Opportunistic seaweeds replace Cystoseira forests on an industrialised coast in Cyprus

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Abstract

Seaweeds are affected by humans worldwide, although no studies have assessed this in Cyprus. The Water Framework Directive requires ecological assessments of European coastal waters with biological indicators. We investigated macroalgal community metrics in the upper subtidal across ca 10 km of shoreline, encompassing undeveloped areas with limited human access as well as the most industrialised and impacted coast of Cyprus (Vasiliko Bay). Quadrats (20 x 20cm) were used to survey the algal communities in summer 2012 and spring 2013. Of the 51 taxa, we recorded, Cladophora nigrescens and Laurencia caduciramulosa (a non-native species) are new records for Cyprus. Brown algae of the genus Cystoseira, e.g., C. barbatula, formed dense forests covering rocky substrata on shorelines with limited human access. Cystoseira spp. decreased in abundance around bathing waters and was very rare in heavily industrialised parts of the bay. In impacted areas, fleshy and filamentous opportunistic species such as opportunistic Ulva and Chaetomorpha species with lower biomass than perennial species, proliferated in spring. The Ecological Evaluation Index (EEI-c) we used was a robust biotic index reflecting anthropogenic stress. Without improved management, the Marine Strategy Framework Directive targets may not be met on some coastlines of Cyprus since seaweed forests are in decline and are further threatened by imminent development.

Keywords: Ocean sprawl; eastern Mediterranean; macroalgae; biological indicators; Ulva; ecological assessment; Marine Strategy Framework Directive.

Introduction

The human ecological footprint is growing worldwide, and this is especially obvious on rocky shores (Halpern et al., 2008). Although the coastal zone is less than 3% of the Earth’s surface, it is home to about 60% of the world’s population, and this is expected to rise to 80% by 2050 (Hyun et al., 2009). The policy responses to this reality in Europe are the Marine Strategy Framework Directive (MSFD, 2008/56/EC), which is an attempt to achieve or maintain ‘good environmental status’ by 2020, and the Water Framework Directive (WFD, 2000/60/EC) that aims to achieve ‘good ecological status’ in coastal waters. A range of biological indicators have been developed to assess environmental and ecological status based on biological quality elements.

Studies worldwide have shown that seaweeds integrate the effects of water quality; in degraded conditions long-lived species tend to be replaced by short-lived, opportunistic species that form less complex habitats (Murray & Littler, 1978). Their responsiveness to anthropogenic disturbances makes macroalgae a key element used to classify coastal waters into different ecological status classes (ESC). There are no studies of seaweed communities across gradients of human impacts in Cyprus, and this setting is interesting since it is so highly oligotrophic (Kletou & Hall-Spencer, 2012). Numerous macroalgal indicators have been designed to assess ecological quality, each tailored to different biogeographic provinces (Neto et al., 2014). The Ecological Evaluation Index continuous formula (EEI-c) has been adopted in the central and eastern Mediterranean to assess the ESC’s of coastal waters using benthic macrophytes (Orfanidis et al., 2001; 2011). Here we tested this index in our surveys of coastal waters off Cyprus.

Although all marine ecosystems have been impacted by humans, rocky reefs are amongst the most affected as they have multiple pressure stressors acting synergistically (Firth et al., 2016). Undeveloped shores of the Mediterranean often have a continuous belt of Cystoseira spp. ‘forests’ that support a diverse range of associated species (Bulleri et al., 2002; Cheminée et al., 2013; Pi-
Cystoseira forests can host richer and more abundant juvenile fish assemblages compared to turf algae or barren reefs (Thiriet et al., 2016; Cheminée et al., 2017). There are ca. 40 species of Cystoseira described so far and all these perennial brown fucoids, except C. compressa, are included in the Barcelona Convention as they are of high marine conservation importance. There has been a major global loss of canopy-forming algae and of Cystoseira forests throughout the Mediterranean; urbanisation, nutrient enrichment, sediment loading, physical disturbance, invasive species, overfishing and marine heat waves have all contributed to these losses (Strain et al., 2014; Mineur et al., 2015).

Cyprus is presently undergoing very rapid changes in coastal use (Hadjimitsis et al., 2016) but there are no published studies about the impact of this expansion in resource exploitation on marine ecology. Baseline information on marine biota and sensitive ecosystems is lacking. A few macroalgal investigations were carried out at pristine locations of Cyprus for WFD and MSFD, which resulted in high ecological assessments (Stavrou & Orfanidis, 2012). Here, we conducted surveys along a 10 km stretch of coast to assess whether ocean sprawl is being managed effectively to maintain this good ecological status. We analysed seaweed assemblages on natural and modified hard substrata in the upper sublittoral zone across a gradient of anthropogenic pressures. Our surveys covered shores with limited human access, bathing waters and the most industrialised parts of Cyprus – the aim was to describe seaweed communities on shores with low to high levels of human influence, to identify patterns of change in macrophytic coverage and biomass that might be relevant to coastal pressures, substratum type and seasonality, and assess the ESC’s using the biotic index EEI-c that has been developed for Mediterranean waters.

