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Research Article

Recent Plant Traits of *Caulerpa taxifolia* var. *distichophylla* in the Turkish Aegean Sea

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ABSTRACT

A research cruise was conducted along the Turkish coast of the Aegean Sea between May and August 2024 to assess the distribution and plant characteristics of *Caulerpa taxifolia* var. *distichophylla*. During the survey, samples of *Caulerpa taxifolia* var. *distichophylla* were identified at one station in August 2024 in Tatlısu Gulf, Altınova Bay, Balıkesir among 321 stations. Specimens were collected from one station located at a depth of 20 m. The density of shoots was estimated to be 344 m-2. Morphological analyses revealed that the specimens were characterized by a light green, delicate, feathery thallus with thin prostrate stolons and erect fronds with pinnae. The erect fronds ranged in height from 2.10 mm to 105 mm, with a mean of 46.51 ± 1.4 mm, and in width from 1.30 mm to 4.10 mm, with a mean of 2.68 ± 0.003 mm. A significant relationship was found between the number of pinnae and frond length, with a slope of approximately 2.15. The relationship between frond length and width followed a curved-linear (logarithmic) model, with a slope of approximately 0.515. This study provides the latest comprehensive biometric data on *C. taxifolia* var. *distichophylla*, which has spread to the north of the Turkish Aegean Sea after its in the Gulf of Izmir in 2011, and contributes to the understanding of its invasive potential and ecological impacts in the region.

Keywords: *Caulerpa taxifolia* var. *distichophylla*, biometry, invasive species, Turkish Aegean Sea

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INTRODUCTION

The Mediterranean basin, especially the eastern basin and seas such as the Levant and the Aegean, has become a hotspot for the introduction and invasion of exotic species (Zenetos & Galanidi, 2020; Çinar et al., 2021). Invasions of organisms can threaten the status of species found in natural communities (Ceccherelli & Cinelli, 1998). Fish, benthic fauna and macroinvertebrates represent the most intentionally and accidentally introduced species in the eastern Mediterranean. Most of the invaders are species of Indo-Pacific origin and temperate and tropical specimens (Çinar et al., 2021). The invaders affect the already established Mediterranean ecosystem and change the ecosystem in time and space. Their density and population dynamics of seaweeds guide to understand the interaction with strengths of variation in their life history between the isolated and mixed populations (Schemske et al., 1994). Clonal vegetative growth is common and induces highly populated aggregations, foraging and movement to suitable adjacent space, followed by rapid rates of expansion and a reduced risk of mortality (Wright, 2005).

Ninety-eight species of marine algae have been introduced into the Mediterranean Sea. Nine species were invasive and had ecological and economic impacts (Siguan & Ribera, 2002). These nine species were *Caulerpa taxifolia*, *Caulerpa racemosa*, *Sargassum muticum*, *Lam-*

inaria japonica, *Asparagopsis armata*, *Undaria pinnatifida*, *Womersleyella setacea*, *Acrothamnion preissii* and *Lophocladia lallemandii*. Fifty species have increased in number in the last 20 years. In the western Mediterranean, sixty-seven species were non-indigenous species with locality of Japanese or Pacific waters (Siguan & Ribera, 2002). Twenty-nine non-indigenous species (Red Sea or Indian Ocean origin) were found in the eastern basin (Siguan & Ribera, 2002). Zenetos & Galanidi (2020) updated the non-indigenous seagrass species found in the Mediterranean. Cinar et al. (2021) revised the phytobenthos in the Turkish waters of the eastern Mediterranean. Out of a total of 253 alien species compiled by Çinar et al. (2021) for Turkish Aegean waters, 28 belonged to phytobenthos.

The genus *Caulerpa* has some species having invasive feature in the Mediterranean and other seas. The presence of the efficient mechanisms of plant tissue regeneration makes the genus *Caulerpa* highly invasive and adaptive to dispersal and establishment of new population (Welling et al., 2009). There is no information on overall potential grazers of *Caulerpa taxifolia* var. *distichophylla* in the Mediterranean, but a gastropod, *Bittium reticulatum* has been observed on *C. taxifolia* var. *distichophylla*, presumably feeding on it. Besides, Mutlu et al. (2022) observed a large-sized non-indigenous invasive gastropod, *Conomurex persicus* grazing on fronds of *C. t.* var. *distichophylla* in Antalya Gulf, Turkey.

The Chlorophyta *Caulerpa taxifolia* var. *distichophyla* is a taxonomically recognized variant of *Caulerpa taxifolia* native to southwestern Australia that has recently emerged in the Mediterranean region (Tsirintanis et al., 2022). This variety was first documented in Syria in 2003 (Bitar et al., 2017) and later in Turkey in 2006 (Cevik et al., 2007, misidentified as *C. taxifolia*). Later, the species was identified in Sicily in 2007, where significant drift biomass was observed along the coastline (Cormaci & Furnari, 2009; Meinesz et al., 2010; Jongma et al., 2013). The invasive Chlorophyta rapidly expanded its range in the central and eastern Mediterranean (Musco et al., 2014; Aplikioti et al., 2016; Picciotto et al., 2016; Ellul et al., 2019a). The species was colonized on the bottom of dead *Posidonia oceanica* matte in Sicily (Musco et al., 2014). Maritime traffic and global warming are likely to facilitate the further spread of *C. taxifolia* var. *distichophylla* in the Mediterranean (Mannino et al., 2019).

