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RESEARCH ARTICLE

Seasonal variation in epiphyte flora of the invasive species *Codium fragile* subsp. *fragile* on the Çanakkale Strait coast (Marmara Sea, Turkey)

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Abstract

Seasonal changes in the epiphyte flora of an invasive species, *Codium fragile* subsp. *fragile* (Suringar) Hariot 1889, along the coast of the Çanakkale Strait (Dardanelles) are reported. Samples were collected between December 2011 and November 2012 from depths of 0-1 m. The whole thallus was examined for epiphytes and 48 taxa epiphytes were identified (27 taxa Rhodophyta, 7 taxa Ochrophyta and 14 taxa Chlorophyta). The most common epiphytes were Ceramiales (Rhodophyta), Ectocarpales (Ochrophyta) and Ulvales (Chlorophyta) in this order.

Keywords: *Codium*, invasive, epiphyte, Çanakkale Strait (Dardanelles), Turkey

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Introduction

Algae exist in natural environment either as native or invasive species. Invasive species have irregular features in terms of distribution. *Codium fragile* (Suringar) Hariot 1889 is one of the most successful invasive algal species (Trowbridge

1996, Scheibling and Anthony 2001, Inderjit *et al*. 2006, Chavanich *et al*. 2006, Tsiamis and Panayotidis 2007, Lutz *et al*. 2010, Madariaga *et al*. 2014). Macroalgae are essential species for marine ecosystems due to providing living areas, shelter and nutrition for different creatures. However, the invasion of some macroalgae may provide advantages or disadvantages for creatures living in the same ecosystem.

Species of *Codium* Stackhause (Bryopsidales, Codiaceae) occupy many habitats in marine ecosystems. This genus includes nearly 100 species. They grow in rocky and sandy habitats of seas. There are three invasive subspecies of *C. fragile* in all seas, that is, *Codium fragile* subsp. *atlanticum* (A. D. Cotton) P.C. Silva 1955, *Codium fragile* subsp. *scandinavicum* P.C. Silva 1957 and *Codium fragile* subsp. *tomentosoides* (van Goor) P.C. Silva 1955. *C. fragile* subsp. *fragile* is a cosmopolitan taxon in tropical seas, so is *C. fragile* subsp. *tomentosoides* (van Goor) P.C. (González and Santelices 2004).

Codium fragile subsp. *fragile* (Suringar) Hariot 1889 is siphonaceous and its type locality is Japan (Womersley 1984). The features of the alga have been described in detail by Silva (1955), González and Santelices (2004) and D'Amours and Scheibling (2007).

The optimum temperature for growth and reproduction is 24 °C for *Codium*, but they can also tolerate low temperatures (for reproduction 12 °C, in winter -2 °C) and they are successful in low light conditions. They use nitrite, nitrate, ammonium and urea as nitrogen sources and they store residual nitrogen (Chapman 1999).

In recent years, *C. fragile* subsp. *fragile* reveals wide distribution along the Çanakkale Strait (Dardanelles) coast as well as more and more areas on the coasts of Turkey compared to previous years and has attracted attention due to its hosting of epiphytes (Erduğan *et al*. 2009). Due to its morphological structure, it contains more epiphyte species than other algal species.

C. fragile subsp. *fragile* was identified as *C. fragile* for the first time on the coasts of Turkey by Güner *et al*. (1985). *C. fragile* were also reported from Balıkesir (Aysel *et al*. 2002), Bursa (Erduğan *et al*. 2002), Tekirdağ (Okudan *et al*. 2002), İzmir (Dural-Tarakçı *et al*. 2003), Aydın (Okudan *et al*. 2003), and Muğla (Aysel *et al*. 2003).

Due to the fact that this taxon (*C. fragile*) is represented only by a single sub-species in the whole Mediterranean Sea, the taxon was revised to "*C. fragile* subsp. *tomentosoides*" by Gallardo *et al.* (1993). After the revision, *C. fragile* subsp. *tomentosoides* was reported from Yalova coasts (Aysel *et al*. 2004), Kocaeli coasts (Marmara Sea) (Erduğan *et al*. 2004), the Çanakkale Strait and Marmara Sea (Aysel *et al*. 2000; Erduğan *et al*. 2009).