Materials and Methods

Study Area

Some areas to the west of Vasiliko Bay have not been developed and access is limited to recreation. At the western side of the bay there are restaurants and fish farms offshore, but they have clean ‘Blue Flag’ bathing waters. By stark contrast, the east of the bay has a completely developed foreshore; there is a naval base, a crude oil import terminal, the main power station in the region, a desalination plant and a large cement plant. The recent discovery of major gas reserves in the eastern Levantine (Ruble, 2017) has triggered further developments in eastern Vasiliko Bay; infrastructure has been built including a 1.2 km long offshore jetty and fuel storage facilities on land. Further coastal disruption is underway, such as land reclamation west of Vasiliko port and construction of a liquefied petroleum gas and bitumen storage area east of the port, where heavy dredging is anticipated to create an approach canal to the berth.

Sixteen rocky coastal sampling sites were selected along ca 10 km of coastline extending from Agios Georgios westwards to Zygi eastwards and encompassing Vasiliko Bay (Fig. 1). Conglomerate is the dominant substratum at sites 14-16. All other sites were limestone bedrock, the dominant intertidal and shallow sublittoral substratum. Sites 11 and 13 were exceptions, as they were breakwaters made of quarried limestone boulders that have been in place for several decades. Coastal defence breakwaters were also present at sites 9, 10 but sampling here occurred on natural submerged hard substrata.

Field and Laboratory work

At each sampling site, four to six replicate macroalgal samples (n = 4-6) were taken from smooth horizontal surfaces in the upper subtidal (0.3-1.5 m below the water level), in the summer (June-July of 2012) and spring (March-April of 2013). Each sampling unit was a 0.04 m² photoquadrat (20 cm x 20 cm) placed haphazardly over vegetated hard substrata. Macroalgae within the quadrat were then scraped off with a chisel and transported to the laboratory. Vertical photographs were also taken of the scraped area that allowed an estimation of coverage of small and encrusting species (e.g., coralline algae). To minimise the adverse impacts of scraping to Cystoseira forests, parts of the holdfast attached to the substratum were left behind to allow regeneration. In the laboratory macroalgae were sorted to the lowest possible taxonomic level, and the abundance of each taxon was estimated as percent coverage of the sampling surface. The surface covered by each sorted taxon in vertical projection was quantified within a transparent cuboidal container filled with seawater and having at its bottom a square 20 x 20 cm matrix divided in 100 squares, where each square represented 1% of sampling surface. In situ photographs of quadrats were processed to estimate percent coverage of obvious species and where appropriate modify the estimations made in the laboratory. Sorted macroalgae were blotted on filter paper and weighed (wet weight) and then dried and reweighted (dry weight). Photomicrographs to aid identification of macroalgae species were taken using Olympus CX41 microscope and Olympus SZ stereo microscope fitted with a Q. Imaging Micropublisher 5.0 RTV camera. For nomenclature the AlgaeBase taxonomic database was used (Guiry & Guiry, 2018). To assess ecological quality, the abundance of the two Ecological Status Groups (ESG I and ESG II), the Ecological Evaluation Index continuous formula (EEI-c) and the Ecological Quality Ratio (EQR) were calculated for each site following Orfanidis et al. (2011).

Statistical Analysis

Preliminary analysis indicated that where macroalgae formed dense canopies, calculations of percent coverage based on in situ vertical photographs underestimated short, encrusting and sciophilic macroalgae species that develop under the dense canopy of taller photophilic species.
Thus, data obtained using the scraping method and quantified in the lab were combined with those from \textit{in situ} photo-quadrats of scraped substrata to add coverage of encrusting algae. Average seaweed coverage (%) and dry biomass (g m$^{-2}$) was calculated for all late-successional ESG I and opportunistic ESG II species. To identify the main drivers of change and potential interaction effects in coverage (%) and dry mass (g m$^{-2}$) for both ESG I and ESG II between sites and time, a two-way analysis of variance (ANOVA) was computed. The fixed factor sites comprised 16 site levels and the fixed factor time comprised the two sampling seasons: summer 2012 and spring 2013.

