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MORPHOLOGICAL AND REPRODUCTIVE PHENOLOGY OF *CYSTOSEIRA COMPRESSA* (ESPER) GERLOFF & NIZAMUDDIN (FUCALES, FUCOPHYCEAE) IN THE GULF OF TRIESTE (NORTH ADRIATIC SEA)

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ABSTRACT

In a wider context regarding the characterization of Cystoseira *populations, studies concerning growth and reproduction resulted to be particularly important for a wider understanding of species' abundance and distribution, and therefore of the community structure, also with the aim of environmental restoration and mitigation in partially degraded areas. Only partial data are available on the morphological and reproductive phenology of* Cystoseira compressa. *In order to define for the northern Adriatic Sea the variability of diacritic characteristics of this species, and to evaluate the seasonal periodicity of growth and reproduction, a study was carried out at Izola (Slovenia). 6 thalli of* C. compressa *were taken randomly, every month, for one year and morphometric parameters were measured for every sample. The morphological plasticity of the thallus and the phenological cycle, characterized by the succession of two dominant forms, were described.*

Key words: *Cystoseira compressa*, phenology, morphology, Gulf of Trieste, northern Adriatic Sea

FENOLOGIA MORFOLOGICA E RIPRODUTTIVA DI *CYSTOSEIRA COMPRESSA* (ESPER) GERLOFF & NIZAMUDDIN (FUCALES, FUCOPHYCEAE) NEL GOLFO DI TRIESTE (NORD ADRIATICO)

SINTESI

Studi sulla crescita e riproduzione di specie algali risultano particolarmente importanti ai fini di interventi di restauro e mitigazione di aree degradate. Allo scopo di definire la fenologia morfologica e riproduttiva e la variabilità stagionale dei caratteri diacritici di Cystoseira compressa *è stato condotto uno studio nel Nord Adriatico ad Izola (Slovenia). 6 talli di* C. compressa *sono stati raccolti random mensilmente per un anno e sono stati analizzati i parametri morfometrici. Vengono descritti la plasticità morfologica del tallo, caratterizzato dalla successione di due forme dominanti, ed il ciclo fenologico.*

Parole chiave: *Cystoseira compressa*, fenologia, morfologia, Golfo di Trieste, Nord Adriatico

INTRODUCTION

The genus *Cystoseira* C. Agardh (Fucales, Fucophyceae) is characterized by a notable taxonomic complexity and a wide infra- and intra-specific polymorphism, depending on geographical distribution and ecological conditions (Gòmez *et al.*, 1982; Barcelo & Seoane Camba, 1984; Motta, 1989; Oliveras & Gòmez-Garreta, 1989; Cormaci *et al.*, 1992; Serio, 1995; Otero-Schmitt & Pérez-Cirera, 1996; Pizzuto 1998; Alongi *et al.*, 1999, Marzocchi *et al.*, 2003). Key reports on *Cystoseira* genus are the study of Savaugeau (1912), focusing mainly on the species of the European Atlantic as Western Mediterranean coasts, the monographs by Valiante (1883) on the Gulf of Naples species and by Ercegović (1952) on the Adriatic species.

According to Roberts (1978), this genus is in progress of active speciation and the biogeography of *Cystoseira* species has been investigated by Giaccone (1991); for the Mediterranean Sea, Ribera *et al.* (1992) reported 29 species, 15 varieties and 13 forms, however, for an accurate evaluation of species, variety and form number, one must also take into consideration the recent revisions by Gòmez-Garreta (2000) and Furnari *et al.* (2003). In order to solve problems linked to the taxonomy and evolutionary biology, several studies have been carried out on distribution, growth, morphology and chemistry of different species (Giaccone & Bruni, 1971, 1973; Giaccone, 1973; Khailov, 1978, 1979; Firsov & Khailov, 1979; Khailov & Firsov, 1979; Amico *et al.*, 1985; Giaccone & Motta, 1987; Piattelli, 1990; Hoffmann *et al.*, 1992; Ribera *et al.* 1992, 1995; Amico, 1995; Montesanto & Panayotidis, 2001). In the Mediterranean, *Cystoseira* stands often represent a climax stage in photophilous communities. The development of these canopy algae, referred to as keystone species *(sensu* Paine, 1969) or ecological engineering species *(sensu* Jones *et al.*, 1994), ranging from shallower to sub-littoral rocky shore in exposed or sheltered situations, leads to an increase of space heterogeneity forming complex communities (Ballesteros, 1988; Rull & Gòmez-Garreta, 1990; Benedetti-Cecchi *et al*, 2001; Falace & Bressan, 2004; Falace & Bressan, *in press*). The canopy can modulate the structure of the biotic community, modifying the rates of recruitment and mortality of the epibionts and may affect the density and efficiency of predators, providing shade and shelter for diversified assemblages of animals and algae (Boudouresque, 1971; Tigànus, 1972; Celan & Bavaru, 1978; Hicks, 1980; Dean & Connell, 1987; Belegratis & Bitis, 1989; Aarnio & Mattila, 2000; Hernández-Carmona *et al.,* 2000). Furthermore, it plays a crucial role on understorey assemblage's growth by significantly affecting the physical factors, such as light (Reed & Foster, 1984; Kennelly, 1989; Figueiredo *et al.*, 2000; Melville & Connell, 2001), desiccation (Menge, 1978; McCook & Chapman, 1991), currents and the rates of transport and deposition of suspended particulates (Hawkins, 1983; Jenkins *et al.* 1999; Airoldi, 2003; Piani *et al.*, 2004).

