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Phenology, growth and biomass of *Cystoseira balearica* in Calvi (Corsica)

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ABSTRACT: Six plants of *Cystoseira balearica* Sauv. were examined in the field over a period of 4 yr in the Calvi area (northwestern coast of Corsica, France) in spring (March), summer (June) and autumn (October). On each occasion, branch and stem length was measured and presence of iridescence and conceptacles was observed. The phenology of the different plants and survivorship of individual branches of these plants were followed through tagging. It is shown that *C. balearica* has 2 growing periods, losing its branches twice a year (in late summer and in winter). An average plant produces 2.4 g C yr^{-1}; more than 90 % of this biomass enters the ecosystem in the form of dead organic remains. This represented about 3.7 t C for the whole population of *C. balearica* in Revellata Bay near Calvi.

INTRODUCTION

Cystoseiracean algae inhabit rocky substrates in the intertidal and subtidal zones of many temperate and tropical regions (Nizamuddin 1970). This is especially the case in the Mediterranean Sea where the different species of *Cystoseira* form a productive belt which plays an important ecological role as shelter and food. In the Calvi area, on the northwest coast of Corsica, France, *Cystoseira balearica* used to be the dominant component of the macroalgal vegetation on rocky substrates in the infralittoral down to a depth of 30 m (Clarisse 1984). However, since 1987 a dramatic regression of these algae has been noticed (Hoffmann et al. 1988).

Several studies have examined the distribution, growth and morphology of *Cystoseira* spp. in the Mediterranean and Black Sea (Sauvageau 1912, Ercegovic 1952, Boudouresque 1969, Bavaru 1972, Knoepffler-Peguy 1973, Khailov 1978, 1979, Firsov & Khailov 1979, Gomez Garreta et al. 1982). On the western coast of the United States, the demography of *C. osmundacea* stands was studied by Gunnill (1986) and Schiel (1985a). However, little is known about the phenology, biomass and productivity of individual plants of *Cystoseira*, especially of *C. balearica*, that is fundamental to nearshore food chains.

Questions such as when do plants grow, what sizes do they attain, and when do they reproduce, and a description of their survivorship are relevant to an understanding of the distribution and abundance of species and hence to community structure. Yet it is only by continued observation on marked plants that seasonal periodicity in growth and reproduction can be established. We therefore designed a tagging program over 4 yr (1983 through 1986) to determine the growth, reproduction and survivorship of individual branches of the brown alga *Cystoseira balearica* near Calvi.

STUDY SITE

The study was conducted at STARESO, the oceanographic station of the University of Liège, Belgium, located in Revellata Bay on the west side of the Gulf of Calvi (northwestern Corsica). The coast is composed of carboniferous granites with very rugged cliffs. The bottom of the bay is occupied by sand colonized by seagrass meadows (mainly *Posidonia oceanica*). The annual pattern of surface temperatures presents a summer maximum in August (mean monthly temperature 1981 to 1990: 24.6 °C) and a winter minimum in February (mean monthly temperature 1981 to 1990: 13 °C). Strong winds mainly occur during winter. Further information about hydrology and physical and chemical properties of the gulf waters can be found in Bay (1984) and Frankignoulle (1986).

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Six plants of *Cystoseira balearica* were regularly surveyed at the 'crique Levy' near the STARESO marine station in Calvi. The 6 plants were on a plot of 1 m^2 at a depth of 4 m and grew on the NE face of a rock with an inclination of 10 to 15 %. *C. balearica* was accompanied at this site by *Padina pavonica*, *Acetabularia acetabulum*, *Dictyopteris membranacea*, *Dictyota dichotoma*, *Udotea petiolata*, and *Halopteris scoparia*.

MATERIALS AND METHODS

From February 1983 until June 1986, plants were examined every spring (February or March), summer (June) and autumn (October). On these occasions, a lightweight numbered plastic tag (10 × 5 mm) was attached with a plastic cable to every new stem and primary branch ≥ 2 cm in length. On each occasion a different tag colour was used. For each stem and primary branch, length was measured with a ruler. Numbering of individual branches permitted monitoring of the number and length of branches per stem and per plant, the appearance or disappearance of branches and stems, and the length-increment of individual branches and stems between 2 occasions. Furthermore, the presence of conceptacles and iridescence was noted.