The seasonal macroalgal abundance data % coverage were square-root transformed and analysed using PRIMER v7.0.13. A non-metric multidimensional scaling (nMDS) analysis based on Bray Curtis dissimilarity was undertaken (number of restarts: 100) and a Similarity Profile Analysis (SIMPROF) was used to distinguish statistical differences in macroalgal communities among sites. In addition to this, a one-way and a two-way analysis of similarity (ANOSIM) were performed as complementary analysis based on sites, time and the crossing of the two.

The level of anthropogenic stress at each sampling site was calculated using the MALUSI index (Papathanasiou \\& Orfanidis, 2018). The MALUSI stress index considers different intensities of indirect and direct pressures (such as agriculture, urbanisation, industrialisation, sewage outfall, aquaculture, fresh water and sediment run off) around a 3 km radius of the study site. Sampling sites were then grouped into three categories based on the MALUSI index scores (2-4 = low stress; >4-8 = medium stress, and >8 = high stress). Sampling sites were also grouped based on the substratum type (natural limestone, natural conglomerate and ‘modified’). The ‘modified’ sampling sites were those on the external side of port breakwaters or where there was coastal hardening. Comparisons of the macroalgal community structure were conducted using one-way ANOSIM. Similarity percentage procedure (SIMPER) analysis was used to identify the species that contributed most to the dissimilarities between different levels of each category and the top three species that contributed to the similarity within each level of category across the two seasons (Clarke \textit{et al.}, 2014).

To assess differences in ecological quality between grouped sites, Ecological Quality Ratio scores were analysed using a Kruskal-Wallis test followed by a Dunn’s
pairwise comparison with a Bonferroni correction for the substratum type and stress category (Dinno, 2016). A Mann-Whitney test was used for seasonal comparisons. Main and interaction effects between sites and time were identified using a two-way ANOVA and to see how EEI-c score matched with the MALUSI index scores, a Pearson’s Correlation was computed.

For all two-way ANOVA analyses, the normality of errors and homogeneity of variances were visually inspected and tested via a Shapiro-Wilk test and Levene’s test, respectively. To achieve the normal distribution of errors and homogeneity of variances, the data were square-root transformed and the analysis was repeated, without requiring proceeding to a non-parametric test. For the Pearson’s Correlation analysis, a power transformation was conducted, and normality of data and equal variances were verified with a Shapiro-Wilk test and F-test, respectively. For all the statistical analyses the significance level $\alpha$ was set at 0.05. Graphical material was generated with R-studio v3.4.2 package: ggplot2 (Wickham, 2016).

Results

Macroalgal abundance and biomass

A diverse range of macroalgal taxa was sampled from the upper subtidal, including 21 Ochrophyta, 15 Rhodophyta and 11 Chlorophyta (Table 1, Table 1 in supplementary material). *Cladophora nigrescens*, *Chondrophycus cf. glandulifera* and the alien *Laurencia caduciramulosa* are new records for Cyprus. Two more non-native species were sampled (Caulerpa cylindracea and *Stypopodium schimperi*), though in small proportions. Two seagrasses (*Posidonia oceanica*, *Cymodocea nodosa*), a Chrysophyte and Cyanobacteria were also found in samples from hard substrata.

There were around 4-10 macroalgal taxa per sampling site with the lowest diversity recorded at site 10, a heavily industrialized area (MALUSI stress index score = 10). At all sites, there was $>100\%$ algal coverage due to multiple layers of vegetation, except at site 7, near the naval port, and on conglomerate substrata (sites 14 – 16, Fig. 2). Canopy-forming *Cystoseira* and other ESG I species dominated on undeveloped shores, but their abundance was low in industrialised areas. For example, total coverage of ESG I species at site 2 was 121 ± 15%, while at site 11 coverage of the same group dropped to 15 ± 4%. The total coverage of opportunistic ESG II species on industrialised coasts matched the coverage of *Cystoseira*-dominated sites (e.g., ESG II coverage was 111 ± 9% at site 13) but their biomass was lower (ESG I biomass at site 2 was 1.11 ± 0.27 kg m$^{-2}$, while ESG II biomass at site 13 was 0.37 ± 0.07 kg m$^{-2}$) (Fig. 2). The highest total biomass was found at site 2, which also had the highest coverage of *Cystoseira*.