The distribution history of the species in Mediterranean and Turkish waters is as follows: *Caulerpa taxifolia* var. *distichophylla* was first reported from Syria in 2003, followed by Turkey in 2007 (Cevik et al., 2007). The species was then chronologically observed from waters of Sicily (Cormaci & Furnari, 2009; Meinesz, Chancollon & Cottalorda, 2010; Jongma et al., 2013; Musco et al., 2014), Cyprus (Çicek et al., 2013; Tsiamis et al., 2014; Aplikioti et al., 2016), Malta (Schembri et al., 2015), Rhodes (Aplikioti et al., 2016), Libya (Shakman et al., 2017), Lebanon (Bitar et al., 2017) and Tunisia (Chartosia et al., 2018). In Turkish marine waters the species occurred in Iskenderun Bay (Cevik et al., 2007), in Izmir Gulf, Aegean Sea (Turan et al., 2011), Antalya Bay (Mutlu et al., 2022), Alanya Bay, Sea of Marmara (Taşkın et al., 2023). Mutlu et al. (2022) documented the species' seasonal and depth-related plant characteristics and competition with *C. prolifera*. Some alien macrophytes including *C. taxifolia* var. *distichophylla* occurred interestingly in some hydrothermal systems of Aeolian Islands, Tyrrhenian Sea, Italy where occurrence of *Caulerpa cylindracea* Sonder, 1845, *Caulerpa taxifolia* and *Halophila stipulacea* (Forsskal) Ascherson, 1867 as well was reported by Gaglioti & Gambi (2018).

Understanding of invasion with mechanisms and succession of marine organisms can help researchers to regulate and conserve marine organism population by knowing biotic and abiotic characteristics of ecosystem, disturbance regimes and life history traits of invaders (Sol et al., 2012). Therefore, the present study was aimed to provide initial assessment of the invasion of *C. taxifolia* var. *distichophylla* with an emphasis on the morphometric characteristic from the Turkish Aegean Sea water.

MATERIAL AND METHODS

Specimens and environmental data acquisition

A research cruise conducted from late May to late August 2024 (Figure 1b) aimed to assess the distribution and species composition of submerged vegetation along the Turkish coast of the Aegean Sea. Some seagrasses (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera* spp, and *Halophila stipulacea*) and many species of seaweeds were recorded and their distribution will be detailed in a later paper in preparation. A total of 321 survey stations were established during daylight hours (Figure 1). In addition, a detailed transect in Altınova Bay extended from the shoreline to deeper waters and included four different bottom depths of 10, 15, 20, and 30 m to check the occurrence of the species in the vicinity, as specimens of *Caulerpa taxifolia* var. *distichophylla* were identified at one station in Tatlısu Gulf, Altınova Bay, Balıkesir Province, Turkey.

Specimens of *C. taxifolia* var. *distichophylla* were collected from a station (designated as A20) situated at a depth of 20 meters (Figure 1). SCUBA divers meticulously gathered running stolons from the specimens within a defined 0.4 x 0.4 m quadrant. This sampling procedure was applied for all 321 stations located between 7 m and 30 m by SCUBA diving conducted at 10, 15, 20 ad 30, and sometimes at 5 m where the bottom was suitable for the ship security.

The material examined comprises unpreserved specimens, including 15 stolons and 55 fronds. Of these, 54 fronds were used for the purpose of counting the pinnae of the fronds. The specimens were collected at locations with the coordinates 39.21621 N and 26.70309 E, at a depth of 20 m by SCUBA diving. The collection was made at 17:29 by Yaşar Özvarol and Barış Akçalı on 9 August 2024.

On board the R/V "Akdeniz Su", after sorting the materials obtained by SCUBA divers the tangled fronds, stolons, and rhizoids of the species were untangled in preparation for biometric measurements (see Figure 5). Measurements were performed on fresh, unpreserved specimens.

During the shipboard sampling, physicochemical (temperature, salinity, pH, oxygen, and total suspended solids) and optical parameters (Secchi disk depth, photosynthetic active radiation, PAR)

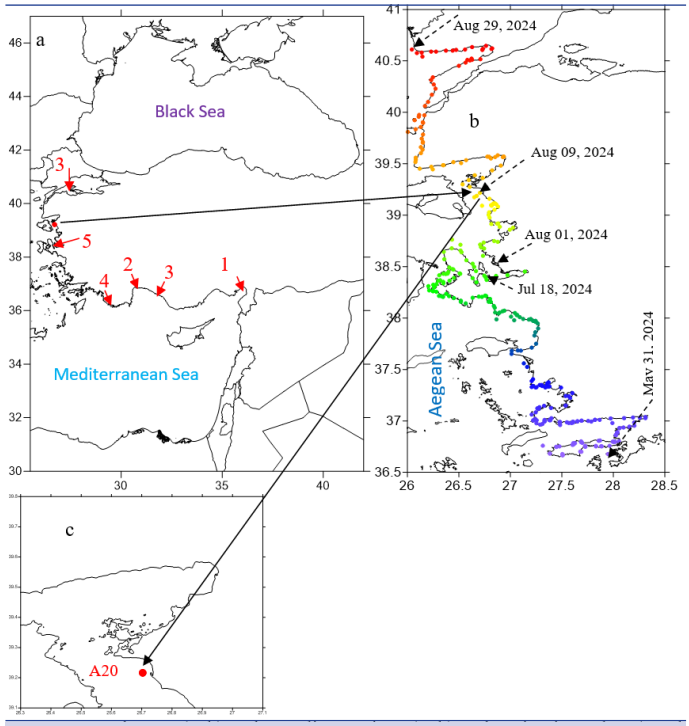

Figure 1. Study area (a, b) and sampling stations (o, b) and station in Tatlısu (Freshwater) Gulf, Altınova, Balıkesir, Turkey where *Caulerpa taxifolia* var. *distichophylla* occurred (o, c). Arrow (a) shows arrival time during the present study (b) and locations and citation number of previous records of the species along the Turkish waters: 1: Cevik et al. 2007, 2: Mutlu et al. (2022), 3: Taşkın et al. (2023), 4: Jongma et al. (2013) and 5: Turan et al. (2011). Colored stations (b) were purposed to show location in T-S diagram (see Figures. 2, 3).

were measured from surface and near-bottom waters. Water samples were collected on board using a 5-l Niskin bottle at surface and near-bottom waters. The physicochemical parameters were measured using multiparameter probes (AZ Combo, model 84051). PAR was measured using an ampoule (Spherical SPQA-4671 model, Li-Cor Inc.) and a multiparameter recorder (LI-1400 model, Li-Cor Inc). PAR ampoule was casted from the surface (on air and then 20-30 cm below surface) to the near-bottom depth down to max 50 m which was the length of the PAR cable. The profiled PAR values were then converted to percent values for each water depth in referring sea surface value as 100% at each station. The light extinction rate (Kd) was then calculated. These all environmental measurements were deployed at all 321 stations.