Several *Cystoseira* species have been enclosed, as sensitive species, among the marine coastal indicators of environmental quality (Montesanto & Panayotidis, 2001). In the Mediterranean, in fact, the increase in eutrophication and pollution, as a result of natural and anthropogenic disturbances, has been accompanied by a decline of *Cystoseira* belts (UNEP, 1996; Cormaci & Furnari, 1999; Munda 1993a, 1993b, 2000; Falace, 2000; Falace & Bressan, 2003). Over the last three decades, environmental alterations in the Adriatic Sea have changed the floristic diversity and leading algal associations, and a marked qualitative/quantitative decline of macrophytes occurred (Munda 1991, 1993a, 1993b, 2000; Sfriso *et al.*, 1993; Cormaci & Furnari, 1999; Falace, 2000; Falace & Bressan, 2003; Falace *et al.*, *in press*). The principal variations observed concern the increase of opportunistic, with rapidly growing turfed species, and the reduction/disappearance of leathery Fucales (Falace, 2000; Falace & Bressan, 2003). At present, *Cystoseira barbata* (Stackhouse) C. Agardh and *Cystoseira compressa* (Esper) Gerloff & Nizamuddin are the only species belonging to this genus still present in the surrounding of Trieste, in relation to their wider tolerance to environmental stresses (Falace, 2000).

In a wider context of research on the architectural complexity of *Cystoseira* (Falace & Bressan, 2004; Falace & Bressan, *in press*; Piani *et al.*, 2004), a study was conducted in the North Adriatic Sea aimed at analysing the phenology of *C. compressa*, in order to evaluate for this biogeographical area the seasonal periodicity of growth and reproduction.

MATERIALS AND METHODS

The study was carried out in a protected sea area near Izola (Slovenia) (45°32′41.3″ N, 13°40′39.2″ E) (Fig. 1). The area is located in the Gulf of Trieste (northern Adriatic Sea), a semi-enclosed shallow system (max. depth 25 m) characterized by strong river run-off and wide seasonal and inter-annual temperatures and salinity variability. Variations within the current system are highly dependent on the *bora* wind, which blows in an offshore direction (Mosetti, 1972; Zore Armanda & Gačić, 1987). The tidal range is 97 cm on average. Surface sediments have been subdivided by Ogorelec *et al.* (1991) into seven zones on the basis of grain-size and mineral composition. The sedimentation rate estimated in the central part of the Gulf is 1.08 mm yr^{-1}, whereas at 5 km from the Isonzo River mouth it is 1.45 mm yr^{-1} (Bertuzzi *et al.*, 1996).

Samples were collected in the upper sublittoral zone on semi exposed rocky low-shores characterised by a dense population of *C. compressa*, which extends down to 2 metres depth (Fig. 1). In the inner part of the