To evaluate the standing crop, the length-weight relationship of branches and stems was assessed. At the end of the study, branches and stems of different length were weighed after removal of the epiphytes to obtain the fresh weight, then dried for 24 h at 105 °C and reweighed for dry weight.

RESULTS

Survivorship and phenology

All 6 plants studied were still present and alive after the 40 mo investigation period. The mean life expectancy of stems was on average 12 mo; 30 % of the stems lived up to 6 mo, 32 % up to 12 mo and 38 % survived longer than this age. Maximum age recorded for a stem was 33 mo. The largest renewal of stems took place during the winter-spring period. Thus an average of 35 % of stems disappeared between October and March and during the same period 37.5 % new stems appeared (Table 1). The disappearance of a high percentage of tagged stems during the winter was probably the consequence of strong winds and waves observed from December through January. It is impossible to say whether the newly tagged stems were really new stems or whether they were old stems that broke during the stormy winter period, thus losing their plastic tag, and that started to grow again and were tagged again in March. Between March and June, as well as between June and October, less than 10 % of the stems disappeared; during the same period, the rate of formation of new stems was also lowest (less than 10 %). Thus the stems are probably perennial structures.

Table 1. *Cystoseira balearica*. Frequencies of 'old' stems and of stems lost at different periods of the year

% of 'old' stems		% of stems lost during:	
March	62.5 ± 11.4	March–June	5.9 ± 5.4
June	91.2 ± 2.8	June–October	7.7 ± 2.6
October	90.1 ± 6.4	October–March	35.4 ± 10.8

The branches, by contrast, are seasonal structures. *Cytoseira balearica* plants reached their largest size during the summer months when they formed dense stands. In October all the primary branches present in June had disappeared and all the branches observed in autumn were new ones (Table 2). The same is true for the October to March period: only very few branches (less than 1 %) survived the winter and almost all branches observed in March were newly developed. The situation was different in June: only 27.9 % of the branches present in March had disappeared in June. Within the branches present in June, 57 % were already observed in March, whereas 43 % were newly formed. The life expectancy of primary branches varies between 3 and 6 mo. The *C. balearica* plants in the surveyed plot thus lost their branches twice a year and had 2 distinct growth periods.

In March and June conceptacles were observed on 47 to 65 % of the primary branches, with the exception of June 1985 when less than 1 % bore reproductive structures (Fig. 1). In October, less than 15 % of the branches showed conceptacles. In June when the plants were composed of 'old' branches (formed between October and March) and 'new' branches (formed between March and June), only a small proportion (less than 30 %) of the latter branches presented reproductive structures, whereas up to 92 % (June 1986) of the 'old' branches showed the presence of conceptacles. Iridescence was generally associated with 'new', growing branches (Fig. 1). In March and

Table 2. *Cystoseira balearica*. Frequencies of 'old' branches and of branches lost at different periods of the year

% of 'old' branches		% of branches lost during:	
March	< 1	March–June	27.9 ± 2.7
June	57 ± 3.8	June–October	100
October	< 1	October–March	> 99

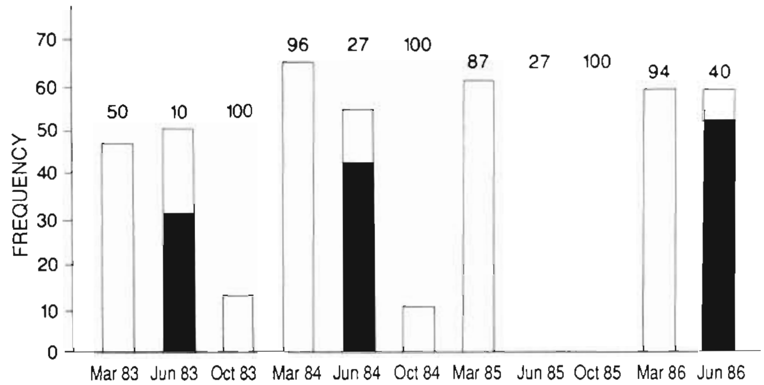

Fig. 1 *Cystoseira balearica*. Frequency of conceptacle-bearing 'old' (black bar) and 'new' (open bar) branches in March, June and October No. above bar = percentage of iridescent branches

October generally more than 90 % of the branches were iridescent; in June the iridescence was observed on less than 40 % of the branches.