Biometrical measurements

The biometry was characterized by morphometry (frond length: FL, frond widest width: FW, bud length: BL, and bud widest width: BW) of the samples (see Figure 5 for details of the measurements). The morphometric parameters (length and width) were measured using a micrometer caliper. Population parameters were the density (number of shoots/m^2 and per quadrant; TS and for buds, BNo), number of fronds per stolon (FNo), number of stolons (#S), number of paired pinnae and ratio of number of pinnae per rachis and per 1 cm of rachis (#F).

A total of 15 runners were measured. The number of pinnae per frond was counted from a total of 36 fronds. The number of buds

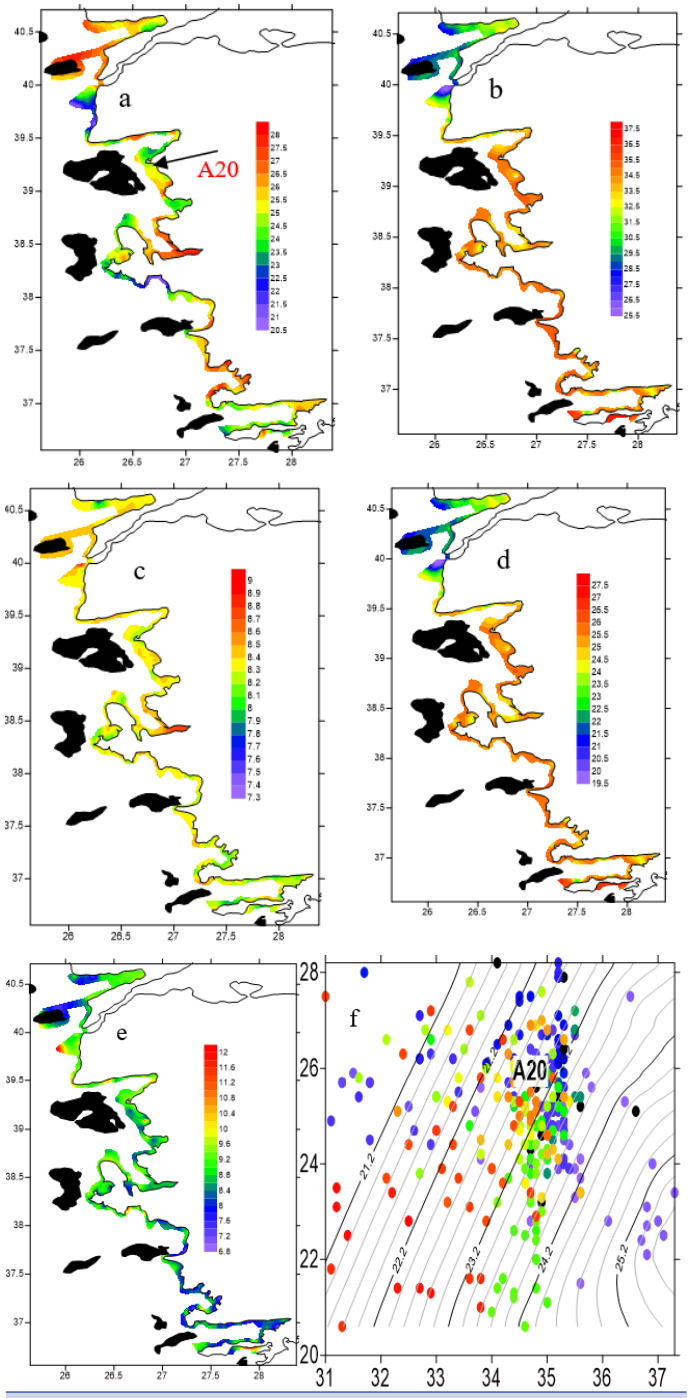

Figure 2. Sea surface water temperature in oC (a), salinity in ppt (b), pH (c), dissolved oxygen in mg/l (d), total suspended matter in mg/l (e) and T-S diagram with isoclines of density, σt at the stations colored with geographical latitudes (f) (see Figure 1b for the station locations).

on the frond was counted by eyes and measured for biometric parameters using a micrometer caliper. Individual weight could not be measured on board since onboard balance which is not affected from the rock and movement of the ship was required. This would be purposed for later laboratorial work at land.

Pearson correlation was used to measure the degree of relationship between number of pinnae and frond length, and between FW (widest width) and FL. These relationships were regressed linearly and logarithmically, respectively. The Student's t-test (Ho: r=0) was used to test the significance of the correlation coefficients at $p < 0.05$.

RESULTS AND DISCUSSION

Study environment

During the survey, sea surface temperature varied between 20.5 and 28.5 °C in the whole study area, while near-bottom waters had a range of water temperature from 18 to 28 °C. Salinity tended to have a decreasing gradient from south to north in the study area. This was more pronounced in the near-bottom waters. Oxygen content and pH increased slightly from south to north in the study area, in contrast to total suspended solids (Figures 2-3).