While the negative effects of invasive taxa have been evaluated by various researchers (Provan *et al*. 2005; Neill *et al*. 2006; Bridgwood 2010, Jones and Thornber 2010; Katsanevakis *et al*. 2014), their positive effects have been reported by only a few studies (Bulleri *et al*. 2006; Erduğan *et al*. 2009; Katsanevakis *et al*. 2014). In fact, invasive taxa like *Acanthophora nayadiformis* (Delile) Papenfuss 1968, *Asparagopsis armata* Harvey 1855, *Hypnea spinella* (C. Agardh) Kützing 1847, *Chorda filum* (L.) Stackhouse 1797, *Colpomenia peregrina* Sauvageau 1927, *Sargassum latifolium* (Turner) C.Agardh 1820, *C. fragile* subsp. *fragile,* and *Ulva fasciata* Delile 1813 contain various important polysaccharides. Most of the time, they are a source of nutrition, shelter and are location of nesting for other species (Trowbridge 1993). Among them, the epiphyte flora of *C. fragile* subsp. *fragile,* especially, has been investigated in recent years (Schmidt and Scheibling 2006; D'Amours and Scheibling 2007; Scheibling *et al*. 2008; Lutz *et al*. 2010; Villasenor-Parada and Neill 2011; Rohr *et al*. 2011).

In this study, the seasonal variations and negative-positive effects of the epiphyte flora on the invader *C. fragile* subsp. *fragile*, which has been common and abundant in recent years, in the Çanakkale Strait coasts, were investigated.

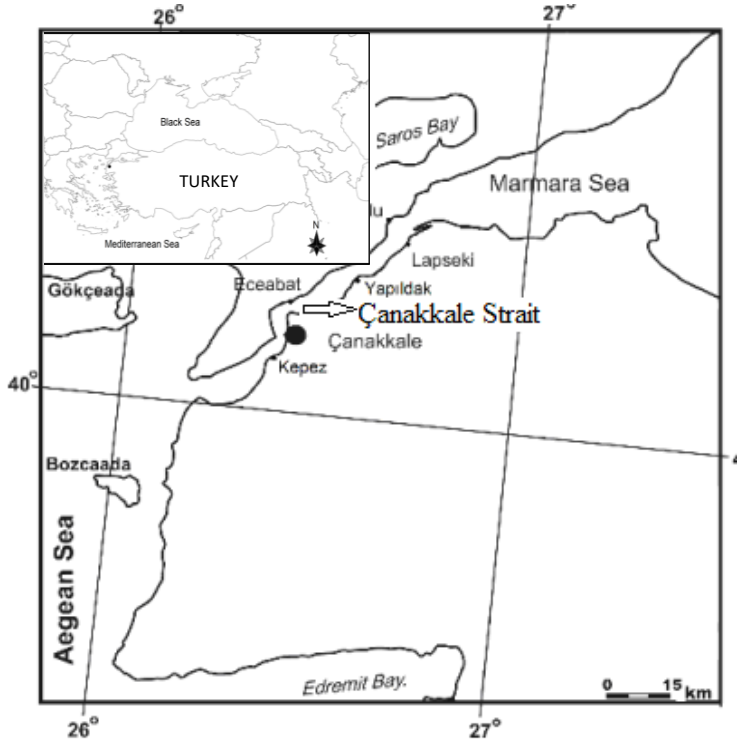

Figure 1. Sampling area in the Çanakkale Strait

Materials and Methods

The samples of C. *fragile* subsp. *fragile* distributed along the Çanakkale Strait from Kepez and Yapıldak were collected (Figure 1) at 0-1 m depth. During the sampling, an area of 50 m^2 was screened to obtain *C. fragile* subsp. *fragile* samples containing epiphytes. The sample survey was monthly carried out at the stations of Kepez and Yapıldak from the upper infralittoral zone between December 2011 and November 2012. The samples placed in 4% formaldehyde solution were brought to laboratories for investigation. Species definitions were made on the host taxa without a zone separation (bottom, middle and top). The samples were examined via using the Olympus BX-51 microscope.

Results

The epiphyte species diversity and their temporal distributions on host species *C. fragile* subsp. *fragile* between December 2011 and November 2012 are presented in Table 1. Rational distribution of epiphyte species according to their divisions is shown in Figure 2. Temporal variations in epiphyte species number are shown in Figures 3 and 4.

