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Macroalgae fouling community as quality element for the evaluation of the ecological status in Vela Luka Bay, Croatia

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Abstract

One year qualitative and quantitative study of communities of three major taxonomic groups has been carried out at test panles placed in the upper infarlittoral zone of coastal area of Vela Luka Bay, Croatia. A list of 44 taxa was recorded. *Chaetomorpha* sp., *Ulva* sp., *Fosliella farinosa*, *Sphacelaria cirrosa*, *Polysiphonia scopulorum* were the most frequent dominant taxa. Among 27 algal taxa with noticeable presence only three were classified as ESG (Ecological State Groups) I. Low diversity and species richness together with massive presence of the green algae (as *Ulva* sp.) and negligible presence of ESG I taxa, may lead to erroneous conclusion that Vela Luka Bay is eutrophicated area. Low values of biomass and *R/P* (Rhodophyceae by Phaeophyceae ratio) Index together with dominance of Phaeophyta also support conclusion that there is no negative impact of nutrient enrichment on macrophyta fouling community in Vela Luka Bay.

Keywords: artificial habitats, bioindicators, coastal waters, fouling organisms, Vela Luka Bay

Intoduction

The major structuring factors influencing the benthic communities are species recruitment onto a surface, competition between resident organisms and disturbance by predation and/or environmental factors [1], although pollution also influences the development of these communities [2]. Changes in the development of benthic communities caused by organic pollution are often obscured by the interactions between nutrient enrichment and a variety of other ecological factor [3]. In order to distinguish these effects, the use of artificial panels is a good alternative method to field studies [4]. The panels may be easily manipulated and placed under a variety of environmental conditions [1]. Artificial structures are colonized by the most competitive assemblages of floral and fauna species in response to a combination of physical, chemical and biological factors, from the intertidal to the shallow subtidal [5]. Number of factors (age, texture, depth, complexity, inclination and position in the water column) influences colonization of epibiota on artificial panels [6–10]. Vertical surfaces are more densely colonized than horizontal surface [8,11,12].

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In the last years, the increasing need for stable and comparable criteria of environmental quality in the European aquatic ecosystems, reactivated the use and search of pollution biological indicators [13]. Some ecological indices are focused on the presence/absence of a given indicator species, while others take into account species biomass and abundance, the different ecological strategies adopted by organisms [Feldmans *R/P* (Rhodophyceae by Phaeophyceae ratio) index] [14], the diversity (species richness), or the energy variation in the system through changes in the biomass of individuals [13]. Evidence on the suitability of benthic macrophytes as indicators of effects against different pollution gradients is undoubted [15,16]. Marine benthic macrophytes, as photosynthetic sessile organisms being at the base of food web, are vulnerable and adaptive to human and environmental stress of water and sediment. They respond to aquatic environment representing reliable indicators of its changes [17]. A universal pattern is that highly stressed or disturbed marine environments are inhabited by annual species with high growth rates and reproductive potential, while undisturbed marine environments by perennial species with low growth rates and reproductive potential [18–21]. This was the spark to develop the biotic index EEI (Ecological Evaluation Index), based on the functional-morphological model of Littler and Littler [22] and use it to divide marine benthic macrophytes in two different ecological groups, the late-successional [perennials, ESG (Ecological State Groups) I] and the opportunistic (annuals, ESG II) [23]. Thus, the presence and/or the abundance of some benthic macrophytes could be used for the classification of the Ecological (quality) Status, in the terms of the Water Frame Directive [(WFD) 2000/ 60/ EC) [24]. A cost-effective monitoring system to cover the demands of WFD could include summer destructive samplings, functional-form classification, and use of the EEI. Colonization by local infra-upperlittoral benthic communities can be used as biological indicator of environmental changes because they are exhaustively studied [25] as well as they integrate the environmental changes occurring in marine ecosystems, and they are strongly affected by pollution [26]. Further studies are needed to better understand periphyton response to different substrata types and possible seasonal changes of the community structure, especially studies on pollution impact on the macroalgal communities of artificial substrata [27]. The aim of the present study was to give the development of fouling communities using artificial panels and to demonstrate that several ecological indexes based on the composition and abundance of the test panels phytobenthos in the upper infralittoral zone could give good tools for the rapid assessment of the ecological quality of coastal waters.

