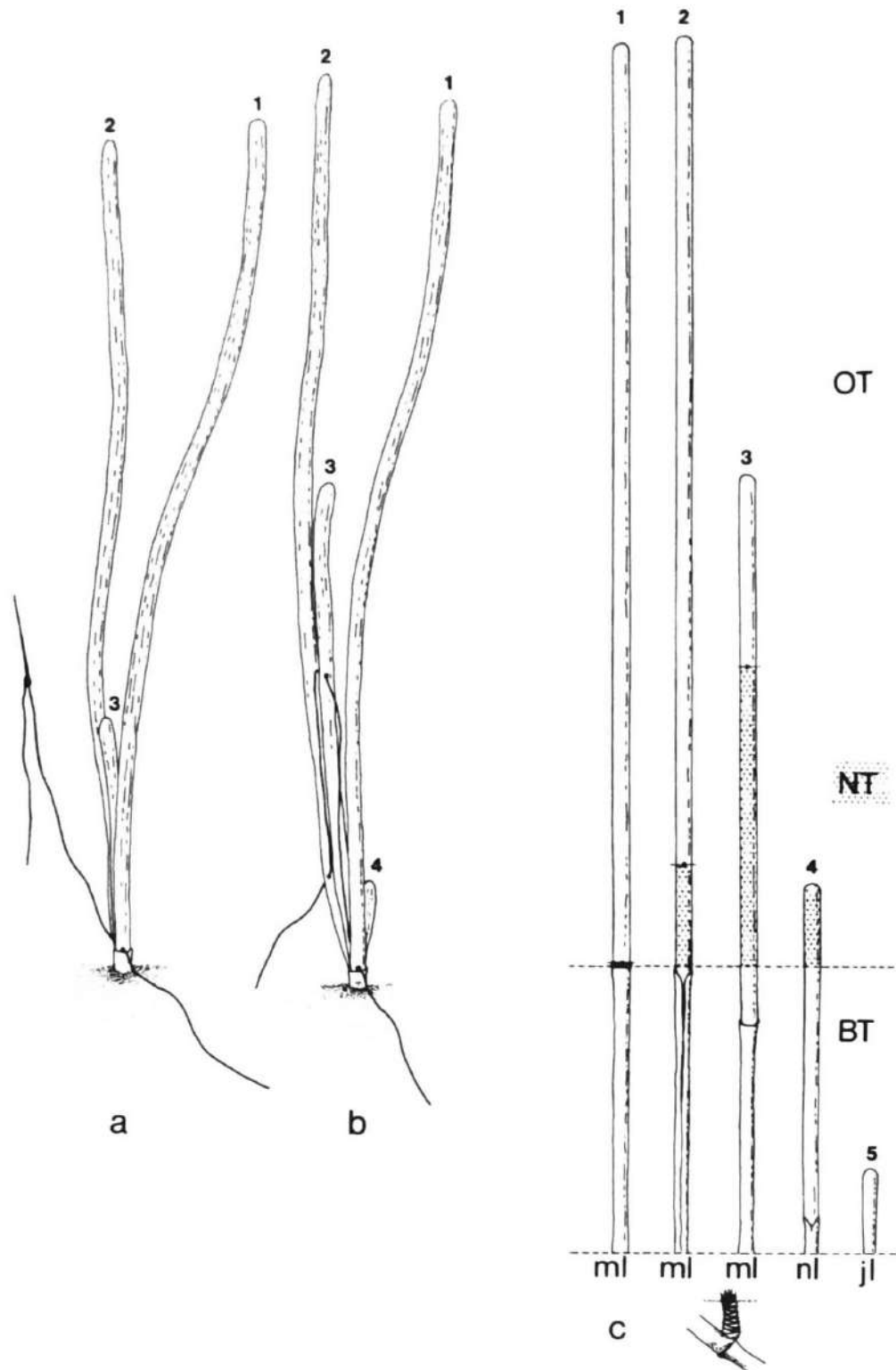


Fig. 2a–b. Method for marking of the shoots. (a) Marks were made at the base of the oldest leaf blade, at level of its insertion with the sheath, using a needle and thread. (b) Position of marks after the 15 days marking period. (c) Leaves of the marked shoot were classified as mature (ml), new (nl) and juvenile (jl) leaves. Note the different tissue fractions: old (OT), new (NT) and basal (BT) tissues. Numbers 1 to 5 indicate the leaves order from the oldest to the youngest one.