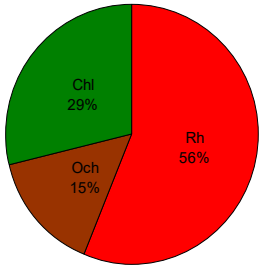

Figure 2. Proportion of epiphyte species on *Codium fragile* subsp. *fragile* (Rh: Rhodophyta, Och: Ochrophyta, Chl: Chlorophyta)

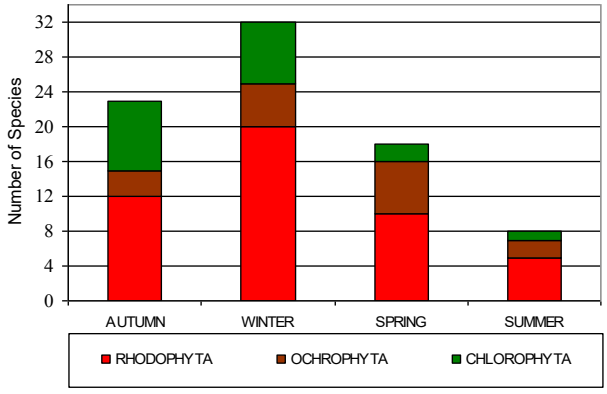

Figure 3. Seasonal epiphyte distribution on the invasive *Codium fragile* subsp. f*ragile*

Table 1. The list of epiphyte species and their temporal distributions on *Codium fragile* subsp. *fragile*: (1) December 2011, (2) January 2012, (3) February 2012, (4) March 2012, (5) April 2012, (6) May 2012, (7) June 2012, (8) July 2012, (9) August 2012, (10) September 2012, (11) October 2012, (12) November 2012

	Winter			Spring			Summer			Autumn		
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Rhodophyta												
Eryhropeltidales												
Erythrotrichia carnea (Dillwyn) J.Agardh 1883		+										
Bangiales												
Bangia atropurpurea (Mertens ex Roth) C.Agardh 1824						+						
Porphyra umbilicalis Kützing 1843			+	+								
Achrocaetiales												
Acrochaetium secundatum (Lyngbye) Nägeli 1858	+	+	+		+		+	+	+	+	+	+
Colaconematales												
Colaconema codicola (Børgesen) H.Stegenga, J.J.Bolton, and R.J.Anderson 1997		+										
Colaconema savianum (Meneghini) R. Nielsen 1994			+									
Bonnemaisoniales												
Asparagopsis armata Harvey 1855	+	+	+								+	+
Bonnemaisonia hamifera Hariot 1891						+						
Gigartinales												
Chondracanthus acicularis (Roth) Fredericq 1993	+	+	+							+	+	+
Hypnea musciformis (Wulfen) J.V.Lamouroux 1813											+	
Rhodymeniales												
Lomentaria clavellosa (Lightfoot ex Turner) Gaillon 1828									+			
Ceramiales												
Antithamnion cruciatum (C.Agardh) Nägeli 1847					+			+				
Antithamnion tenuissimum (Hauck) Schiffner 1915		+										
Ceramium virgatum Roth 1797	+	+	+							+	+	+
Ceramium rubrum var. *barbatum* G.Feldmann-Mazoyer 1941	+			+	+					+	+	
Ceramium virgatum var. *implexo-contortum* (Solier) G. Furnari 2003	+	+	+	+	+		+	+	+	+	+	+
Ceramium siliquosum var. *elegans* (Roth) G. Furnari 1999	+	+		+	+							
Ceramium siliquosum var. *zostericola* (Feldmann-Mazoyer) G.Furnari 1999			+		+							
Dasya rigidula (Kützing) Ardissone 1878										+	+	+
Chondria capillaris (Hudson) M.J.Wynne 1991	+	+	+							+	+	+
Chondria dasyphylla (Woodward) C.Agardh 1817			+									
Palisada perforata (Bory) K.W.Nam 2007	+									+		
Vertebrata fruticulosa (Wulfen) Kuntze 1891	+											
Vertebrata thuyoides (Harvey) Kuntze 1891										+	+	
Lophosiphonia obscura (C.Agardh) Falkenberg 1897	+	+										