Material and methods

The fouling community on polyester test panels was studied in the Vela Luka Bay – Bobovišće, the island of Korcula, the Adriatic Sea (42°50′ N and 16°43′ E). The Vela Luka Bay is closed, shallow and hidden bay, well protected from the north and the south winds. According to Dadić et al. [28], high water oscillations are predominant (in several days periods) during the summer. During the winter, low frequency oscillations are predominant and water exchange is not altered, e.g. water enters in surface layer and exits in bottom layer. Time needed for water exchange ranges from one day to five days depending on sea conditions, wind effects, currents and the stratification in the bay. Water exchange time is longer during the summer when contaminant inflow is the highest. Although the bay is closed and shallow, the oxygen content is high. Water quality analysis show high nitrate, nitrite and phosphorus content, especially in shallow regions of the bay. Phytoplankton structure and biomass shows that Vela Luka Bay is naturally eutrophic area. According to zooplankton biomass this bay can be categorized as the zone D (high zooplankton biomass).

The test-panels were placed in the area of shipyard "Greben" (site Bobovišće) in order to evaluate the environmental impact caused by urbanisation, tourisms and shipbuilding industry.

Four samplings were carried out every three mounths in period between July and July (throughout one year), in order to monitor the characteristics of fouling vegetation on polyester test panels (20 × 20 cm). One metal structure was placed at the quay, and eight test panels were fixed vertically by ropes, at approximately 0.5 m and 2.5 m depth. Panels were collected after 3, 6, 9 and 12 months of immersion. This overall design gave information on succession patterns and potential recruit available at different period of the year. After collection of the panels were kept in the buckets containing 2% formaldehyde for further analysis.

Examination of the panels took place in The Laboratory of Benthos – The Institute of Oceanography and Fishery, Split. The panels were carefully removed from the buckets in the laboratory, placed in an aquarium filled with seawater, and photographed with a digital camera. According to Boduresque [29] and Braun-Blanquet [30] total cover percentage of fouling community was determined for each panel. The structure of the fouling community was estimated using the Constant Area Method. Four subsamples (2 × 2 cm squares) were randomly scratched from each side of the panel, i.e. eight samples per

Tab. 1 The list of algal taxa found on test panels at both depths.

CHLOROPHYTA
Bryopsidophyceae
Blastophysa sp.
Blastophysa rhizopus Reinke
Bryopsis sp.
Dasycladophyceae
Acetabularia acetabulum (Linnaeus) Silva
Ulvophyceae
Cladophora sp.
Chaetomorpha sp.
Chaetomorpha aerea (Dillwyn) Kuetzing
Ulothrix sp.
Enteromorpha sp.
Ulva sp.
Ulvella sp.
Phaeophila dendroides (Crouan) Batters
PHAEOPHYTA
Phaeophyceae
Dictyota dichotoma (Hudson) Lamouroux
Dictyota linnearis (C. Agardh) Gerville
Padina pavonica (Linnaeus) Thivy
Feldmannia irregularis (Kuetzing) Hamel
Colpomenia sinuosa (Mertens) Derbes i Solier
Ectocarpus paradoxus Montagne
Ectocarpus confervoides Kjellmann
Entonema sp.
Myrionema sp.
Myriotrichia sp.
Giraudia sphacelarioides Derbes & Solier
Sphacelaria cirrosa (Roth) C. Agardh
Sphacelaria plumula Zanardini
Sphacelaria tribuloides Meneghini
Stypocaulon scoparium (Linnaeus) Kuetzing
RHODOPHYTA
Bangiophyceae
Goniotrichum alsidii (Zanardini) Howe
Compsopogonophyceae
Erythrotrichia carnea (Dillywyn) J. Agardh
Florideophyceae
Fosliella farinosa (Lamouroux) Howe
Acrochaetium sp.
Acrochaetium davesii (Dillwyn) Naegeli
Aglaothamnion furcellarie (J. Agardh) G. Feldmann
Antithamnion cruciatum (C. Agardh) Naegeli var. profundum G. Feldmann
Ceramium codii (Richards) G. Mazoyer
Heterosiphonia wurdemannii (Bailey) Falkemberg
Dasya ocellata (Grateloup) Harvey
Dasya arbuscula (Dillwyn) C. Agardh
Lophosiphonia cristata Falkemberg
Polysiphonia scopulorum Harvey
Laurencia sp.
Gelidium sp.