Cold water of the Black Sea through the Sea of Marmara occurred in the Dardanelles Strait exit in the Aegean Sea, but warmer water occurred in northern part of the Aegean Sea. In this specific region with the effect of river Meriç located in the northernmost study area, the less saline water occurred as compared to the southern part of the study area (Figures 2, 3).

At station A20, sea surface temperature was about 25.5 °C and sea surface salinity was 34.6 (Table 1, Figures 2-3). Sea surface pH was 8.26 and near bottom water pH was 8.31 at A20. Dissolved oxygen was high in both waters, where total suspended solids were measured at around 25.5 mg/l (Table 1).

Regarding the sea surface water, the TS plot showed that the stations in Altınova Bay had similar temperatures, but A20 (σt=23.0) was different from the other stations in the bay. Like the sea surface values, the near-bottom water density at A20 was estimated to be σt=23.4 (Figures 1-3).

The Secchi disk read 18 m at A20, which measured PAR at 17:29 on August 9, 2024. PAR values were measured in units of µmol photons/cm^2/s. However, the percentage of light reaching the near-bottom waters was similarly estimated to be ~ 20% of the surface PAR (Figure 4). Kd was estimated to be 0.069 (22.83%) per unit depth (Figure 4b).

Species traits

Description: The *Caulerpa* specimens from the Turkish Aegean were identified as *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini, 2013 based on their morphological characteristics. The specimens were characterized by a light green thallus, feathery and delicate, with narrow prostrate stolons and erect fronds bearing pinnules (Figure 5). The stolons were slender with short rhizoidal stems (Figure 5). The erect fronds were simple, ranging from 2.10 to 105 mm with an average length of 46.51±1.4 mm. The erect fronds were observed to be terete at the base and compressed towards the apex, bearing distichous (rarely tristichous) and closely arranged (but never overlapping) pinnules in one plane. The pinnules themselves were noted to be compressed (Figures 5, A1). There was a significant correlation between the number of pinnules and the length

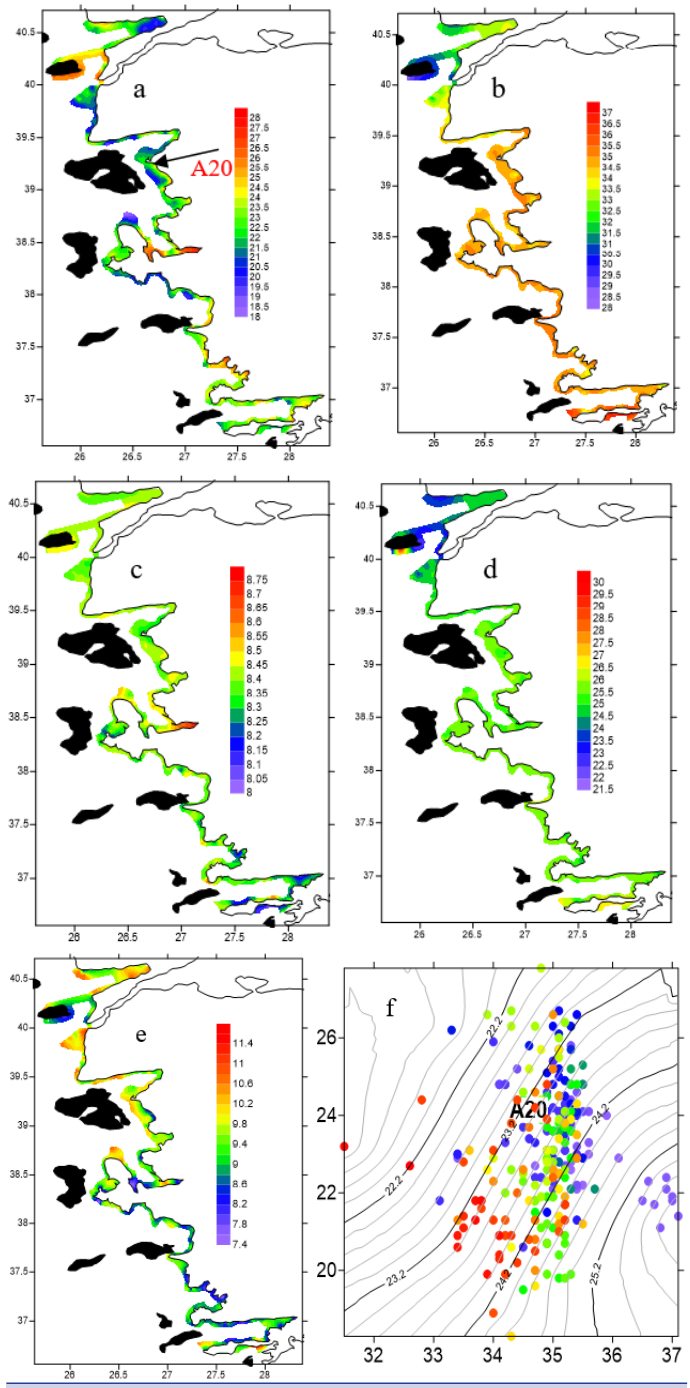

Figure 3. Near-bottom water temperature in oC (a), salinity in ppt (b), pH (c), dissolved oxygen in mg/l (d), total suspended matter in mg/l (e) and T-S diagram with isoline of density, σt at the stations colored with geographical latitudes (see Figure 1b for the station locations).

of the frond. The slope of the relationship was approximately 2.15. The number of pinnae showed considerable variation with a mean of 106. The number of lateral branchlets (pinnules and ramuli) per 1 cm frond length showed considerable variation, with values ranging from 1.24 to 7.14 branchlets for the main frond and from 0.57 to 5.20 for the buds (Figure 7). However, the mean values for both frond types were similar. The relationship between frond length and width was modeled using a curved-linear (logarithmic) function (Figure 8). The slope of the relationship was estimated to be approximately 0.515.