Table 1. Continued

Polysiphonia morrowii Harvey 1857		+										
Polysiphonia fucoides (Hudson) Greville 1824	+	+	+		+	+	+	+	+	+	+	+
Ochrophyta												
Dictyotales												
Padina pavonica (Linnaeus) Thivy 1960	+									+	+	+
Ectocarpales												
Ectocarpus siliculosus (Dillwyn) Lyngbye 1819	+	+	+	+	+	+	+	+	+	+	+	+
Colpomenia peregrina Sauvageau 1927		+	+	+	+							
Petalonia fascia (O.F.Müller) Kuntze 1898	+	+	+	+	+							
Scytosiphon lomentaria (Lyngbye) Link 1833				+								
Sphacelariales												
Sphacelaria cirrosa (Roth) C.Agardh 1824						+			+			
Sphacelaria rigidula Kützing 1843	+											+
Chlorophyta												
Ulvales												
Ulva compressa Linnaeus 1753	+	+										
Ulva intestinalis Linnaeus 1753			+									
Ulva linza Linnaeus 1753		+		+						+		+
Ulva sp. Linnaeus											+	
Ulva lactuca Linnaeus 1753										+	+	
Ulva rigida C.Agardh 1823	+	+	+		+	+				+	+	+
Cladophorales												
Cladophora albida (Nees) Kutzing 1843									+			
Cladophora dalmatica Kützing 1843	+	+	+							+		+
Cladophora hutchinsiae (Dillwyn) Kützing 1845											+	
Cladophora prolifera (Roth) Kützing 1843										+	+	
Cladophora sericea (Hudson) Kützing 1843											+	
Bryopsidales												
Bryopsis hypnoides J.V.Lamouroux 1809	+	+	+									
Bryopsis pennata J.V.Lamouroux 1809	+	+										
Bryopsis plumosa var. *prolifera* Schiffner 1935		+										

In this study, a total of 48 epiphyte taxa were determined on the host species *C. fragile* subsp. *fragile*. *Rhodophyta* was the order that contained the most epiphyte taxa with 27 taxa (56.0%), *Chlorophyta* had 14 epiphyte taxa (29.0%) and *Ochrophyta* had 7 epiphyte taxa (15.0%) (Table 1 and Figure 2).

The number of epiphyte algae species on the host species *C. fragile* subsp. *fragile* was regularly decreased from winter to summer. Actually, the increase in the number of epiphyte species was expected in spring, but not in winter because in spring, there is an increase in the algae of the coasts of the Çanakkale Strait. However, most samples are identified in epiphytes. On the other hand, the results revealed that seasonal variation in epiphytism was quite evident (Figures 3 and 4).

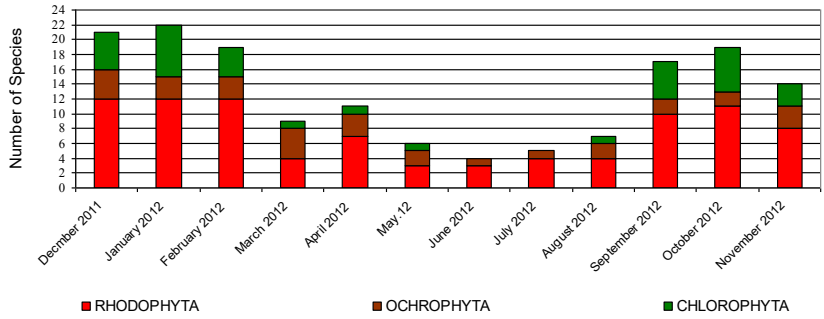

Figure 4. Monthly epiphyte distribution on the invasive *Codium fragile* subsp. *fragile*

Some of the algae (e.g. *E. siliculosus*) were dominant all year round, while others were observed for several months (Figure 5). The most commonly observed epiphytes were 12 species recorded for 5 months or longer. These were *C. virgatum* var. *implexo-contortum, P. fucoides, A. secundatum, C. capillaris, A. virgatum, C. acicularis, A. armata, C. rubrum* var. *barbatum,* from Rhodophyta, *E. siliculosus* and *P. fascia* from Ochrophyta and *U. rigida* and *C. dalmatica* from Chlorophyta (Figure 5).

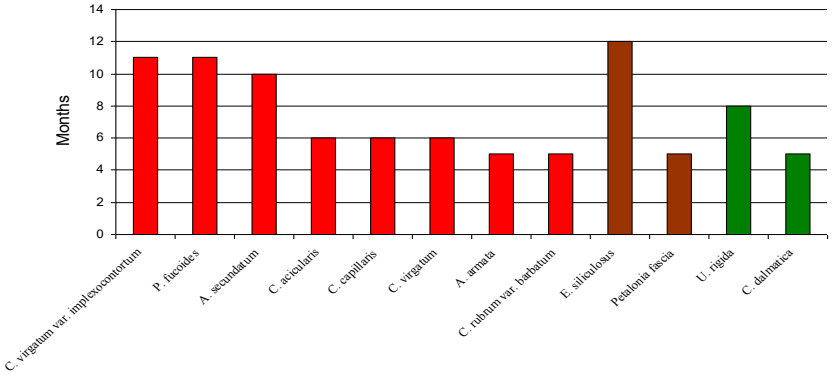

Figure 5. The number of months (more than five months) epiphyte species were observed (Red; Rhodophyta, Brown; Ochrophyta, Green; Chlorophyta species)

Though no single section of the thallus (bottom, middle, top) was preferred, epiphytes thrived especially in the middle and top of the thallus (Figure 6a, b). This may be due to the feathery structure of the bottom of the thallus (Figure 7).