Materials and Methods

Sampling area

The meadows studied were chosen within El Médano bay on the south of Tenerife (UTM 28RCS4801, 28RCS4802, 28RCS4902) as shown in Figure 1. *Cymodocea nodosa* is the only vascular hydrophyte present in this bay and forms meadows at 1–35 m depth. The sampling station (Fig. 1) was located at the east of the bay, at 5–7 m depth, where salinity is practically constant throughout the year (36.7‰–36.9‰) and water temperature varies between 18.5 °C (January–February) to 24.5 °C (August–September). All field studies were carried out with SCUBA diving.

Leaf phenology

Monthly, from June 1990 to May 1992, the following phenological parameters were measured: shoot density, total number of leaves per shoot, length and width of leaves and length of the oldest sheath of each shoot. Shoot density was monitored in four quadrats of 30 cm side randomly located. These were also used for obtaining biomass data. The number of shoots included in each sample were counted. Fifty shoots of *Cymodocea nodosa* were selected for the biometric study of their leaf blades and sheaths. Each leaf on the shoot was measured in age order (from leaf 1 or mature to leaf 4 or juvenile). Using an electronic calibrator, the length of each leaf was taken from the ligule to the apex (precision 1 mm) and its width was measured at the middle of its length (precision 0.1 mm). The length of the sheath of the oldest leaf was measured from its origin on the orthotropic rhizome to the ligule.

Leaf and rhizome growth

Leaf growth was measured from August 1991 to July 1992, using a similar method to that employed by other authors for different seagrasses, e. g. Zieman (1974) with *Thalassia testudinum* Banks ex König; Ott (1980) and Romero (1985) with *Posidonia oceanica* (Linnaeus) Delile; Pérez (1989), Peduzzi and Vuković (1990) and Terrados (1991) with *Cymodocea nodosa*. Monthly, leaf growth was estimated by perforating all shoots included in a fixed quadrat of 30 cm sides. The marking method was carried out with a needle of 0.5 mm diameter and thread, crossing each shoot at the base of the oldest leaf blade, at the level of its insertion with the sheath (Figs 2a and b). This modification of the Zieman marking method (Zieman 1974) simplified the field work and the recognition of the marked shoots. After about 15 days, marked shoots were harvested. Following Terrados (1991) and Terrados and Ros (1992), the leaves of the marked shoots were classified as mature, young and new ones (Fig. 2c). Previously to the processing of the

leaves, their epiphytes were carefully removed with a razor blade. The length and width of each leaf were measured, taking separately the surface of old, new and basal tissues, the latter including all the sheaths and juvenile leaves (Fig. 2c). The total number of leaves per shoot and number of young and new leaves were counted. The different tissues fractions obtained were then dried at 105 °C for 24 h and weighed. The methodology used for the estimation of the leaf growth was the same as that employed by Pérez (1989) and Terrados and Ros (1992).

The annual growth of rhizomes was measured from four samples from an area with 50 cm sides and 20 cm depth. The seasonal growth pattern of rhizomes was studied following the method proposed by Caye and Meinesz (1985). According to Pérez (1989) and Terrados (1991), rhizome segments were dated in the laboratory and the length and biomass of each annual fraction of rhizome as well as the age of shoots were noted down.

Biomass cycle

Monthly, from June 1990 to May 1992 four samples for estimation of above-ground and below-ground biomass were collected. The sample areas were delimited with the aid of quadrats of 30 cm sides and 20 cm depth, randomly located and sunk in the meadow. Plants were harvested with a shovel, placed in a cloth mesh bag and washed free of sediment. In the laboratory, the plants were separated into leaves, rhizomes and roots. The biomass of each fraction was obtained separately as dry weight (dw) after heating at 105 °C for 24 h.

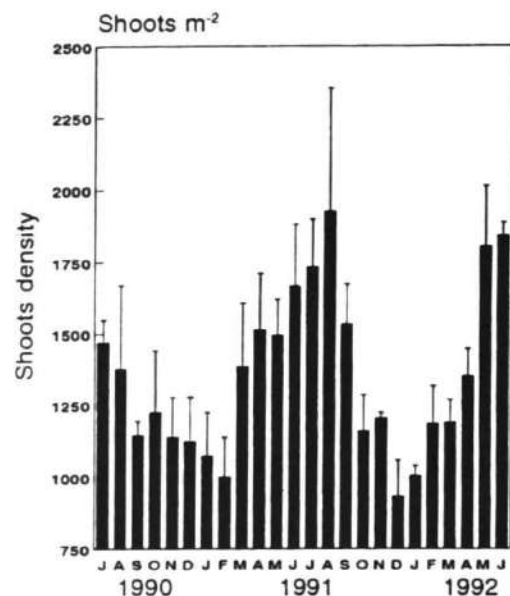


Fig. 3. Annual variation of the shoot density (vertical lines indicate standard error of the mean).