Remarks: *C. taxifolia* var *distichophyla* has a similar identical structure to *Caulerpa mexicana* and both *C. mexicana* and *C. taxifolia* have the type of distichous frond but the *C. mexicana* has a type between clavate; club-shaped (wider than tip parts of ramuli) falcate ramuli and *C. taxifolia* has variant of falcate; sickle-shaped ramuli. The basal part of ramuli of both species was contracted, but it is not contracted for the *C. taxifolia* var *distichophyla*. For *C. taxifolia*, the maximum frond length ranged from 16.6 to 18.1 cm and width from 13.3 to 18.5 mm. The number of branchlets varied between 6-18 and 156-210 with an average of 76 to 94 and 10-12 per 1 cm frond length. For *C. mexicana*, maximum frond length ranged from 10 to 12.5 cm and width from 7 to 9 mm. The number of branchlets varied from 10-28 to 120-194 with an average of 12-15 to 20-27 with 16-18 per 1 cm frond length and the slope of the relationship between frond length and the number of branchlets was estimated to be less (0.81-0.97) than 1 for *C. taxifolia* and more (1.49-1.73) than 1 for *C. mexicana* (Fig. A2) (Mutlu et al., 2024). The number of branchlets of *C. taxifolia* varied between 6-18 and 156-210 with an average of 76 to 94 and 10-12 per 1 cm frond length. The slope of the relationship between frond length and number of branchlets was estimated to be less (0.81-0.97) than 1 for *C. taxifolia* and more (1.49-1.73) than 1 for *C. mexicana* (Fig. A2) (Mutlu et al., 2024).

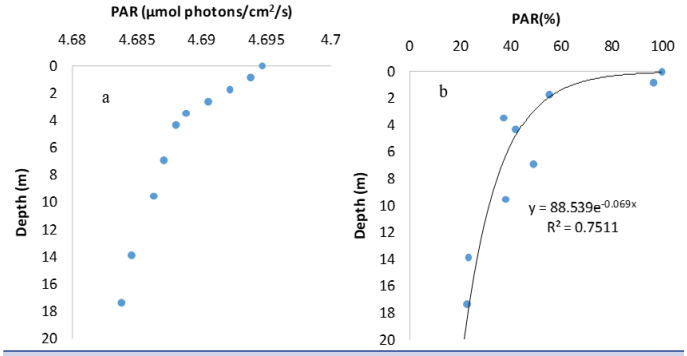

Figure 4. PAR profile in µmol photon/cm2/s (a) and percent based on sea surface PAR (b) along the water depth from the surface to bottom at 20 m.

Distribution: In addition to the previous record in the Sea of Marmara, Iskenderun Bay, İzmir Bay and Antalya Bay in the Levant Sea of the Turkish coasts (Figure 1), one site was inhabited by specimens of *Caulerpa taxifolia* var. *distichophylla* in shallow and coastal waters of the Aegean Sea (Altınova Bay, Turkey). The distribution occurred at 20 m.

Biometry

Specimens of *Caulerpa taxifolia* var. *distichophylla* at the station were found in runner stolon organization attached to the bottom substrates (Figure 5). Such occurrence was identical to the species on the bottom, unlike *Caulerpa mexicana* and *Caulerpa taxifolia* (Mutlu et al., 2024) with highly elongated stolon throughout the bottom. The biometric parameters of the species were recognized as density and morphometric variables to characterize the recent measurements made from the live specimens in the Turkish waters of the Aegean Sea (Table 2).

Frond length (FL) varied between 2.10 and 105 mm with a mean of 46.51±1.4 mm and frond width between 1.30 and 4.10 with a mean of 2.68±0.003 mm (Table 2). Turan et al. (2011) characterized biometry of *C. taxifolia* collected from the Izmir Gulf, Aegean Sea as follows: The mean stolon diameter, width of fronds, maximal length of pinnules and width of pinnules of a total of 50 *C. taxifolia* samples were 1.6±0.5 mm, 9.9±2.3 mm, 5.4 ±1.3 mm and 1.1 ±0.1 mm, respectively.

Table 3. Basic statistics of number of pinnae (ramuli) per 1-cm frond length for the main fronds, and for the buds (BP#/BL).

	FP#/FL	BP#/BL
Min	1.24	0.57
Max	7.14	5.20
Mean	2.39	2.27
SD	0.77	0.96

Table 1. Physicochemical properties of the sea surface and near-bottom waters at station A20.

Depth (m)	Secchi	T (°C)	S (ppt)	pH	TSM (mg/l)	DO (mg/l)	σ_t
0.5		25.5	34.7	8.26	25.6	9.4	22.9636
20	18	23.7	34.6	8.31	25.5	9.5	23.4286

Table 2. Depth-wise distribution of morphometrical and density variables of *Caulerpa taxifolia* var. *distichophylla* (mean±SD). FL: frond length in mm, FW: frond width in mm, BL: bud length in mm, BW: bud width in mm, LA: leaf area in m^2 per quadrant, TS: shoot density in shoots/m^2, and LAI: Leaf area index (m^2/m^2).

FL	FW	BL	BW	LA	TS	LAI
46.5±1.4	2.68±0.003	29.6±1.4	2.29±0.68	$1.36*10^{-4}$±$5.2*10^{-6}$	344±0	0.165±0

The length of the budding frond ranged from 4 mm to 266 mm and the width ranged from 0.8 mm to 4.0 mm (Table 2).

Shoot density was calculated as 344 shoots/m^2 and leaf area index as 0.165 at A20 (Table 2).