![Fig. 2: Contribution to average total coverage (top panel) and average dry mass (bottom panel) of macroalgae separated into Ecological Status Group I (left) and ESG II (right), and season of sampling (error bars = SE, n= 4-6), for sampling sites across Vasiliko Bay, Cyprus in 2012-2013.](http://epublishing.ekt.gr)
Table 1. Taxa recorded, and % coverage in 134 quadrats (0.04 m²) sampled on hard substrata at 0.3 - 1.5 m depth across Vasiliko Bay in late summer 2012 and early spring 2013. Late-successional (Ecological Status Group I) and opportunistic species (Ecological Status Group II) are separated in five categories based on their sensitivity to pressures (Orfanidis et al., 2011). Taxa with an asterisk correspond to non-native introductions. New records for Cyprus appear in bold.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Ecological Status Group</th>
<th>Summer Coverage (%)</th>
<th>Spring Coverage (%)</th>
</tr>
</thead>
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<tr>
<td><strong>CYANOBACTERIA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanobacteria</td>
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<td>0.02</td>
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<td><strong>CHLOROPHYTA</strong></td>
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<td></td>
<td></td>
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<td>0</td>
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<td>0.39</td>
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<td>0.21</td>
<td>0.75</td>
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<td>3.71</td>
</tr>
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<td>Chaetomorpha linum (O.F.Müller) Kützing</td>
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<td></td>
<td></td>
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<td>0</td>
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<td><strong>OCHROPHYTA</strong></td>
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<td>Cladostephus spongiosum (Hudson) C.Agardh</td>
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</tr>
<tr>
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<td>2.09</td>
<td>0</td>
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<td>Cystoseira foeniculacea (Linnaeus) Greville f. foeniculacea</td>
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<td>8.88</td>
<td>0.36</td>
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<td>Dictyopteris polyposioides (A.P.De Candolle) J.V.Lamouroux</td>
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<td>1.88</td>
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<td>0.04</td>
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<td>11.17</td>
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<td>0.04</td>
<td>1.66</td>
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<td>0.07</td>
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<td>4.7</td>
<td>3.71</td>
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<td>*Stypodium schimpferi (Kützing) M.Verlaque &amp; Boudouresque</td>
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<td>0.31</td>
<td>0.09</td>
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<tr>
<td>Taonia atomaria (Woodward) J. Agardh</td>
<td>IB</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Taxa</td>
<td>Ecological Status Group</td>
<td>Summer Coverage (%)</td>
<td>Spring Coverage (%)</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>---------------------</td>
<td>--------------------</td>
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<tr>
<td>RHODOPHYTA</td>
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<td>0.01</td>
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<td>Jania rubens (Linnaeus) J.V.Lamouroux</td>
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<td>6.67</td>
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<td>Jania virgata (Zanardini) Montagne</td>
<td>IC</td>
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<td>0.16</td>
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<td>*Laurencia caduciramulosa Masuda &amp; Kawaguchi</td>
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<td>0.17</td>
<td>0.02</td>
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<td>0.31</td>
</tr>
<tr>
<td>Posidonia oceanica (Linnaeus) Delile</td>
<td>I</td>
<td>0.41</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Table 2. Two-way ANOVA of Coverage (%) and Dry mass (g m⁻²) for two ecological macroalgal groups: ESG I and ESG II, based on sites, season and the interaction of the two. The “sd” denotes significant different and “ns” denotes not significant.
Abundance and biomass were significantly correlated ($R = 0.943$, $p = 0.001$), as expected. There was a significant interaction between the effects of the sites and time on the ESG I coverage and biomass. The effect of time was observed in most sites, and although ESG I coverage and biomass were reduced at some sites (i.e., 2, 6, and 9) between samplings, it increased in other sites (Table 2). The interactive effects between sites and time were also significant on the ESG II coverage, whereby all sites showed a change in coverage from one sampling period to the other. Significant interaction between the effects of sites and time were notable in biomass of ESG II species as well. Although the biomass of opportunistic macroalgae was different between

Fig. 3: Macroalgal community shifts across Vasiliko Bay, southern Cyprus in 2013. A climax community with *Cystoseira* spp. and *Posidonia oceanica* with several layers of vegetation covered limestone rocky shores with limited human access (left picture). Perennial species co-existed with bushy opportunists, at sites with moderate anthropogenic impact (middle picture). On heavily industrialised coasts opportunistic species dominated (right picture).

Fig. 4: Macroalgal community similarities tested with a SIMPROF test (significant different groups are assigned with a SIMPROF line) and displayed as a non-metric multidimensional scaling (nMDS) plot based on Bray-Curtis similarities. The top panel was run with the average macroalgal % coverage at each site, separated by substratum type and stress level (high stressed and low stressed sampling sites are noted; all others were classified as medium stressed based on MALUSI index scores). The bottom panel was run with the average seasonal macroalgal % coverage at each site, separated by season of sampling.