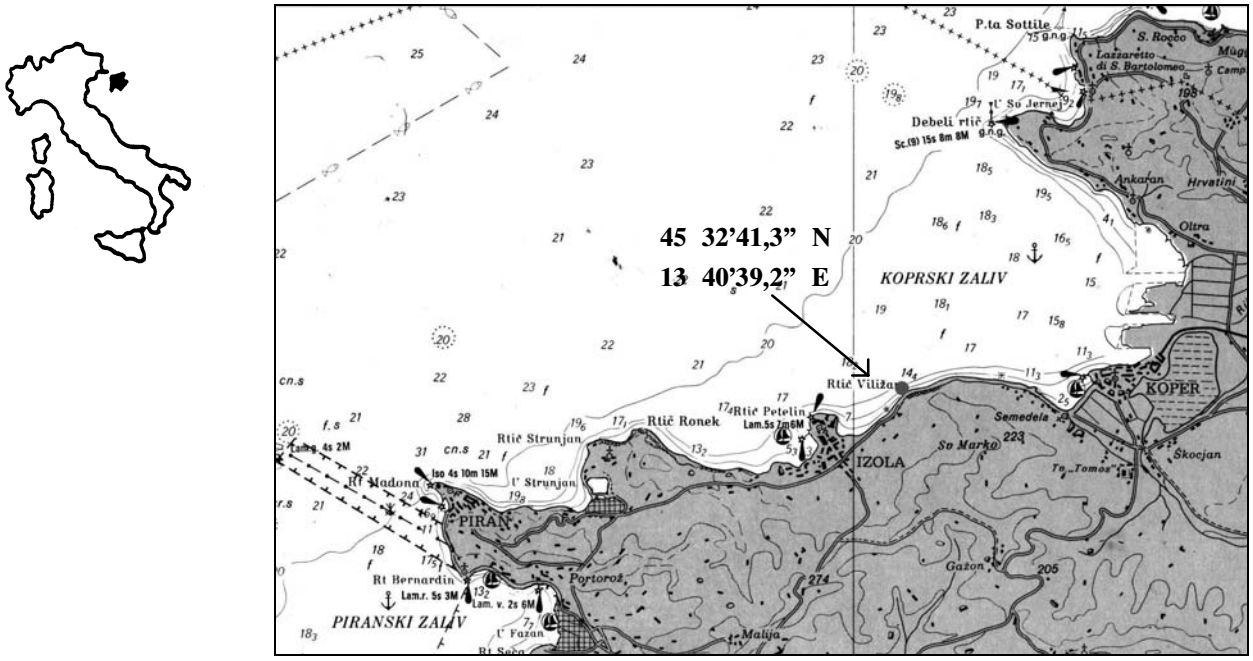

Fig. 1: Sampling site (Izola, Slovenia).
Sl. 1: Vzorčišče (Izola, Slovenija).

small Bay of Izola, surface sediments mainly consist of clayey silt, although in shallow shores the prevailing sediment is sand. Six thalli of *C. compressa* were taken at random every month for one year (April 2002–March 2003), apart from June, August and December, due to international bureaucratic impediments. They were fixed in a 4% formalin seawater solution and send to the laboratory. The morphology was described and the following measures were carried out: the overall height from the basal disc to the apex of the frond; the length of 10, chosen at random, I branches; the diameter of 10 I branches, at 1cm from the ramification from the cauloid and at half the length of the branch; the length and diameter in the middle of the axis of 5, selected at random, II branches. The reproductive phenology was examined, describing the presence of fertile conceptacles.

RESULTS
Morphology of the thallus

C. compressa is a caespitose plant attached to the substratum by a small disc. From November to January, the analysed samples show a "rosette-shaped" form, characterized by flattened I branches, smooth borders and rounded apex. The II branches are short, distichous and alternate. At the base of I and II branches a middle-rib is well distinguishable. The cryptostomata (depressions with hair tufts) are arranged, on both I and II branches, in two rows from the base to the apex. In January, the ramifications appear denser near the apex and sparse in the basal portion of the thallus; I and II branches are still flattened.

In February-March, the examined thalli present a transitory shape, with the coexistence on the same plant of two different typologies of I branches: a) short and flattened like in the winter form; b) lengthened and thin towards the upper of the axis with cryptostomata arranged in different layers. In transversal section, these branches appear to be cerebral-shaped or more or less triangular-elliptical in the upper portion, whereas at the base they are still flattened. Near the apex of the fronds, the II branches are thin and thick, ramified, and disposed on more layers, whereas at the base they are alternate, distichous with the cryptostomata disposed on two strings. The aerocysts (air-bladders) first appear, starting from April, on the more apical II branches. The aerocysts can be isolated or disposed in chain.