Results

Leaf phenology

Shoot density showed a regular seasonal fluctuation. The mean annual value of density was 1354 shoots m^{-2} reaching a mean maximal value of up to 1928 m^{-2} in summer and decreasing to 934 shoots m^{-2} in winter (Fig. 3).

All leaves per shoot also presented a seasonal pattern in their length measurements, showing maximal lengths in spring–summer (up to 31 ± 5.8 cm – leaf 1 –; 27.8 ± 8.5 cm – leaf 2 –; 11.6 ± 7.9 cm – leaf 3 –; 5.3 ± 2.2 cm – leaf 4 –) and minimal va-

lues in winter (up to 14.7 ± 6.9 cm – leaf 1 –; 9.6 ± 6.3 cm – leaf 2 –; 2.6 ± 2.2 cm – leaf 3 –) (Fig. 4). The percentage of leaves with broken apices varied with age, with the mean annual value of 73% of leaves 1 broken, 13% of leaves 2 and 0.4% of leaves 3. Broken leaves 4 were not observed during this study. The width of the leaves was maximal in summer reaching up to 3.4 ± 0.5 mm and it was minimal in winter, with up to 1.7 ± 0.4 mm (Fig. 5). Shoot surface area ranged from 22 ± 7.2 cm^2 leaf shoot $^{-1}$ in summer and 4.6 ± 2.2 cm^2 leaf shoot $^{-1}$ in winter. Leaf area index (LAI) varied from 0.97 $m^2 m^{-2}$ in winter to 3.8–3.9 $m^2 m^{-2}$ in spring–summer (Fig.

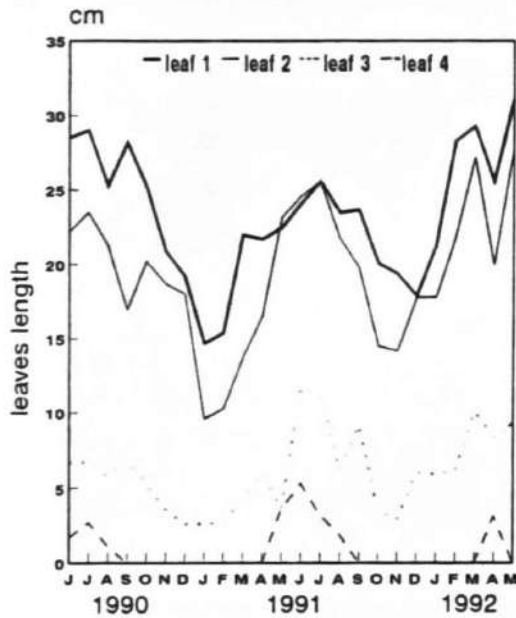


Fig. 4. Annual variation of the mean length of the different leaves per shoot, from leaf 1 or mature to leaf 4 or juvenile.

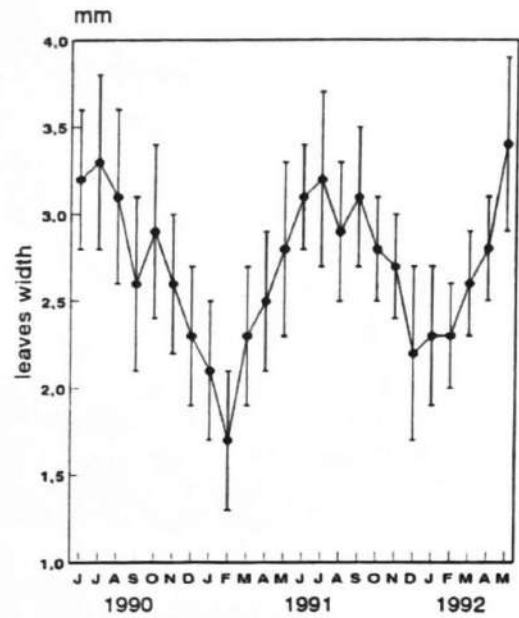


Fig. 5. Annual variation of the width of the leaves (vertical lines indicate standard error of the mean).