Growth and biomass

Fig. 2 shows the relation of dry weight W (mg) and length L (cm) of the primary branches for *Cystoseira balearica*. It corresponds to the general biological relation between these values, i.e. decrease of linear growth with increasing body mass:

$$W = a L^b = 1.46 L^{2.02}$$

The biomass of the stems was evaluated at 25.1 mg dry weight (cm length)$^{-1}$.

Total stem biomass increased from spring to autumn (Fig. 3); the mean for the 6 plants varied from 0.635 to 1.274 g of dry weight plant^{-1}. The highest stem biomass recorded for 1 plant was 1.669 g dry weight. Between October and March stem biomass as well as stem length (Fig. 4) decreased. In March, a high percentage of shorter new stems was also observed. Mean length varied between 2.2 and 3.7 cm; the longest stem reached 13 cm. Mean number of stems plant^{-1} varied little from one season to another (10.1 to 14.8) (Fig. 4). A slight increase was observed in 1985. The highest number of stems plant^{-1} observed was 20. The increase of biomass from March to October was mainly due to an increase in stem length and not in number. Calculated on the basis of results from 1984 and 1985, stem biomass produced plant^{-1} and yr^{-1} represented an average of 0.68 g dry weight.

The standing crop of primary branches was highest in June, except for 1985 when the maximum was observed in March (Fig 5); the minimum biomass occurred in October. In March the mean biomass of branches plant^{-1} varied between 1.08 and 3.42 g dry weight, in June between 1.28 and 5.9 g, and in October between 0.63 and 1.2 g. Maximum biomass of branches observed plant^{-1} amounted to 7.2 g dry weight. As previously mentioned, almost all branches present in March and October had newly grown since the previous October and June respectively. The biomass observed is thus produced in the 3 preceding months. In June the biomass can be divided into 3 parts: the biomass already present in March, the bio-

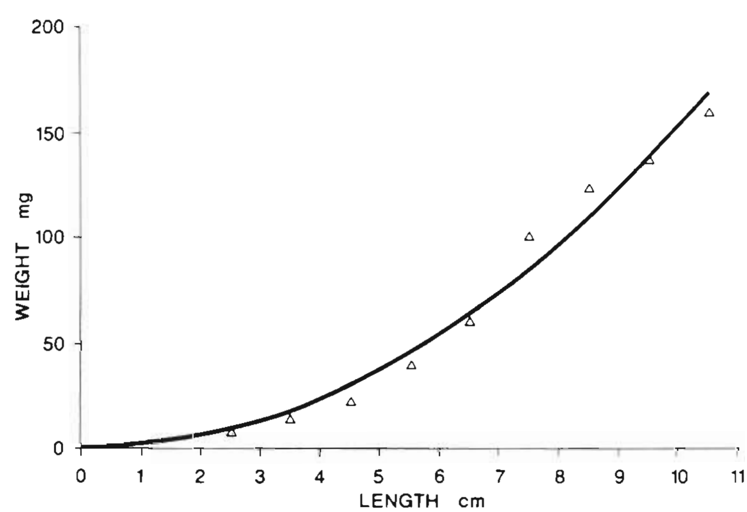

Fig. 2. *Cystoseira balearica*. Changes in dry weight of branches with increasing length

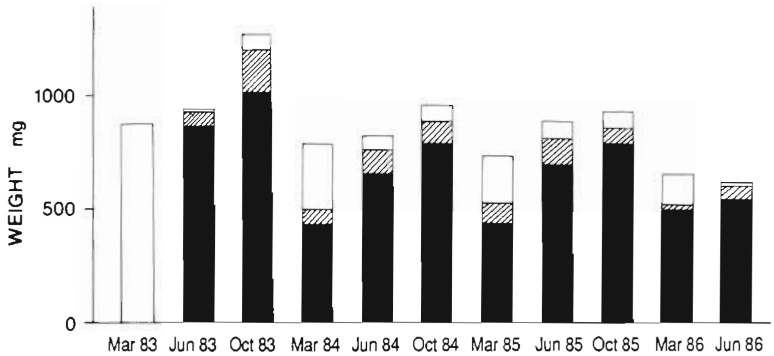

Fig. 3. *Cystoseira balearica*. Mean stem biomass (dry weight) plant^{-1} Black bar: biomass at previous campaign; hatched bar: biomass increase of these 'old' stems since previous campaign; open bar: biomass due to newly grown stems since previous campaign

mass produced by branches already present in March, and the biomass produced by new branches. Mean biomass of branches produced plant^{-1} was 7.7 g in 1983, 4.9 g in 1984 and 4.7 g in 1985. An important decrease is observed in the standing crop of *Cystoseira balearica* when the values of March or June are compared over the entire study period. From 1987 onwards the decline was so pronounced that growth measurements became meaningless (Demoulin unpubl.). It should be noted that this estimate is a minimal one because it reflects only the growth of whole primary branches while each living branch, as long as it stays on the stem, not only grows, but also sustains losses of its own structural elements (secondary branches), so that the biomass formed by it is in fact greater than the average mass of the branch. Furthermore, the plants did not necessarily present their maximum biomass during the measurements which took place in June and October.