The epiphyte species of two orders Ceramiales and Ulvales were conspicuously dominant. There were six taxa from *Ulva*, five taxa of *Ceramium* and *Cladophora* and three taxa of *Bryopsis.*

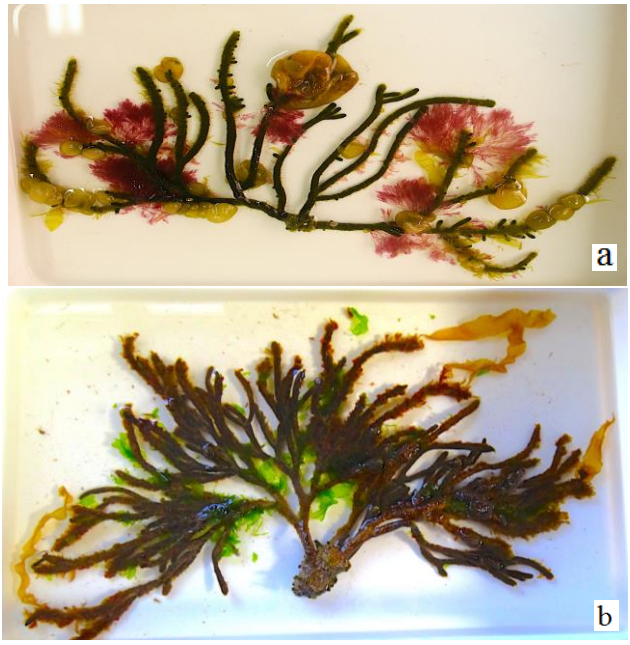

Figure 6a, b. The emplacement of epiphytes on *Codium fragile* subsp. *fragile*

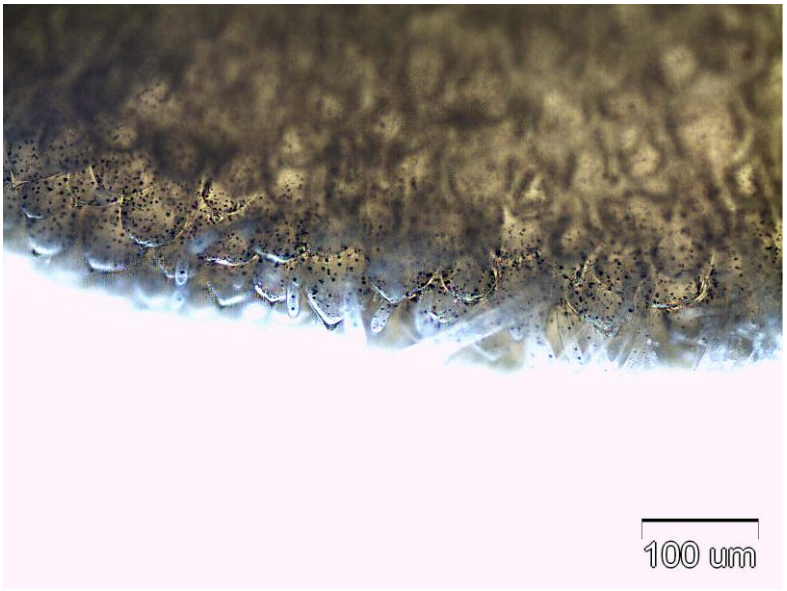

Figure 7. The feathery structure of *Codium fragile* subsp. *fragile*

Discussion

C. fragile subsp. *fragile* was widely spread along the Çanakkale Strait coasts especially in 2005-2009 (Erduğan *et al*. 2009). Between 2009 and 2013, it was recorded that the distribution area was narrower than that in previous years. In the present study, the epiphyte flora of *C. fragile* subsp. *fragile* was determined to have a great extent. Fifty epiphyte species were recorded on its thallus. In previous studies, Trowbridge (1999) recorded 17 taxa, Villasenor-Parada and Neill (2011) 9 taxa, Jones and Thornber (2010) 43 taxa. Species from *Ulva* and *Ceramium* were the most common species recorded in the epiphyte flora, similar to the study by Gonzales and Santelice (2004).