Tab. 1 *(continued)*

Falkenbergia rufolanosa (Harvey) Schmitz

panel. Samples were examined by light microscopy (Carl Zeiss – Jena, ocular 10×, lens 8 and 40×). Each sample was carefully sorted and identification at species and functional group-level was attempted. Fouling species were identified using authoritative keys and texts [31–36].

Phytobenthos fouling community structure was analyzed in terms of total coverage, species number, total species coverage, species frequency, Sörensen similarity coefficient [37] qualitative dominance (*DN*%) of main algal systematic groups, *R/P* ratio and classification in ESG groups, in order to get an indication of the state of health of the study area. The total percentage covers of species (*Ri*) and mean cover of species (*RM*) were analyzed according to Boudouresque [29] and Braun-Blanquet et al. [30]. The frequency and classification in ESG groups were estimated only for algal taxa with noticeable presence (>1% cover). Shifts in marine ecosystem structure and function are evaluated by classifying marine benthic macrophytes in two ESGs (I, II), representing alternative ecological states, e.g. pristine and degraded [17]. The total wet weight of fouling organisms (*TW*, g) was weighted on Tecnica – type EXACTA 1200 EB precision electronic scale (within 0.0001g), after the panel were completely scratched.

Results

Fouling biomass ranged from 55 g × m^{-2} (after 3 month of immersion at 2.5 m depth) to 965.25 g × m^{-2} (after 12 month of immersion at 2.5 m depth). Number of algal taxa ranged from 4 to 18 and the number of animal taxa ranged from 2 to 11. Number of algal taxa was considerably higher than the number of animal taxa (except after 6 month of immersion at 0.5 m depth). Total number of algal taxa was 44 (37 taxa at 0.5 m depth and 41 taxa at 2.5 m depth) – Tab. 1. That gave 34 algal species common for both depths, i.e. Sörensen similarity coefficient was 87.18%.

The *R/P* ranged from 0.33 to 1.20 at 0.5 m depth, and from 0.33 to 1.67 at 2.5 m depth. At 0.5 m depth Phaeophyta (except at the inner side of the panel after 6 month and after 12 month) were dominant over Rhodophyta and Chlorophyta with minimum 12.50% and maximum 50%. Qualitative dominance of Chlorophyta ranged between 20% and 42%, while qualitative dominance of Rhodophyta ranged between 12.50% and 40%. At 2.5 m depth there were no dominant algal groups. Qualitative dominance of Chlorophyta ranged between 20% and 40%, while qualitative dominance of Phaeophyta ranged with minimum 23% and maximum 60%, and qualitative dominance of Rhodophyta ranged between 20% and 44%. Fig. 1 and Fig. 2 show the qualitative dominance (*DN*%) of taxa of the main algal groups found on test panels at two different depths.

Chaetomorpha sp. and *Polysiphonia scopulorum* (100%); *Ulva* sp. and *Fosliella farinosa* (87.50%) and *Sphacelaria cirrosa* (81.25%) were the most frequent taxa. Among 27 algal taxa with noticeable presence only three were classified as ESG I (*Acetabularia acetabulum*, *Padina pavonica* and *Fosliella farinosa*) – Tab. 2.