In spring/beginning of summer, the thallus bearing changes and it becomes erect and densely ramified, especially in the apical region. The I branches are still broader at the base and cylindrical at the apex, while II branches become longer, thinner and ramified. In July, some thalli present roundish I branches with a bare section in the basal portion, above which II branches are less densely ramified. The aerocysts appear less numerous and partly deformed.

At the end of summer/beginning of autumn, the thallus regains the winter "rosette-shaped" bearing; the change occurs with the fall of older branches, which are substituted by new ones with a flattened portion of relatively growing importance, and alternated distichous II branches. The aerocysts are absent.

	Thalli		I branch		I branch (diam. 1 cm)		I branch (diam. half length)		II branch		II branch (diam. half length)		Concept.
Month	length	SEM	length	SEM	length	SEM	length	SEM	length	SEM	length	SEM	
Apr	255.6	9.8	170.4	11.1	2.6	0.1	1.5	0.1	49.7	3.2	1.4	0.1	
May	448.3	27.7	324.3	24.5	2.5	0.1	1.5	0.1	100.4	5.9	0.9	0.0	*
Jul	251.2	79.3	132.3	27.8	1.9	0.1	1.5	0.1	62.7	5.8	1.0	0.1	*
Sep	62.5	9.2	35.6	2.3	1.9	0.1	2.0	0.1	17.7	1.3	1.9	0.1	
Oct	61.7	6.8	24.9	3.3	2.5	0.2	2.7	0.2	12.9	1.0	2.4	0.1	
Nov	54.0	3.8	33.5	4.1	2.7	0.2	2.7	0.1	13.1	1.0	2.9	0.1	
Jan	60.8	6.3	35.4	4.6	2.6	0.2	2.4	0.1	13.9	0.9	3.0	0.1	
Feb	120.3	9.9	75.9	6.6	2.4	0.2	1.8	0.1	20.4	1.2	2.0	0.2	
Mar	128.3	13.9	79.3	8.6	2.7	0.1	2.1	0.1	33.6	1.6	2.3	0.1	

Tab. 1: Phenological data (SEM: mean standard error). Measurements are in mm.
Tab. 1: Fenološki podatki (SEM: srednja standardna napaka). Mere so izražene v mm.

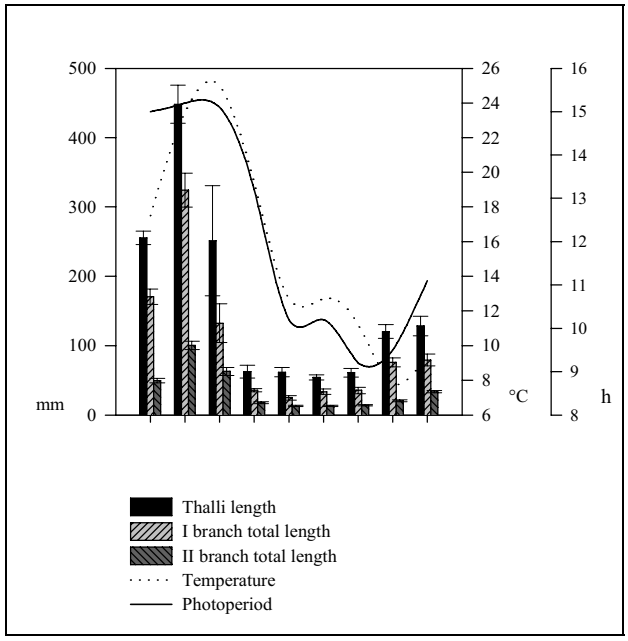

Fig. 2: Diagram of thalli, I and II branches average lengths related to the photoperiod and temperature trend.
Sl. 2: Diagram steljke in povprečne dolžine poganjkov I in II glede na fotoperiodične in temperaturne trende.

Height of the thallus

The monthly average values vary from a minimum of 54 mm in November to a maximum of 448.3 mm in May (Tab. 1). The maximum vegetative development is observed in spring/summer, in accordance with the higher temperature and photoperiod length in the study area (Fig. 2). Starting from September, with the gradual changes in temperature and photoperiod, the reduction in the size of the frond is attained.