High density of the epiphyte taxa in the middle and top sections of the thallus was clearly noted. In some periods of the year, some epiphytes (e.g. *Cladophora* spp.) were recorded from the bottom sections. The structure of the thallus has a significant effect on this density increase. When the feathery structure with epiphytic appearance is viewed by microscope, it is formed by extreme growth of utricles producing a spongy structure with excess surface area. For this reason, epiphyte flora grows easily on the thallus (Gonzales and Santelice 2004; Jones and Thornber 2010). The middle and top sections of the thallus are loose and this is an advantage for epiphyte flora, which may explain the high density in these sections compared to the bottom section. The epiphyte density in the middle and top sections of *C. fragile* subsp. *fragile* was related to the morphological characteristics as in the studies of Villasenor-Parada and Neill (2011) and Schmidt and Scheibling (2006). The bottom section of the thallus has stiff tissue and therefore it is not easy for epiphyte spores to attach. This is a disadvantage for vegetating epiphyte flora. As reported by Schmidt and Scheibling (2006), we have determined a decrease in epipyte flora due to tissue aging and wave movements. Villasenor-Parada and Neill (2011) determined that epiphytes settled in the older bottom section of the thallus. In the present study, discrepancies between the middle and bottom sections of the thallus were determined. *E. siliculosus* was mostly determined at the bottom of the thallus, but generally, all of the species were found in the middle and top section of the thallus, probably due to the competition between epiphyte species and differences of biological features of the species. However, there is fully not valid and explanatory evidence as to why some species prefer different parts of the thallus.

Though red algae are known to have wide distribution in warm water, the number of epiphyte red algae in cold periods was quite high in this study. We expected that there might be a relationship between the quantity of the epiphytes and low water temperature (TÜİK 2011, 2012) (9.90 °C in December, 7.90 °C in January, 6.90 °C in February). The main reason for this assumption was the study by Jones and Thornber (2010), which stated that during the cold period, the epiphyte is protected by *C. fragile* subsp. *fragile*.

Kepez station was near the discharge field which positively affected the number of epiphytes. Therefore during the study, different epiphyte species was observed on *C. fragile* subsp. *fragile*.

It should not be ignored that the negative effects of global warming and associated problems for marine ecosystems may be transformed into positive effects for the epiphyte community. Housing a rich epiphyte flora (48 taxa) on thallus is an indicator of these advantages.

In previous studies, the total number of algae in the Çanakkale Strait has been determined as 421 (Aysel *et al*. 2000; Aysel *et al*. 2001; Taşkın *et al*. 2006; Erduğan *et al*. 2009; Taşkın *et al*. 2010; Taşkın 2012; Taşkın and Pedersen 2012). In this study, about 11.4% of these epiphyte taxa (48 taxa) was determined. This ratio could be evaluated as a significant level with respect to the *Codium* spp. which could be traditionally evaluated as a significant level for the species in the marine ecosystem due to its hosting of epiphytes.

Recently, possibly due to the effects of global warming, there have been rare and endangered taxa which are epiphytic on algae (Erduğan *et al*. 2017). Besides, as the epiphytic algae increases, the growth of the host algae (invasive and natural taxa) may be negatively affected. More researches are needed in order to uncover the effect of epiphytism. Particularly, anthropogenic effects on the distribution of rare epiphytic taxa should be primarily evaluated in future researches.

Çanakkale Boğazı kıyılarındaki (Marmara Denizi, Türkiye) istilacı *Codium fragile* subsp. *fragile* türünün epifit florasının mevsimsel değişimleri

Öz

Çanakkale Boğazı (Çanakkale Boğazı) kıyılarındaki istilacı *Codium fragile* subsp. *fragile* (Suringar) 1876, türünün epifit florasındaki mevsimsel değişiklikler bildirilmiştir. Örnekler Aralık 2011 ile Kasım 2012 arasında 0-1 m derinliklerden toplanmıştır. Tüm tallusun epifitleri incelenmiş ve 48 epifit taksonu tespit edilmiştir (27 takson Rhodophyta, 7 takson Ochrophyta ve 14 takson Chlorophyta). En sık görülen epifitler, Ceramiales (Rhodophyta), Ectocarpales (Ochrophyta) ve Ulvales (Chlorophyta) ordolarına aittir.

Anahtar kelimeler: *Codium*, invasif, epifit, Çanakkale Boğazı, Türkiye

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