Maximum number of primary branches and maximum total length were observed in June (Fig. 6). Mean number of branches plant^{-1} varied between 23.3 and 65.8; the maximum observed amounted to 68 branches. Mean total length of primary branches plant^{-1} varied between 1.2 and 4.5 m; the maximum observed amounted to 5.4 m for 1 plant. Mean number of branches stem^{-1} varied between 1.9 and 3.4 except for June 1983 when 5.7 branches stem^{-1} were observed.

DISCUSSION

The most frequently occurring growth cycle within the genus *Cystoseira* seems to consist of 1 seasonal growth period, the development of reproductive fronds and the abrupt shedding of most of the thallus. Thus, most Mediterranean species lose their branches generally in autumn with the beginning of the cold season, only leaving the holdfasts with the perennial stems during a more or less long resting period in the winter (Sauvageau 1912). A similar growth cycle has been described for *C. osmundacea* (Turner) A. Ag. in California (Schiel 1985a) and also from several species of the related genus *Sargassum*, i.e. *S. muticum* (Yendo) Fensholt (Norton 1977, Aguilar-Rosas & Machado Galindo 1990), *S. sinclairii* Hook. & Harv. (Schiel 1985b) For *C. balearica* this growth cycle is described by Gomez Garreta et al. (1982) for plants growing on the island of Mallorca. In contrast to these findings, the plants of *C. balearica* included in our tagging program lost almost all (more than 99 %) their branches twice a year, i.e. during the late summer (between June and October) and during the winter (between October and March); the stems, on the contrary, are perennial structures.

Thus 2 distinct growth periods of new branches exist: the first type of branches appears during winter; in March these already reached a mean length of 7 cm

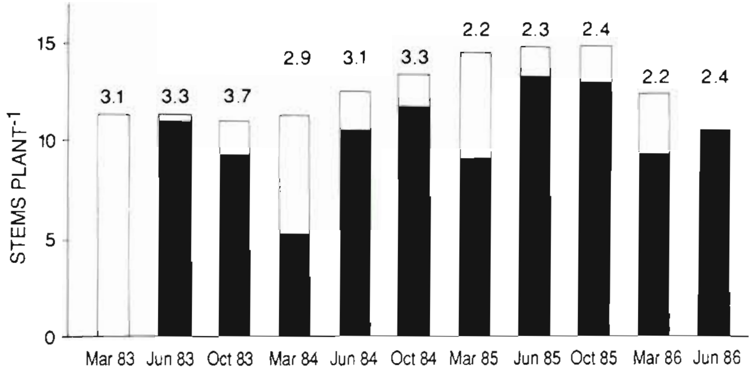

Fig. 4. *Cystoseira balearica*. Mean no. of stems plant^{-1} over time (black bar: 'old' stems; open bar: 'new' stems). No. above bar = mean length (cm) of stems

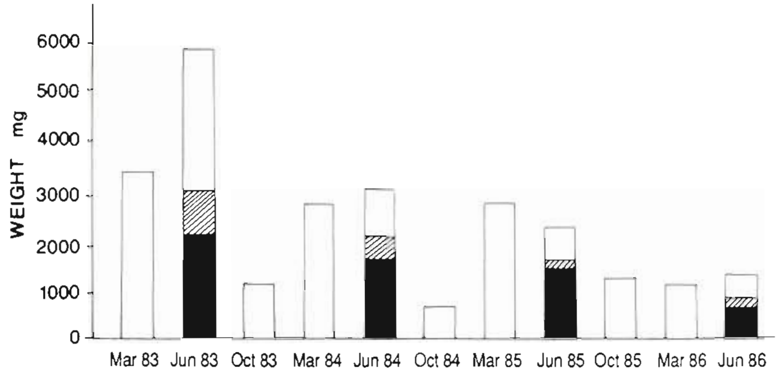

Fig. 5. *Cystoseira balearica*. Mean branch biomass (dry weight) plant^{-1} Black bar: biomass at previous campaign; hatched bar: biomass increase of these 'old' branches since previous campaign; open bar: biomass due to newly grown branches since previous campaign

and up to 60 % of them bore reproductive structures. They reached their maximum length in summer when also generally 50 to 60 % bore conceptacles (except in 1985).