Primary branches

I branches (Tab. 1, Fig. 2) are more developed during April-July (average length 209.0 mm) with a maximum in May (324.3 mm). From September, the thalli lose their fronds, and in October I branches reach their minimum (24.9 mm). Following the seasonal cycle, the frond, besides varying in sizes, also changes from a morphological point of view. In fact, from April to July, I branches appear to be flattened at the basal part, whereas towards the apex they are thin and cylindrical. In September, with the fall of older branches and the contemporary growth of new ones, the frond takes the "rosette-shaped" form that remains till January; in February, the change towards a more developed and erect form of the thallus is observed, characterized by cylindrical branches with thinner apices and bases, and thicker II branches. During these morphological variations, the diameter of the I branches at 1 cm from the ramification from the cauloid varies between a minimum of 1.9 mm in July and September to a maximum of 2.7 mm in November and March (Tab. 1, Fig. 3). A similar pattern may be observed for the diameter at half the length of the I branch: the minimum (1.5 mm) is reached between April and July, when the branches are cylindrical, while the maximum (2.7 mm) is observed between October and November, when the thallus takes on the winter form.

Secondary branches

The length : diameter ratio of II branches follows the same trend as recorded for I branches (Fig. 3). In May, the average length reaches the maximum (100.4 mm) and the diameter the minimum (0.9 mm). In April-July, during the greatest vegetative development, the length of II branches (Tab. 1, Fig. 2) reaches the highest values (49.7-100.4 mm), while the minimum (17.7-13.1 mm) is recorded starting from September.

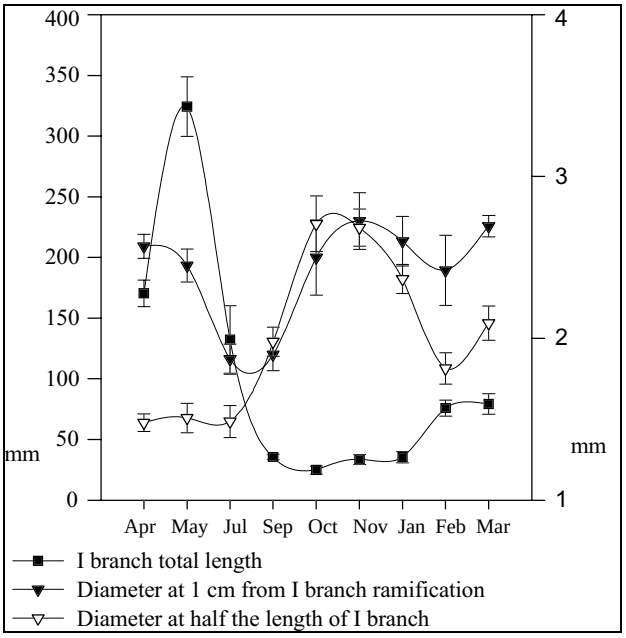

Fig. 3: Diagram of the I branches total length and diameter, measured at 1cm from the ramification and at half the length.
Sl. 3: Diagram poganjkov I, skupna dolžina in premer, izmerjen 1 cm od razrasti in na polovici njihove dolžine.

Reproductive phenology

Matured conceptacles can be observed during the May-July period (Tab. 1). The receptacles at the apices of terminal branchlets are pedunculate, bi-trifurcated and present internal aerocysts, while the receptacles in the lower part of the branches are lacking in aerocysts.

DISCUSSION AND CONCLUSIONS

Unlike other species of the same genus, the phenology of *C. compressa* has been poorly investigated and only partial data, concerning the reproductive-vegetative cycle, are available. The *C. compressa* thallus presents a morphological plasticity, which is very changeable in size and appearance in relation to the principal environmental parameters, and in particular according to the wave-exposure: in exposed shores, the predominant life-form is the rosette-shaped one (Hamel, 1939; Gòmez-Garreta, 2000). The name *Cystoseira abrotanifolia* (Linnaeus) C.Agardh has been misapplied by several authors as a synonym of *C. compressa* (Gòmez-Garreta, 2000). John *et al.* (2004) cite *Cystoseira abrotanifolia* (Stackh.) C. Agardh and *Cystoseira fimbriata* (Desf.) Bory, as synonyms of this species. Ercegović (1952) included thalli from the exposed sites in a subspecies (subsp. *rosetta),* which was moved down by Cormaci *et al.* (1992) to a forma. For Garreta *et al.* (2001) the f. *rosetta* is regarded as a synonym of *C. compressa*, since in the Iberian Peninsula the autumn and winter plants from sheltered places display a bearing similar to those from exposed locations.