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the sites, it only changed at a few sites between the two sampling periods and overall time did not affect the biomass of ESG II species (Table 2).

**Community structure**

Shifts in macroalgal community structure were observed across a gradient of stress (Fig. 3; Table 3). Late-successional species, particularly *Cystoseira barbatula* and to a lesser extent *Cystoseira foeniculacea* f. *foeniculacea*, formed dense aggregations at the sites with limited human influence. Their canopy was often partly covered by epiphytes (e.g., the *Jania* spp., *Dictyota dichotoma* and *nivalis*), *Cladophora* *papillata* and there was a diverse understorey of *Corallinacea* and fleshy seaweeds (e.g., *Padina pavonica*, *Dasyclus vermicularis*, *Anadyomene stellata*, *Rytiplaeca tinctoria*, *Cladophora* spp.). On modified coasts *Cystoseira* forests were almost absent, here opportunistic species (e.g., the *Jania* spp., *Dictyota mediterranea*, *Sphacelaria cirrosa* and *Wrangelia penicillata*) and there was a diverse understorey of *Corallinacea* and fleshy seaweeds (e.g., *Padina pavonica*, *Dasyclus vermicularis*, *Anadyomene stellata*, *Rytiplaeca tinctoria*, *Cladophora* spp.). On modified coasts *Cystoseira* forests were almost absent, here opportunistic species (e.g., the *Jania* spp., *Dictyota dichotoma* and *nivalis*) and *rhytiplaeca* and *anguinata* and *Cystoseira foeniculacea* were almost absent, here opportunistic species (e.g., the *Jania* spp., *Dictyota dichotoma* and *nivalis*).

Macroalgal community structure differed across sites (one-way ANOSIM, $R = 0.6, p < 0.05$) depending largely on levels of stress and substratum type and to a lesser extent on the time of sampling (Fig. 4; Table 3). The macroalgal community at highly stressed sites was different compared to medium and low stressed sites. The macroalgal communities were also affected by substratum type (Table 3), for example *Padina pavonica* was more abundant on conglomerate than on limestone substrata and *Cystoseira barbatula* was the most abundant species on natural substrata but was absent from modified substrata where it was replaced by *Halopteris scoparia* turf. The macroalgal assemblages within the Vasiliko Bay changed between the two sampling periods, though the effect of time was not strong (Table 3), mainly because it was only prominent in some sites (two-way ANOSIM, $R = 0.4, p < 0.05$; Fig. 4). Spring blooms of green algae were recorded at some sites; for example, *Ulva* spp. increased from 0% to 54% coverage on the industrial site 9 and *Chaetomorpha* spp. increased from 0-2% to 11-52% coverage on conglomerate substrata (Table 4).

**Ecological status classes**

Shifts in macroalgal communities across the study area were well reflected by the EEI-c biotic index and further supported by the MALUSI stress index (Fig. 5, MALUSI data Table 2 in supplementary material). The two indices had a significant negative correlation on averaged seasonal values (Pearson’s correlation, $p = -0.647, p < 0.01$) and in the summer (Pearson’s correlation, $p = -0.487, p = 0.056$). Overall, there was significant inter-site variability on EQR reflected on both sampling periods (two-way ANOVA, $df = 15, F = 8.808, p < 0.05$). Low ESC was recorded at sites 10 – 13 in both seasons. Good-High ESC was assessed at the other sites but in most cases, spring ecological assessments produced lower EQR values due to the increase in the abundance of opportunistic species (Fig. 5). The highest ESC scores were assessed at sites 2 and 6, which also had the highest macroalgal biomass whereas the lowest was assessed at sites 10 and 11, which had among the lowest species di-

<table>
<thead>
<tr>
<th>Pairwise groups of sites</th>
<th>R statistic</th>
<th>Significance level</th>
<th>Average Dissimilarity</th>
<th>Main taxa responsible for dissimilarity</th>
<th>Av. Coverage %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seasons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer, Spring</td>
<td>0.069</td>
<td>0.001 sd</td>
<td>74.96</td>
<td>Jania spp.</td>
<td>17.5, 6.7</td>
</tr>
<tr>
<td><strong>Stress Category</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low, Medium stressed</td>
<td>-0.063</td>
<td>0.899 ns</td>
<td>63.71</td>
<td><em>D. mediterranea</em></td>
<td>3.5, 8.5</td>
</tr>
<tr>
<td>Low, High stressed</td>
<td>0.557</td>
<td>0.001 sd</td>
<td>83.85</td>
<td><em>C. barbatula</em></td>
<td>58.8, 6.2</td>
</tr>
<tr>
<td>Medium, High stressed</td>
<td>0.494</td>
<td>0.001 sd</td>
<td>84.11</td>
<td><em>H. scoparia</em></td>
<td>4.9, 21.3</td>
</tr>
<tr>
<td><strong>Rocky Substratum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone, Modified</td>
<td>0.714</td>
<td>0.001 sd</td>
<td>85.76</td>
<td><em>H. scoparia</em></td>
<td>3.2, 49</td>
</tr>
<tr>
<td>Limestone, Conglomerate</td>
<td>0.421</td>
<td>0.001 sd</td>
<td>74.51</td>
<td><em>P. pavonica</em></td>
<td>4.9, 21.3</td>
</tr>
<tr>
<td>Modified, Conglomerate</td>
<td>0.649</td>
<td>0.001 sd</td>
<td>87.92</td>
<td><em>H. scoparia</em></td>
<td>49, 0.6</td>
</tr>
</tbody>
</table>