A part of these deciduous branches was certainly used as food, e.g. by urchins (Frantzis et al. 1988) or as nest material, e.g. by fish (Lejeune 1985). Thus up to 220 g freshweight of *Cystoseira balearica* branches could be found in the nests of *Symphodus tinca* (Labridae). A couple of the latter, building 3 to 5 nests yr^{-1}, could thus cut off up to 1 kg of branches yr^{-1}. Most of the branches seem however to be simply shed by the plants in late summer, which corresponds to the phenology of most Mediterranean *Cystoseira* species (Sauvageau 1912).

The second type of branches was only present during a short period; they only reached a mean length of 5 cm and were generally not reproductive. These latter branches, present during the October campaign, disappeared before spring.

The reason of the loss of these autumn branches can not be established with certainty, but it is likely that they disappeared as a result of external mechanical factors and not because of the internal biological cycle of the species. An indication for this is that the stems, which reached their maximum length in October, were on the average shorter in March; these were indeed broken by the strong waves in this area during the December-January period which automatically also leads to branch loss.

Branch and stem losses are very high compared to the total organic matter formed by the thallus; thus the perennial biomass of the plants only increased by 20 mg yr^{-1} due to new stems and the growth of the latter. The main growing season of *Cystoseira balearica* was the winter-spring period in which ca 70 % of the total yearly biomass is produced.

Besides extensive sea grass meadows formed by *Posidonia oceanica* and *Cymodocea nodosa* and which cover more than 50 % of the Revellata Bay, phytoplankton and benthic algae on the rocky coast are the basic compartments of primary producers around Calvi. Although these sea grass beds are very productive (Bay 1984), they do not seem to be of great importance as carbon suppliers to the marine food web. Dauby (1989) showed, indeed, by stable carbon isotope ratio analyses that the fraction of the diet of particle-feeding organisms originating from *Posidonia* is very low (mean 6 %) compared to the planktonic (mean 59 %) and the seaweed carbon (35 %). Mean yearly biomass production by *C. balearica* in this study amounts to 6.5 g plant^{-1} yr^{-1} Considering a carbon content of 37 % (Atkinson & Smith 1983), this production corresponds to 2.4 g C plant^{-1} yr^{-1}. If we admit an average of 20 plants m^{-2}, an estimated 130 g dry weight m^{-2} is produced per year (= 48.1 g C m^{-2} yr^{-1}). On the basis of the assumption that, in Revellata Bay, *C. balearica* has its optimum growth between depths of 1 and 9 m (Clarisse 1984), the yearly production along the 9 km long shoreline is estimated to be about 10 t of

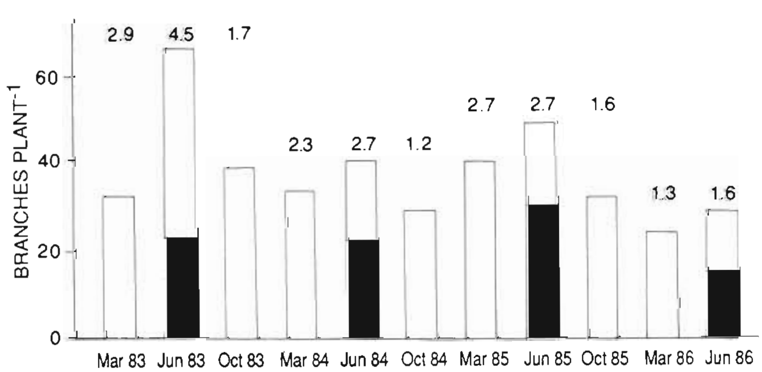

Fig. 6. *Cystoseira balearica*. Mean no. of branches plant^{-1} over time (black bar: 'old' branches; open bar: 'new' branches). No. above bar = total length (m) of branches plant^{-1}

dry biomass (= 3.7 t C). The dramatic regression of the *Cystoseira* belt observed since 1987 may thus have important consequences for this Mediterranean ecosystem.

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