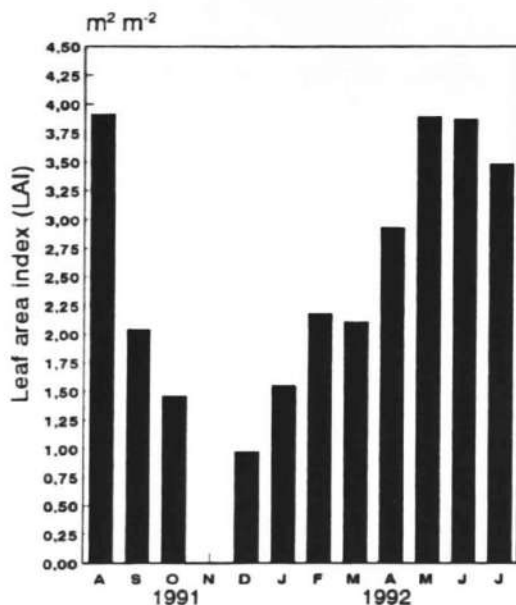


Fig. 6. Annual variation of the leaf area index (LAI). No data in November.

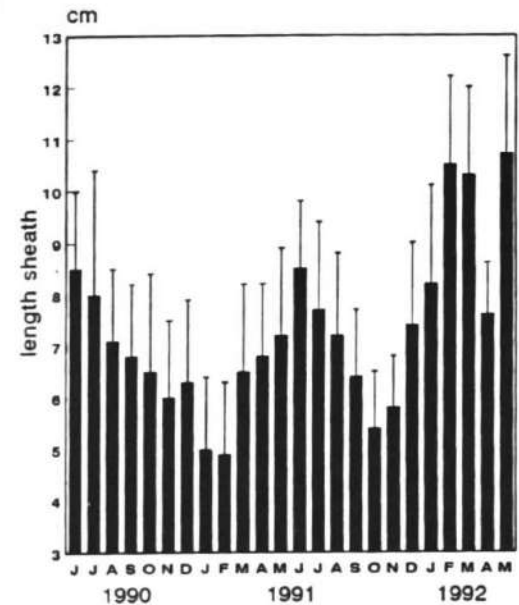


Fig. 7. Annual variation of the length of the oldest sheath per shoot (vertical lines indicate standard error of the mean).

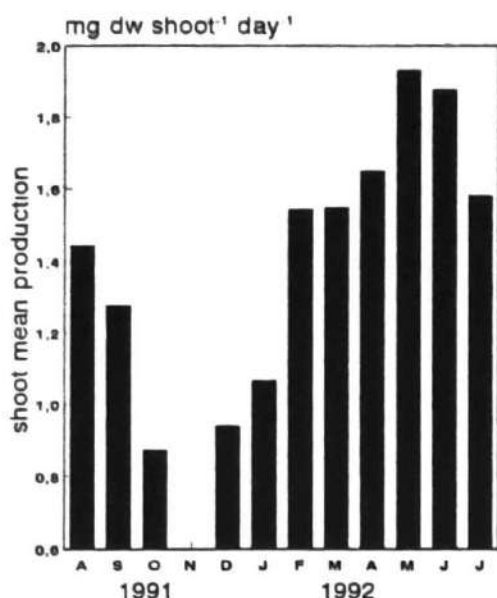


Fig. 8. Annual variation of mean production per shoot and day. No data in November.

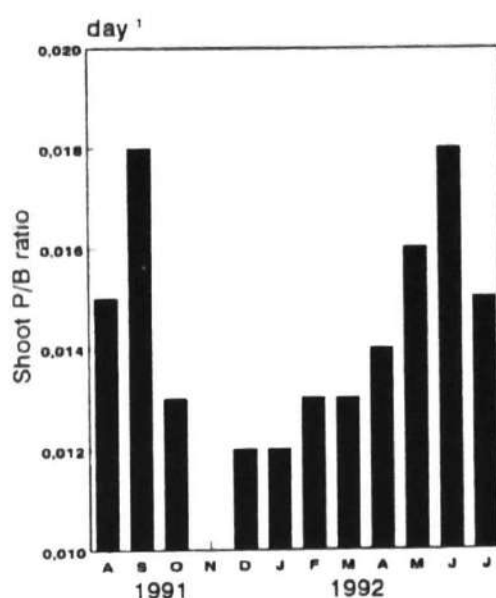


Fig. 9. Annual variation of shoot P/B ratio. No data in November.

6). Sheaths showed a seasonal fluctuation in their length, with a maximal elongation in summer, when they reached up to 8.5 ± 1.3 cm, and a minimal one in winter, with up to 4.9 ± 1.4 cm (Fig. 7). After a intense period of storm occurred in November 1991, the sheaths showed a noticeable elongation (Fig. 7) to reach the new level of sediment that was up to 15 cm deep in some places of the meadows studied.