Table 3. Pairwise differences in macroalgal community composition across Vasiliko Bay, southern Cyprus, calculated using ANOSIM (R statistic and Significance level). The average dissimilarity and main taxa responsible for these differences calculated by SIMPER analysis are given as well as their average percent coverage. The “sd” denotes significant different and “ns” denotes not significant.
versity and biomass. The overall EQR of the Vasiliko Bay was similar in spring and summer (Man-Whitney test, \( W = 5106, p = 0.09 \)), although the effect of time on EQR was prominent on some site levels, showing significant differences in sites 1, 2, 5, 7, 9 and 16 (two-way ANOVA, \( df = 1, F = 8.035, p < 0.05 \)). No interaction effect was observed between sites and time (two-way ANOVA, \( df = 15, F = 1.559, p > 0.05 \)). Significant differences of the EQR score were also observed between the different levels of coastal stress as well as between modified and natural substrata (Table 5). No differences in the EQR scores were detected between natural substrata limestone and conglomerate and between low and medium stressed sampling sites.

Discussion

Our surveys on the southern coast of Cyprus identified 51 taxa of macrophytes. Three species are reported for the first time from Cypriot waters, expanding the existing checklist of seaweed species (Tsiamis et al., 2014). One of these, Laurencia caduciramulosa, is native to SE Asia and was described for the first time from the Mediterranean Sea by Furnari et al. (2001).

Our results are consistent with global observations that human impacts combine to cause the loss of perennial canopy-forming brown seaweeds and a proliferation of opportunistic macroalgae (Scherner et al., 2013; Strain et al., 2014). In our surveys, canopy-forming Cystoseira dominated shallow subtidal hard substrata showing

### Table 4.
The three species with maximum contribution (%) to site similarity, their contribution % to the similarity, and the site with their highest abundance within each category for summer and spring, generated via SIMPER analysis of similarity.

<table>
<thead>
<tr>
<th>Category</th>
<th>Summer</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MALUSI stress categories</strong></td>
<td>Top 3 species with max. contribution (%) for site similarity</td>
<td>Top 3 species with max. contribution (%) for site similarity</td>
</tr>
<tr>
<td><strong>Low stressed sites</strong></td>
<td>C. barbatula 47.1 2 C. barbatula 40.6 2</td>
<td>Jania spp. 24.6 2 D. mediterranea 34.9 1</td>
</tr>
<tr>
<td></td>
<td>Jania spp. 18.9 3 D. mediterranea 5.9 3</td>
<td>D. vermicularis 18.9 3</td>
</tr>
<tr>
<td><strong>Medium stressed sites</strong></td>
<td>C. barbatula 37.2 16 C. barbatula 35.3 8</td>
<td>P. pavonica 22.1 15</td>
</tr>
<tr>
<td></td>
<td>Cladophora spp. 8.2 6 Jania spp. 4.5 11</td>
<td>Jania spp. 12.2 6</td>
</tr>
<tr>
<td><strong>High stressed sites</strong></td>
<td>H. scoparia 44.6 13 H. scoparia 53.0 11</td>
<td>Ulva spp. 17.7 9</td>
</tr>
<tr>
<td></td>
<td>Jania spp. 17.5 9 P. pavonica 21.3 15</td>
<td>Ulva spp. 12.3 9</td>
</tr>
<tr>
<td><strong>Substratum</strong></td>
<td>Cladophora spp. 4.5 11</td>
<td>Jania spp. 7.2 12</td>
</tr>
<tr>
<td><strong>Limestone</strong></td>
<td>C. barbatula 37.1 2 C. barbatula 43.7 2</td>
<td>Jania spp. 18.1 6</td>
</tr>
<tr>
<td></td>
<td>Jania spp. 12.9 3 D. mediterranea 20.2 1</td>
<td>D. mediterranea 11.2 6</td>
</tr>
<tr>
<td><strong>Modified</strong></td>
<td>H. scoparia 51.1 13 H. scoparia 54.7 11</td>
<td>Jania spp. 17.5 9</td>
</tr>
<tr>
<td></td>
<td>Jania spp. 17.5 9 Ulva spp. 18.6 9</td>
<td>Ulva spp. 19.9 14</td>
</tr>
<tr>
<td><strong>Conglomerate</strong></td>
<td>Cladophora spp. 5.0 11 D. dichotoma 9.4 10</td>
<td>C. barbata 16.6 15</td>
</tr>
<tr>
<td></td>
<td>C. barbatula 38.2 16 P. pavonica 34.2 15</td>
<td>Chaetomorpha spp. 27.0 16</td>
</tr>
<tr>
<td></td>
<td>Cladophora spp. 25.0 15</td>
<td>C. barbata 16.6 15</td>
</tr>
<tr>
<td></td>
<td>P. pavonica 19.9 14</td>
<td>C. barbata 16.6 15</td>
</tr>
</tbody>
</table>
Fig. 5: Top panel: Mean values (error bars = SE, n = 4-6) variation of Ecological Evaluation Index (EEI-c) across Vasiliko Bay, Cyprus, in summer 2012 and spring 2013. Lower panel: Mean values (error bars = SE, n = 8-10) variation of EEI-c and MALUSI index across Vasiliko Bay, Cyprus, for the period summer 2012 to spring 2013. Ecological status classes colour categorisation corresponds to EEI-c scores.