According to Garreta *et al.* (2000), the phenological cycle of our specimens is characterized by the succession of two dominant and well-distinguishable forms: a winter rosette-shaped one, with short primary branches, and a spring one, more luxuriant with erect fronds (Fig. 4). The morphological characteristics of sampled thalli partially coincide with those described by Huvé (1972) for the sheltered stations in the North-West Mediterranean, even if our samples were collected in a site with elevated hydrodynamism. If compared with the Gòmez *et al.* (2000) measures, in the Gulf of Trieste the lengths of the thalli show in spring-summer intermediate values between the ones reported for the exposed and sheltered locations. Since we collected thalli only at a single site, future research will require comparable estimates among systems with different regimes of hydrodynamism and disturbance, in order to bear out the phenological cycle and the eventual coexistence of the two forms in both sheltered and exposed conditions.

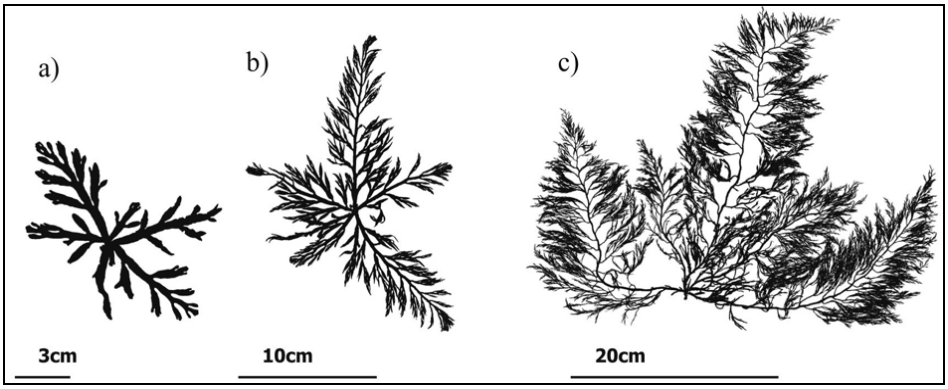

Fig. 4: Dominant phenological phases of** C. compressa **in the studied area (digitalized images).
Sl. 4: Prevladujoče fenološke faze** C. compressa **v preučevanem območju (digitalizirane slike).

To a large extent, the thallus's overall length at its maximum height depends on the length of the I branches and to a lower extent on those of the II branches. Furthermore, the morphological changes are characterized by a marked variation in the diameter of the branches. In winter, when the photoperiod length is shorter, the thallus seems to present a mechanomorphic adaptation that determines the presence of broad flattened branches, which offer a larger surface to the radiant flux.

Studies on growth and reproduction result to be particularly important for a wider understanding on the abundance and distribution of the species, and therefore on the community structure, also with the aim of environmental restoration and mitigation actions in partially degraded areas (Celan & Bavaru, 1978; Falace & Bressan, 2004).

Finally, frond morphology variations are determinant in order to define the structural complexity of the thallus architecture, which in turn involves a wider diversification and heterogeneity of the habitat, additional substratum and ecological gradients for the epibionts (Falace & Bressan, 2004; Falace & Bressan, *in press*; Piani *et al.*, 2004).

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MORFOLOŠKA IN RAZMNOŽEVALNA FENOLOGIJA VRSTE *CYSTOSEIRA COMPRESSA* (ESPER) GERLOFF & NIZAMUDDIN (FUCALES, FUCOPHYCEAE) V TRŽAŠKEM ZALIVU (SEVERNI JADRAN)

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POVZETEK

Med preučevanjem splošnih značilnosti populacij iz rodu Cystoseira *je bilo ugotovljeno, da so raziskave, ki zadevajo njihovo rast in razmnoževanje, še posebno pomembne za poznavanje številčnosti, razširjenosti in sestavo združbe. To je pomembno tudi z vidika ohranjanja okolja ali lajšanja posledic v delno degradiranih območjih. O morfološki in razmnoževalni fenologiji vrste* Cystoseira compressa *je na voljo le nekaj podatkov. Z namenom, da bi v severnem Jadranu definirali variabilnost diaktričnih značilnosti te vrste in ocenili sezonsko periodičnost rasti in razmnoževanja, so avtorji prispevka v Izoli opravili temeljito študijo. V letu dni so vsak mesec naključno vzeli 6 steljk te vrste in izmerili morfometrične parametre vsakega vzorca. Na tej podlagi so opisali morfološko variabilnost steljke in fenološki ciklus, za katerega je značilna sukcesija dveh prevladujočih form.*

Ključne besede: *Cystoseira compressa*, fenologija, morfologija, Tržaški zaliv, severni Jadran

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