Leaf and rhizome growth

The highest growth of leaves was observed in spring–summer, up to $1.9 \text{ mg dw shoot}^{-1} \text{ day}^{-1}$ while the lowest growth rate of $0.8 \text{ mg dw shoot}^{-1} \text{ day}^{-1}$ was recorded in winter (Fig. 8). The P/B ratio of shoots showed minimal values of $0.012\text{--}0.013 \text{ day}^{-1}$ from October to February and maximal values of $0.015\text{--}0.018 \text{ day}^{-1}$ from June to September (Fig. 9).

The mean number of leaves per shoot, including mature leaves as well as new and juvenile ones, varied between 3 and 3.4 leaves shoot⁻¹ from March to October and between 2.4 and 3 leaves shoot⁻¹ from November to February (Fig. 10). The mean number of new leaves per shoot showed values of 0.4–0.6 leaves shoot⁻¹ almost throughout the year, except in April, May and July, when there were 0.8 leaves shoot⁻¹. The leaf appearance frequency presented maximal values of $0.042\text{--}0.056 \text{ leaves shoot}^{-1} \text{ day}^{-1}$ in May–July and a minimal one in February of $0.025 \text{ leaves shoot}^{-1} \text{ day}^{-1}$.

Leaf production per m² of meadow and day was maximal from May to August, between 2.9 and $3.6 \text{ g dw m}^{-2} \text{ day}^{-1}$, and minimal in December–January, from 0.9 to $1.1 \text{ g dw m}^{-2} \text{ day}^{-1}$ (Fig. 11). The mean annual value of the plastochrone interval (PI) was

27.9 days, that is equivalent to the production of about 13 leaves per shoot per year (Fig. 12). The life time of the leaves was about 75–90 days in autumn–winter and between 45 and 75 days in spring–summer. At El Médano the annual production of leaves was estimated as being about $752 \text{ g dw m}^{-2} \text{ year}^{-1}$, resulting in an annual P/B ratio of 3.5.

Rhizomes showed a pattern of growth similar to that observed in the leaves, with the highest rates of growth in spring–summer, when the internodes were long, and the lowest rates in winter. The biomass distribution in relation to the age of rhizomes is shown in Figure 13. Values obtained in 1992 were similar to those observed in 1990 and 1991. There was a re-

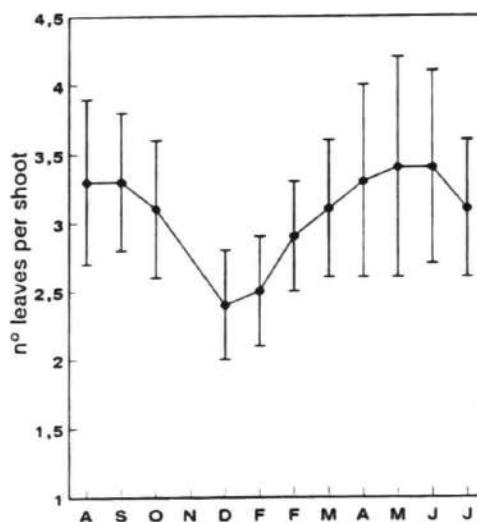


Fig. 10. Annual variation in the number of leaves per shoot (vertical lines indicate standard error of the mean). No data in November.

markable decrease from the third year age class. Therefore, we can assume that the annual rhizome production is equivalent to maximal values reached in the last three years. Shoot age distribution showed a linear decrease with the rhizome age (Fig. 14). The mean biomass/length ratio of rhizomes was 0.015 g dw cm⁻¹ and thus the annual rhizome growth in length could be estimated to be about 2.2 m of rhizome per m⁻² of meadow. The annual rhizome production was of 30–37 g dw m⁻², resulting in a P/B ratio of 0.14–0.16 year⁻¹.