Table 5. The pairwise comparisons based on the EQR score calculated with the EEI-c index (Orfanidis et al., 2011), and statistical differences between different seasons, substrata and stress category in Vasiliko Bay, Cyprus. The “sd” denotes significant different and “ns” denotes not significant.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Average EQR</th>
<th>Statistical test</th>
<th>df</th>
<th>test statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season (Summer, Spring)</td>
<td>0.59, 0.48</td>
<td>Mann-Whitney</td>
<td></td>
<td>W = 5106.0</td>
<td>0.09 ns</td>
</tr>
<tr>
<td>Substratum</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone, Modified</td>
<td>0.63, 0.17</td>
<td>Kruskal-Wallis</td>
<td>2</td>
<td>χ² = 42.3</td>
<td>0 sd</td>
</tr>
<tr>
<td>Limestone, Conglomerate</td>
<td>0.63, 0.75</td>
<td>Dunn’s test</td>
<td></td>
<td>z = 5.7</td>
<td>0.21 ns</td>
</tr>
<tr>
<td>Conglomerate, Modified</td>
<td>0.75, 0.17</td>
<td></td>
<td></td>
<td>z = 1.5</td>
<td></td>
</tr>
<tr>
<td>Stress category</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High, Medium</td>
<td>0.19, 0.70</td>
<td>Kruskal-Wallis</td>
<td>2</td>
<td>χ² = 53.7</td>
<td>0 sd</td>
</tr>
<tr>
<td>High, Low</td>
<td>0.19, 0.71</td>
<td>Dunn’s test</td>
<td></td>
<td>z = -5.3</td>
<td>0 sd</td>
</tr>
<tr>
<td>Low, Medium</td>
<td>0.71, 0.70</td>
<td></td>
<td></td>
<td>z = 0.4</td>
<td>1 ns</td>
</tr>
</tbody>
</table>
the good environmental quality of waters, in which hu-
man access was limited to recreation. Algal biomass was
considerably higher than at impacted sites as there were
more perennial species present, an indication of a healthy
shallow rocky reef ecosystem (Panayotidis et al., 2004;
Sala et al., 2012). The canopy of Cystoseira barbatula
diminished near industrialised areas and got replaced by
simpler communities, dominated by stress-resistant and
ephemeral species such as Halopteris scoparia and Ulva
spp. Similar community shifts from canopy-forming fu-
coids to bushy, turf or fleshy opportunistic species have
been widely reported across gradients of impact around
the Mediterranean Sea (Benedetti-Cecchi et al., 2001;
Thibaut et al., 2005, 2015; Arévalo et al., 2007; Mangiala-
jo et al., 2008; Orlando-Bonaca et al., 2008; Perkol-Fin-
due & Airoldi, 2010; Tsiamis et al., 2013; Ivesa et al.,
2016; Badreddine et al., 2018; Orlando-Bonaca & Rotter,
2018), but this is the first time it is reported from the
oligotrophic waters of Cyprus.