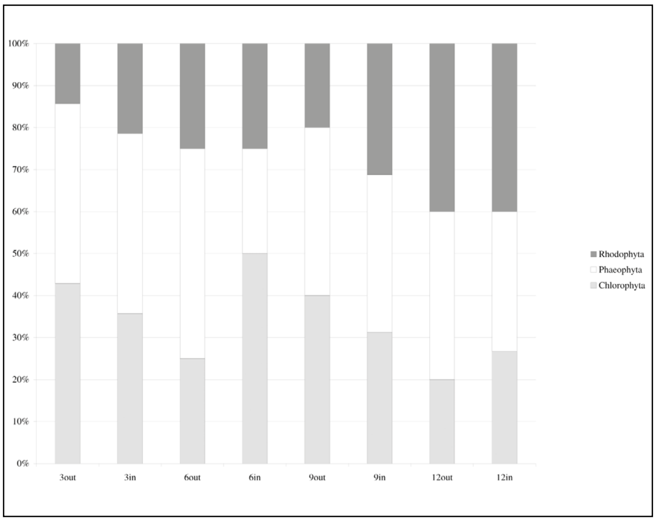

Fig. 1 The qualitative dominance (*DN*%) of taxa of the main algal groups found on test panels (in – inner side; out – outer side) at 0.5 m.

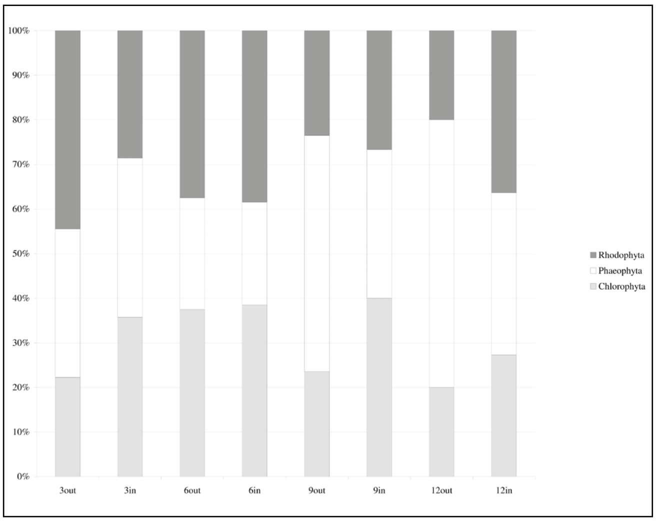

Fig. 2 The qualitative dominance (*DN*%) of taxa of the main algal groups found on test panels (in – inner side; out – outer side) at 2.5 m.

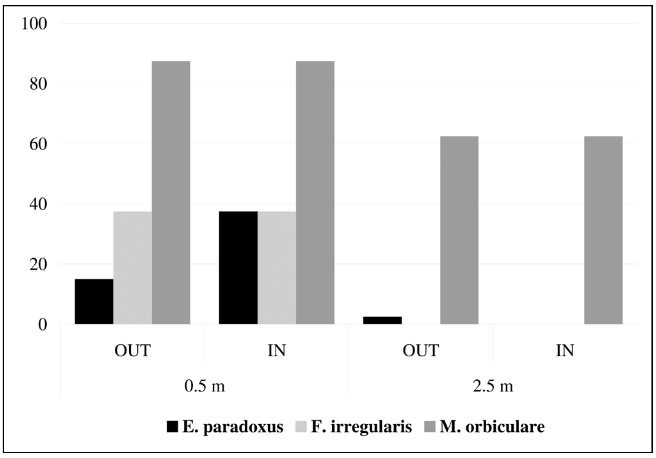

Fig. 3 The mean cover (%) of the dominat algal taxa found on test panels (in – inner side; out – outer side) at 0.5 m and 2.5 m after 3 months of immersion.

Tab. 2 Ecological State Groups classification and the frequency of algal taxa covering at least 1% of the sampling area.