Biomass cycle

Data concerning variations in the above-ground biomass are shown in Figure 15. Values showed a regular

seasonal pattern, with the mean maximal value in summer, especially in July with 249 g dw m⁻². This maximum decreased considerably at the end of summer, reaching mean minimal values of up to 55 g dw m⁻² in winter. Mean shoot biomass varied from 0.12 g dw shoot⁻¹ in February–May to 0.08 g dw shoot⁻¹ in September–December. The below-ground biomass, including rhizome and root biomass, showed less variation than the above-ground one, and no clear seasonality was observed in this fraction. The mean maximal value of rhizome biomass was of 181 g dw m⁻² in November and the minimal one was of 79 g dw m⁻² in March. With regard to root biomass, the mean maximal value was of 227 g dw m⁻² in September and the minimal one of 95 g dw m⁻² in February. However, it may be observed

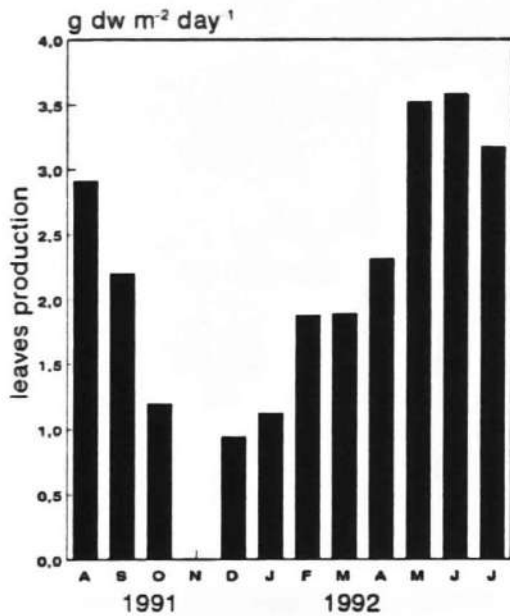


Fig. 11. Annual variation of the leaves production per m² of meadow and day. No data in November.

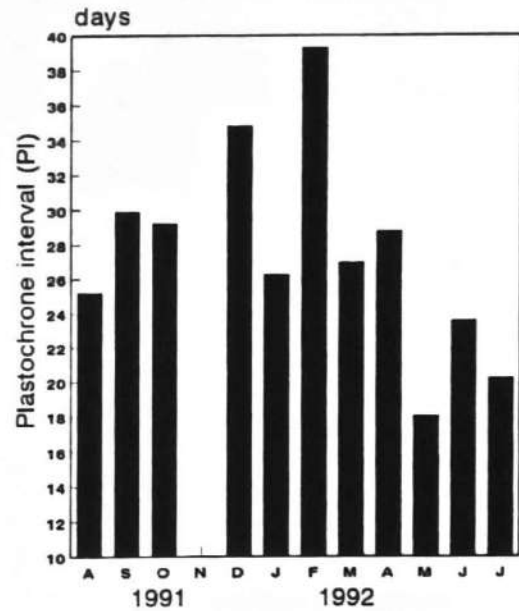


Fig. 12. Annual variation of the plastochrone interval (PI). No data in November.

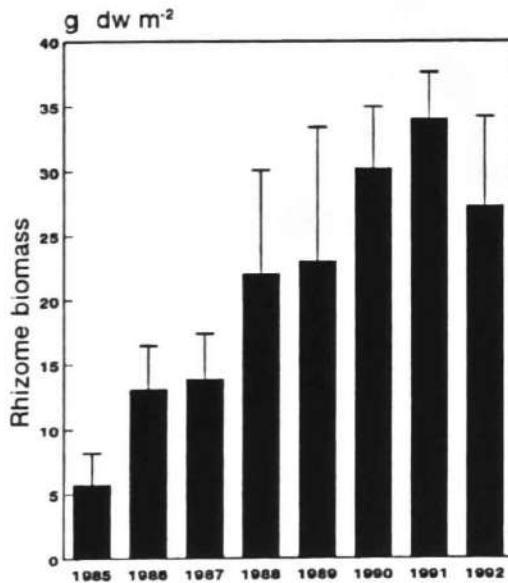


Fig. 13. Rhizome biomass age distribution, from 1985 to 1992 (vertical lines indicate standard error of the mean).

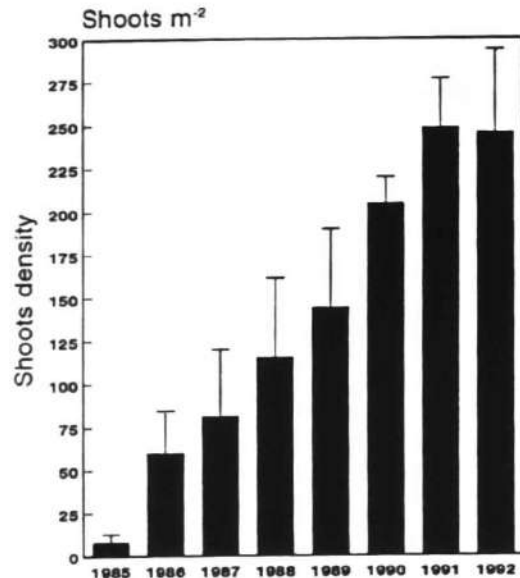


Fig. 14. Shoot age distribution, from 1985 to 1992 (vertical lines indicate standard error of the mean).

that values of below-ground biomass (Fig. 16) were slightly higher in spring–summer, than in autumn–winter.