Opportunistic algae dominated in spring at some im-
pacted sites, but they did not approach the high levels of
biomass found in unimpacted Cystoseira forests. Blooms
of green algae (Ulva and Chaetomorpha spp.) occurred
on highly stressed shores during spring, which may be
due to eutrophication, whereas a bloom of Dictyota med-
terranea was recorded in spring on the western side of
the study area reflecting the typical annual cycle of Dic-
tyotales (Tronholm et al., 2008).

The most significant factors that affected shallow
subtidal communities were human stress level, calculat-
ed with the MALUSI index, and the type of substratum
available for seaweed growth. On breakwaters and coast-
line defences Cystoseira spp. were almost absent, even
though these were constructed using natural limestone
boulders several decades ago. This emphasises the fact
that man-made structures do not function as surrogates of
natural rocky reefs (Bulleri & Chapman, 2010), as they
are composed of different assemblages of species and can
have significantly lower abundances of large perennial
algae (Ferrario et al., 2016). Despite differences in mac-
roalgal community structure, the two natural substrata
studied (limestone and conglomerate), had similar ESC,
as assessed with the EEI-c, mainly because macroalgal
community structure was dominated by species of the
same ESG. The averaged and the summer ESC scores
were negatively correlated with the MALUSI stress in-
dex, which demonstrates that the EEI-c is a robust way
of assessing the environmental quality of coastal waters
as it is unaffected by natural variability of communities
due to different type of substratum and in the summer,
macroalgal community shifts from perennial species to
opportunistic species reflect an increasing gradient of an-
thropogenic stress. The macroalgal biotic index (EEI-c)
differed at some sites between the two survey periods as
opportunistic seaweed increased abundance in spring,
even at low stressed sites. This confirms the need to sam-
ple in summer to accurately assess the ESC of coastal wa-
ters using macroalgal-based indicators (Orfanidis et al.,
2011). Spring assessments can produce the ‘worst’ ESC
scores, but unlike summer assessments, they may not be
always representative of anthropogenic stress.

As in many places around the world, a single human
generation has transformed the coastline of Cyprus cre-
aing a heavily industrialised foreshore in Vasiliko Bay.
Despite major alterations to the area, there had been no
assessments off the marine ecosystem impacts of these
developments. High ESC was reported on other coast-
lines of Cyprus monitored for WFD and MSFD (Stavrou
& Orfanidis, 2012). In this study, low ESC was assessed
along industrialised coastlines where artificial breakwa-
ters and coastal hardening had modified the shores. There
was likely a combination of several impacts such as con-
tamination from ports, cement dust deposition, litter,
warm water from a power station, brine from desalina-
tion unit and possibly waste effluents from fish farms
operations. Major industrial developments are still under-
way in Vasiliko Bay, in 2017 land reclamation killed the
last remnant of Cystoseira habitat in the eastern side of
the bay. We recommend that Cystoseira forests receive
more attention when coastal developments are evaluated
in Cyprus. Our baseline data on macroalgal communities
will allow future comparisons and ecological assess-
ments in the region. The bad ESC scored along the modi-
fied, industrial coastline should alert those responsible for
managing the use of coastal marine resources in Cyprus
as attempts may be needed to meet the obligations of the
European MSFD.

In summary, it is not too late to conserve Cystoseira
forests by raising public awareness and mitigating human
impacts on coastal ecosystems (Gianni et al., 2013). The
disappearance of these fucoid forests leads to systems
with lower biodiversity and reduced ecosystem services
to humanity (Chapin et al., 2000; Cardinale et al., 2012).
Shallow reefs around parts of Cyprus are still covered in
luxuriant Cystoseira forests, but this habitat is threatened
by coastal developments. At the industrialised and modi-
fied forefront of Vasiliko Bay, the Cystoseira canopy
and was replaced by opportunistic algae that had lower
biomass per area. Ecological assessments showed that
the coastal waters in this side of the bay did not meet
the quality targets of European Directives. Despite the
ecological degradation, industrialisation is expanding,
and construction has begun for a booming hydrocarbon
industry, now that large gas reserves have been locat-
ated. Furthermore, there are approved government plans
to construct a new port to serve fish farmers, near the
dense Cystoseira forests west of Vasiliko Bay. As pres-
sures continue to mount, it remains to be seen whether the
MSFD will be applied to ensure that marine resources are
managed sustainably in Cyprus.

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References


Papathanasiou, V., Orfanidis, S., 2018. Anthropogenic eutrophication affects the body size of Cymodocea nodosa in the North Aegean Sea: A long-term, scale-based approach. Ma-

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