Taxa	ESG	Frquency (*f*/16)
Acetabularia acetabulum (Linnaeus) Silva	I	1
Cladophora sp.	II	2
Chaetomorpha sp.	II	16
Pheophila dendroides (Crouan) Batters	II	7
Rhizoclonium sp.	II	12
Ulotrix sp.	II	4
Ulva sp.	II	14
Dictyota dichotoma (Hudson) Lamouroux	II	7
Dictyota linnearis (C. Agardh) Gerville	II	1
Ectocarpus paradoxus Monatgne	II	7
Entonema sp.	II	5
Feldmannia irregularis (Kuetzing) Hamel	II	9
Giraudya sphacelarioides Derbes i Solier		12
Myrionema orbiculare J. Ag.	II	12
Padina pavonica (Linnaeus) Thivy	I	5
Sphacelaria cirrosa (Roth) C. Agardh	II	13
Sphacelaria plumula Zanardini	II	2
Sphacelaria tribuloides Meneghini	II	3
Aglaothamnion furcellarie (J. Agardh) G. Feldmann	II	3
Antithamnion cruciatum (C. Agardh) Naegeli var. *profundum* G. Feldmann	II	7
Dasya arbuscula (Dillwyn) C. Agardh	II	2
Fosliella farinosa (Lamouroux) Howe	I	14
Heterosiphonia wurdemannii (Bailey) Falkemberg	II	1
Lophosiphonia cristata Falkemberg	II	9
Polysiphonia scopulorum Harv.	II	16

ESG – Ecological State Groups.

Acetabularia acetabulum had frequency 6.25% and *RM* of 3% (*r*), Padina pavonica had frequency 31.25% and *RM* raged between 0% and 15% (form + to 2), while *Fosliella farinosa* had frequency 87.50% and mean cover (*RM*) raged between 0% and 15% (form + to 2).

After 3 months of immersion, total percentage cover was 90% (5 in Braun-Blanquet [30] scale) at 0.5 m at both sides of the panels; while total percentage cover was 90% (5) at the outer side and 70% (4) at the inner side of the panel at 2.5 m. *Myrionema orbiculare*, *Ectocarpus paradoxus* and *Feldmannia irregularis* were dominat algal taxa after 3 months of immersion (Fig. 3).

After 6 months of immersion, total percentage cover was 100% (5) at both depths and both sides of the panels. *Sphacelaria cirrosa* and *Polysiphonia scopulorum* were dominat algal taxa after 6 months of immersion (Fig. 4).

After 9 months of immersion, total percentage cover was 90% (5) at both depths and both sides of the panels. *Cladophora* sp., *Giraudya sphacelarioides*, *Myrionema orbiculare* and *Polysiphonia scopulorum* were dominat algal taxa after 9 months of immersion (Fig. 5).

After 12 months of immersion, total percentage cover was 100% (5) at both depths and both sides of the panels. *Cladophora* sp., *Ulva* sp. and *Polysiphonia scopulorum* were dominat algal taxa after 12 months of immersion (Fig. 6).

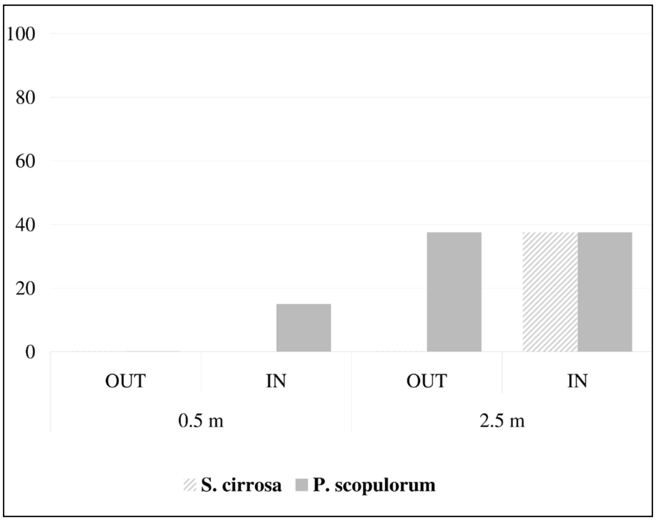

Fig. 4 The mean cover (%) of the dominat algal taxa found on test panels (in – inner side; out – outer side) at 0.5 m and 2.5 m after 6 months of immersion.