Budding

The stolons of the species appeared in a continuous line formed by the bud (Figure 5). Of the total specimens examined in the present study area, the number of fronds per stolon varied between 1 and 7 fronds, with a maximum of about 6 fronds. The maximum number of buds was also about 6 buds per frond (Figure 6). 18 out of 54 fronds were budded with a percentage of 33%. Multiple budding occurred rarely on one main shoot of the specimens (Figure 6).

Interbiometry relationship

The number of lateral branchlets (pinnalus, ramuli) per 1-cm frond length varied between 1.24 and 7.14 branchlets for the main frond, and for the buds, less than that of the main frond, varying between 0.57 and 5.20, but the average values of both frond types were similar to each other (Table 1).

Figure 5. *Caulerpa taxifolia* var. *distichophylla* appearance of entire specimens (a and b) and close-up view of fronds (c and d). F: frond, St: stolon, Rh: rhizoid, FL: frond length, FW: frond width, P: pinnae, R1: rachis 1, and R2: rachis 2. B is bud. Dashed line arrow is remark.

The number of pinnae-frond length relationships was significantly established for the species with a correlation of r=0.9353 (p= 9.0305*10^{-25}). The slope of the relationship was approximately 2.15. The number of pinnae varied between 10 and 260, with an average of 106 (Figure 7).

The relationship between frond length and width was fitted in a curved-linear (logarithmic) model (r= 0.5842, p= 2.163*10^{-5}) (Figure 8). The slope of the relationship was estimated to be approximately 0.515.

The Aegean Sea, particularly the Turkish waters were influenced at south by the Mediterranean Sea and at north by Black Sea through the straits system (Özsoy & Latif, 1996). This peculiarity induced a variety of marine environments in the Aegean Sea and a wide range measurement in the physicochemical and optic pa-

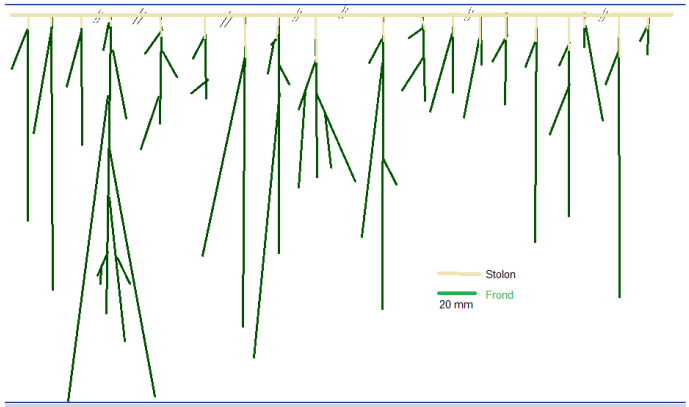

Figure 6. Schematized frond budding (see Fig. 5 for real appearance of budding reticulated with branches) of *Caulerpa taxifolia* var. *distichophylla* found at 20 m. Light green is frond (scale: 2 cm), beige is stolon unscaled. Diagonal break line denotes fronds belonging to each stolon.

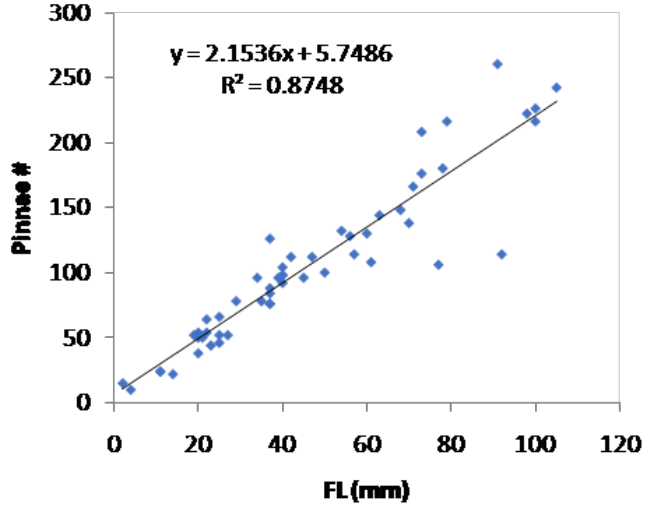

Figure 7. Relationships between frond length and number of pinnae (#P).

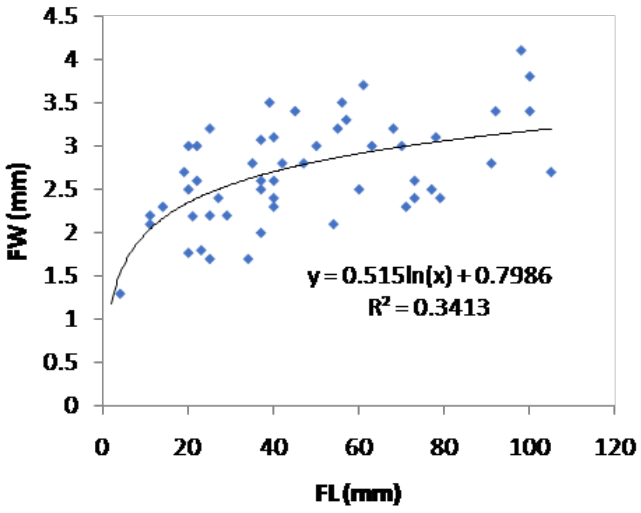

Figure 8. Relationships between frond length and number of pinnae (#P).

rameters (Uçkaç, 2005). Besides, the present entire study area was anthropogenically impacted by the highly populated cities along the coast through the rivers (Çulha et al., 2022). For instance, Izmir Gulf, Yelekçi et al. (2021) measured extreme nutrients, chl-*a* and Çinar et al. (2012) high total carbon content in the sediments. Mutlu (2021) reported hypoxia in the water of the Izmir Gulf.