Discussion

Previously, any study on phenology, growth and primary production of *Cymodocea nodosa* throughout the year has been carried out on the Atlantic coasts. This absence of similar studies over a year prevent us from doing a comparative discussion with the rest of the Atlantic plants. However, some of the Canary Islands data may be compared with that obtained in similar studies carried out in the Mediterranean Sea (Table I).

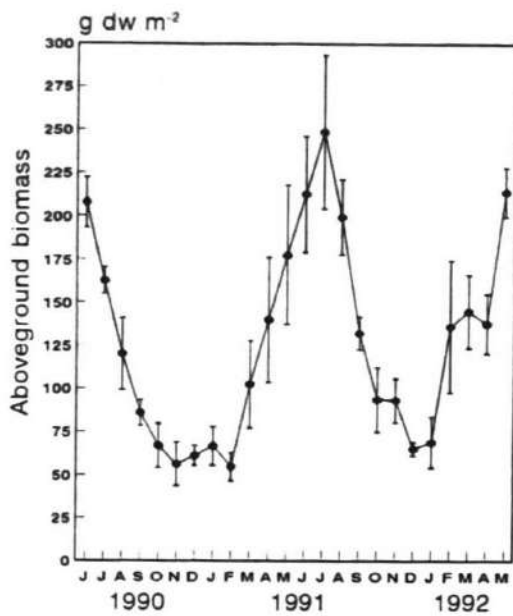


Fig. 15. Annual variation of the above-ground biomass (vertical lines indicate standard error of the mean).

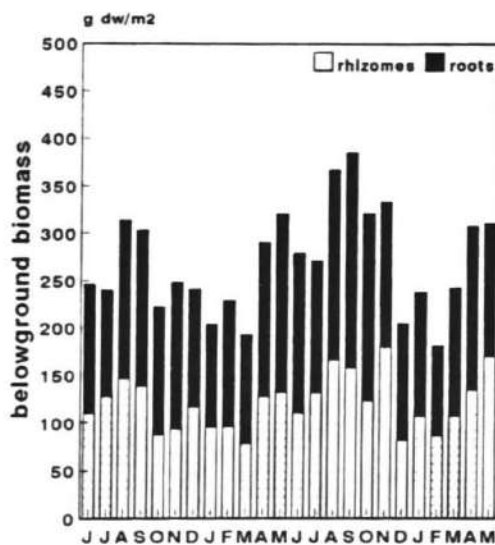


Fig. 16. Annual variation of the below-ground biomass (rhizomes + roots).

Table I. Comparative data between Mediterranean and Canarian studies on different aspects of *Cymodocea nodosa* meadows.

References (Locality)	LAI (m ² m ⁻²)	Density (shoot m ⁻²)	Leaf biomass (g dw m ⁻²)	Total biomass (g dw m ⁻²)	Shoot production (mg dw shoot ⁻¹ day ⁻¹)	Leaf production (g dw m ⁻² day ⁻¹)	Leaf annual production (g dw m ⁻² year ⁻¹)	Leaf P/B annual (year ⁻¹)	Leaves shoot ⁻¹ year ⁻¹	Rhizome annual production (g dw m ⁻² year ⁻¹)	Rhizome P/B annual (year ⁻¹)
Perez 1989 (Ebro Delta)	1–4	1000–2000	208–215	510–631	0.2–1.4	0.2–3.7	388–467	2.2–2.5	13	56–73	0.12–0.17
Peduzzi and Vuković 1990 (Trieste Gulf)	0.12–7.24	–	–	323–1020	–	0.97–1.9	356–692	3	10	–	–
Terrados 1991 (Mar Menor)	0.15–1.80	1000–1900	3–54 (1) 0–170 (2)	190 (1) 370 (2)	<0.01–0.7	0.02–1.4	163 (1) 427 (2)	2.41–2.64 (1)	11.5	46–48 (1) 66–78 (2)	0.27–0.31 (1)
Reyes <i>et al.</i> , this study (El Médano)	0.97–3.90	934–1928	55–249	273–592	0.8–1.9	0.9–3.6	752	3.5	13	30–37	0.14–0.16