In line with Musco et al. (2014), we hypothesize that *C. taxifolia* var. *distichophylla* must be considered potentially invasive and that the *Caulerpa taxifolia* species cluster in general appear to possess ecological traits (Andreakis & Schaffelke, 2012) that make the species particularly adapted for rapid colonization of the shallow-water Mediterranean ecosystem.

After Turan et al. (2011) recorded the *Caulerpa taxifolia* var. *distichophylla* for the first time in the Aegean Sea, the present study on second occurrence of the species expanding to the north in the Turkish Aegean Sea provided significant insights into the morphological and biometric characteristics of this invasive species. The findings indicated that this variant exhibited a delicate, feather-like thallus structure, characterized by narrow prostrate stolons and erect fronds with distinct pinnules. The research highlighted the species' adaptability and potential for rapid colonization in the Mediterranean ecosystem, underscoring its invasive nature. The biometric data collected, including frond length, width, and the number of pinnae, established a foundational understanding of the species' growth patterns and density in its new habitat.

Caulerpa taxifolia var. *distichophylla* was found at one station at 20 m in Altınova Bay among 321 stations visited during the survey (Figure 1). During the survey *Caulerpa mexicana* and *Caulerpa taxifolia* (Figures A1, A2) were found at two stations (10 m and 15 m) in Izmir Gulf and four stations (10, 15, 20 and 30 m) in Dikili Bay, respectively (Mutlu et al., 2024). In Turkish waters, *Caulerpa taxifolia* var. *distichophylla* has been reported for its occurrence in Iskenderun Bay, Kaş, Antalya Bay in the Levant Sea, and the Sea of Marmara (Figure 1a) (Mutlu et al., 2022; Jongma et al., 2013; Taşkın et al., 2023). The present occurrence of the species filled the gap for the records between eastern Mediterranean Sea and Sea of Marmara. In Cyprus, *C. taxifolia* var. *distichophylla* was found both in very shallow waters and at 42 m and 18 m depth on the island of Rhodes (Table 4).

In particular, the relationship between frond length and frond width and the relationship between frond length and the number of lateral branchlets showed a difference in the relationships among the congeneric species. In the present study, three congeneric species were found, and they showed a significant difference in the relationships among the species (Figure A2). Regarding the relationship between frond length and number of lateral branchlets, *Caulerpa taxifolia* var. *distichophylla* had a slope greater than 2, *C. mexicana* greater than 1 but less than 2, and *C. taxifolia* less than 1 (Figure A2).

The frond length of *C. taxifolia* var. *distichophylla* was higher than *C. mexicana* and *C. taxifolia* at maxima and on average (Fig. A2, Mutlu et al., 2024). Frond width was narrower than that of the other two species. Frond length was measured around the maximum, like other Mediterranean sites (Table 4). Frond width was narrower in the Levantine basin than in the western Mediterranean (Table 4).

The shoot density of *C. mexicana* varied between 469 shoots/m^2 (at 15 m) and 630 shoots/m^2 (at 10 m), and *C. taxifolia* between 343 shoots/m^2 estimated at 15 m and 1397 shoots/m^2 at 30 m. The average shoot density of *C. taxifolia* var. *distichophylla* was lower than that of the other two species (Mutlu et al., 2024). The shoot density estimated for the present study was found to be lower than the range of the results obtained from the other sites (Table 4). However, the biometric measurements had similar range as compared to that in the other Mediterranean location, but not in Sea of Marmara (Table 4). This density and morphometric difference could be due to newly establishment of the species in the Turkish Aegean Sea and Sea of Marmara.

However, exclusive biometrics and plant characteristics were not supported to the knowledge of the species from the previous publications from the Turkish waters, including the occurrence in the Turkish Aegean Sea. Although the specimens were found in only one station, this biometric information could still be useful set. Further future studies will help to understand the dynamics of *C. taxifolia* var. *distichophylla* in the Aegean Sea between the Mediterranean Sea and the Sea of Marmara.

The significant correlation between frond length and the number of pinnae, and frond width along with the observed relationships between frond dimensions, contributed to the existing body of knowledge regarding the non-broad-scaled ecological dynamics of invasive marine species and helped to identify of three congeneric species of *Caulerpa*. Furthermore, the study emphasized the importance of ongoing monitoring and research to assess the ecological impacts of *C. taxifolia* var. *distichophylla* on native marine communities.

Table 4. Plant traits (TS: shoot density in shoots/m^2, LAI: leaf area index in m^2/m^2, FNo: number of lateral branchlets per 1-cm frond length, RL: rachis length in mm, FL: frond length in mm, FW: frond width in mm, RhL: rhizoid length in mm, Cov.: surface coverage on ground in m^2, D: bottom depth in m and bottom and substrate type) and distribution of *C. taxifolia* var. *distichophylla* in seas of the Mediterranean basin.

TS	LAI	FNo	RL	FL	FW	RhL	Cov.	D	Loc.	C#
		1.3		25–100	1.5–4.2	1–4		42*	Cyprus	1
		1.3		25–100	1.5–4.2*	1–4		18*	Rhodes	1
				< 60-70		16/18			Sicily	2
				< 60-70		16/18			Sardine	2
				80-100				sandy	Sicily	3
				150				shaded	Sicily	3
				35*, 20				shaded by *P. oceanica*	Sicily	3
				200 vs. 80,					Sicily	3
				140-160				sheltered from the waves, "matte"	Tunisia	4
276.3 (± 51.21							125	4–6	Malta	5
				5.90–170.33	3.60–1.25	0.63–3.48	0.37	14–15	Malta	5
91–972				12.3–41.8*				40*	Malta	6
972 N/m*										6
				100				3m,snady, rocky	Sicily	7
				<100				2, rocky	Sicily	7
				< 50				Out shipwreck	Sicily	7
				100–150				In shipwreck	Sicily	7
				<100				1-2, rocky	Sicily	7
				50-100				4-5m, rocky, edge of *Posidonia*	Sicily	7
				50-100				9-10, border *C. nodosa*	Sicily	7
				30–40	2–4	3			Sicily	8
<100-600	0.0010-0.0084*		5.8-8.1, 16*	24.7-48.4, 40	1.03-1.74*			5-30	Antalya, TR	9
				40	2.0-3.0	4-5		4	Sea of Marmara	10
344	0.165	1.24-7.14, 2.39 0.57-5.20*, 2.27*		2.1-105, 46.5	1.3-4.1, 2.6*	3-80, 20,12 1.3-30*, 9.4*		20	Aegean Sea, TR	PS
*max	*mean	*for bud frond	*max	*RL+FL	*mean	*for bud frond		*max depth		

C#: 1: Aplikioti et al., 2016, 2: Di Martino, Stancanelli & Cantasano, 2018, 3: Musco et al., 2014, 4: Chartosia et al., 2018, 5: Schembri et al., 2015, 6: Ellul et al., 2019b, 7: Mannino et al., 2019, 8: Picciotto et al., 2016, 9: Mutlu et al., 2022, 10: Taşkın et al., 2023.

CONCLUSION

The species has been spreading toward the north where the eutrophic regions are available, which can threat Sea of Marmara and Black Sea when invaded by the specimens in the future. In the central Mediterranean the species had higher length, width and shoot density of the frond as compared Levantine and Ae-

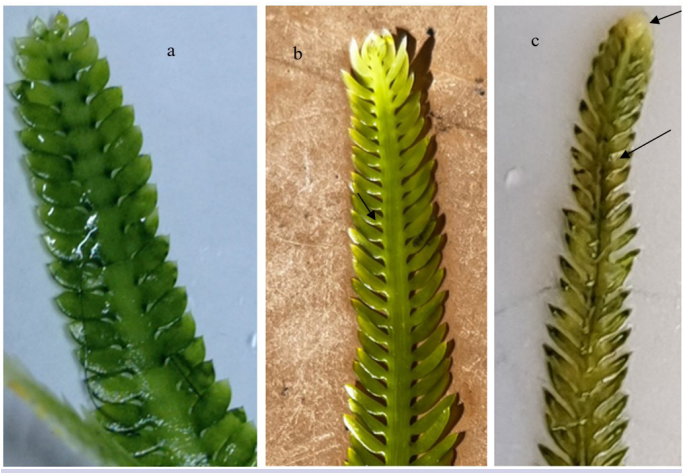

Figure A1. Fronds, rachises and pinnae of *Caulerpa mexicana* (a), *C. taxifolia* (b) and *C. taxifolia* var. *distichophylla* (c) from the Turkish Aegean waters obtained during the present study (Mutlu et al., 2024).

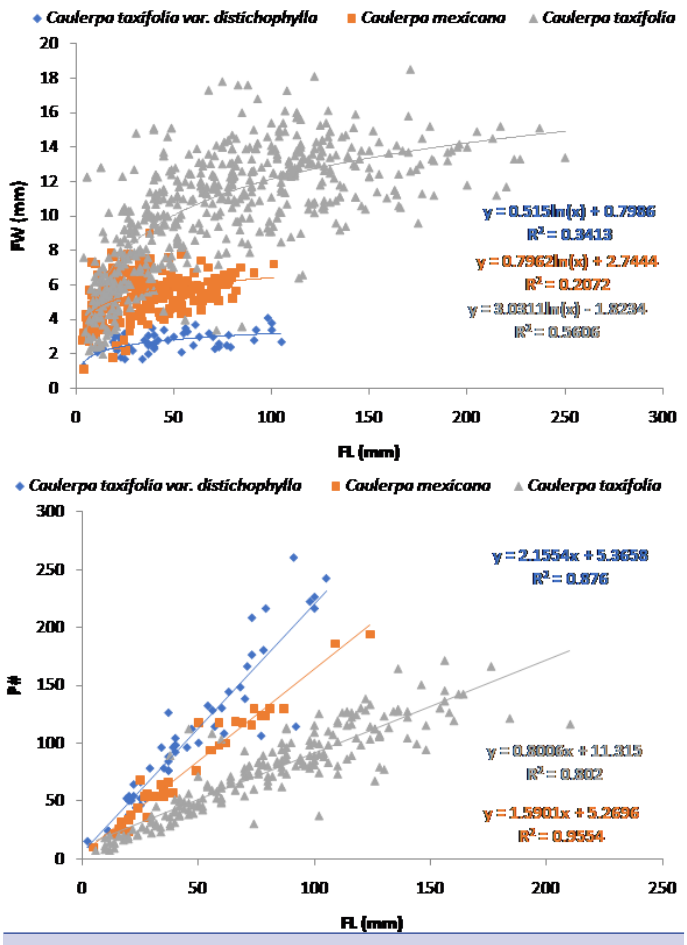

Figure A2. Frond length (FL)-width (FW) and frond length (FL)-number of pinnae (P#) of *Caulerpa mexicana*, *Caulerpa taxifolia* and *C. taxifolia* var. *distichophylla* specimens collected during the present study in the Turkish coast of the Aegean Sea (Mutlu et al., 2024).

gean specimens. Given the potential threats posed by invasive species to local biodiversity, this research served as a crucial step in understanding the implications of biological invasions in the Mediterranean region, particularly considering changing environmental conditions and human activities that may facilitate further spread. Overall, the findings underscored the need for effective management strategies to mitigate the impacts of invasive marine species on fragile ecosystems. Further studies are needed to study spreading of the species and population dynamic of species with compressive environmental parameters such as contents of water nutrients and sedimentary variables.

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Compliance with Ethical Standard: The authors declare that all applicable guidelines for sampling, care, and experimental use of animals in the study have been followed.

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