(1) sandy bottom (2) muddy bottom

Leaf phenology of *Cymodocea nodosa* at El Médano 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, the shoots density and the leaf area index were recorded. The mean lowest of all these parameters were recorded in autumn–winter. According to published data, the leaf phenology of this seagrass in the Canary Islands is similar to that observed in the Mediterranean Sea by Pérez (1989), Peduzzi and Vuković (1990) and Terrados (1991) but some differences in the range of values have been detected. In this sense, Peduzzi and Vuković (1990) observed leaves of up to 50 cm long in summer. The seasonal variation in leaf width of *Cymodocea nodosa* (Fig. 5) can be compared with the data obtained by Pergent *et al.* (1989) in *Posidonia oceanica* (Linnaeus) Delile, using lepidochronological analysis. Although there are many other data on this aspect of the biology of this seagrass (Gessner and Hammer 1960, Drew 1978, Ballester 1985, Caye and Meinesz 1985, Mazzella *et al.* 1986, Terrados 1986, Buia and Mazzella 1991, van Lent *et al.* 1991, Vermaat *et al.* 1993), these are the results of short period researches.

The length of the leaf sheath presented a seasonal behaviour, with a greater elongation in the same period as the leaf blade, showing also a response to burial in other periods of the year. Usually, sheaths are buried in the sediment with their distal ends a few millimeters above or below the surface. In spring–summer when *Cymodocea nodosa* showed the highest density and the greatest size of plants, the sedimentation in the meadows was elevated. Based on field observations as well as on collected material, sheaths seem to answer to this increase in the level of the sediment with an elongation. We think that this is a faster way of response of the plant than the elongation of its orthotropic rhizomes, although these rhizomes may present an elongation during lengthy burial periods. At sites with a great movement of sediment, we have observed shoots of *Cymodocea nodosa* with sheaths uncommonly long, of up to 25 cm. However, other factors such as low intensity of current, quality of sediment and seasonal local variations of temperature, light and nutrients may also determine the elongation of the orthotropic rhizomes or the length of the sheaths.

At El Médano, *Cymodocea nodosa* meadows showed a unimodal annual growth pattern. Leaf growth was continuous throughout the year, with the highest growth rates in spring–summer and the lowest one in winter. The annual P/B ratio of 3.5 year⁻¹ was higher than those reported by Pérez (1989), Pe-

duzzi and Vuković (1990) and Terrados (1991), who obtained values of between 2.2 and 3 year⁻¹. These differences in the annual leaf production may be closely connected with the annual seawater temperature. In the Canary Islands, the minimal winter temperature values varied between 17–18 °C, as opposed to 9–10 °C recorded in the Ebro River delta (Pérez 1989) and 10–12 °C in the Mar Menor (Terrados 1991). These lower temperatures provoked a slower metabolism in this seagrass in the Mediterranean, and this implied very low production values during the winter. At El Médano, *Cymodocea nodosa* maintained a higher level of production during these months, thus increasing the annual production. In this sense, our results are in good agreement with Pérez and Romero (1992) who emphasized the importance of temperature, together with light, as driving forces behind the seasonality of *Cymodocea nodosa*.

The biomass cycle of *Cymodocea nodosa* at El Médano showed a clear unimodal annual pattern, with a mean maximal value of 592 g dw m⁻² in summer and a mean minimal of 273 g dw m⁻² in winter, similar to those reported by other authors from different localities of the Mediterranean (Ballester 1985, Pérez and Camp 1986, Terrados 1986, 1991, Pérez 1989). This variation mainly reflected the seasonality observed in the above-ground biomass as well as in the density of the shoots. Although throughout the year the below-ground biomass was higher than the above-ground one, with the below/above-ground biomass ratio from 1.1 in summer to 4.4 in autumn–winter, the former showed an annual irregular pattern.

In the Canary Islands, *Cymodocea nodosa* produced 13 leaves shoot⁻¹ year⁻¹, the same annual value as obtained by Pérez (1989) and Duarte and Sand-Jensen (1990) and slightly higher than that reported by Caye and Meinesz (1985), Peduzzi and Vuković (1990) and Terrados (1991), of 11, 10 and 11.5 leaves shoot⁻¹ year⁻¹, respectively. This suggests that *Cymodocea nodosa* presents a great plasticity for adaptation to variations of environmental factors. Terrados and Ros (1992) pointed out that *Cymodocea nodosa* has a genetic control for leaf development.

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