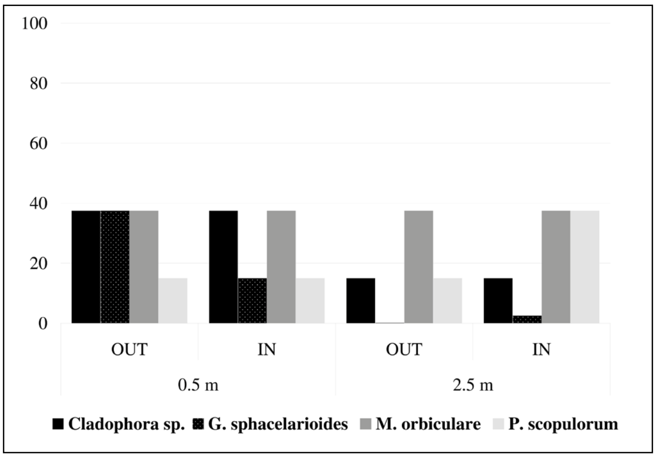

Fig. 5 The mean cover (%) of the dominat algal taxa found on test panels (in – inner side; out – outer side) at 0.5 m and 2.5 m after 9 months of immersion.

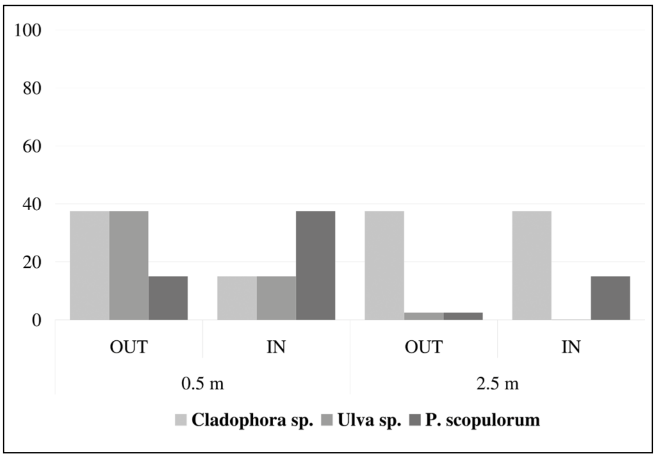

Fig. 6 The mean cover (%) of the dominat algal taxa found on test panels (in – inner side; out – outer side) at 0.5 m and 2.5 m after 12 months of immersion.

Discussion

Organic pollution may increase and speed up the development of fouling communities in originally oligotrophic area [3], or at higher levels, may cause a decrease of biomass and diversity and favor opportunistic species [19,38]. Benthic macrophyta community directly responds to the changes in abiotic variables, reducing its richness, diversity levels and/or enhancing its biomass per surface unit under eutrophication [39]. Therefore it can be used as sensitive bioindicator of ecosystem changes at smaller spatial scales [27]. They provide readable responses with analysis based on a functional group level providing powerful support to traditional species-level analysis. Benthic macrophyte communities have been successfully used as indicators of eutrophication in coastal waters of The Adriatic Sea [40–42].

Fouling biomass was relatively low compare to a similar 12 month study of fouling communities on concrete, plastic and glass panels in Kastela Bay (The Adriatic Sea; from 221 g × m^{-2} to 61.578 g × m^{-2}) [43].

Number of found algal taxa were considerably lower compared to 62 benthic algae taxa found on concrete, plastic and glass panels at the entrance of Kastela Bay [43]. Low diversity and species richness may be the result of organic enrichment [27], althought some authors suggest that low diversity is caused by competition between tolerant and non-tolerant species [3].

In polluted areas, the number of algae species decreases, especially Rhodophytes and Phaeophytes, with an increase in the abundance of Chlorophytes [19,44]. Phaeophyceae are extremly sensitive to environmental disturbance [27]. Feldman's *R/P* Index [14], based on marine vegetation, is highly used in the Mediterranean Sea. It was established as a biogeographical index and it is based on the fact that the number of species of Rodophyceae decreases from the Tropics to the Poles. Its application as indicator holds on the higher or lower sensitivity to disturbances of Phaeophyceae and Rhodophyceae [13]. Low *R/P* values and dominance of Phaeophyta over Rhodophyta and Chlorophyta at 0.5 m depth indicated that there was no negative impact of nutrient enrichment on macrophyta. In some cases functional groups was preferable than taxonomic grouping of organisms to reduce spatial and temporal community variability and to discover patterns without loosing important information [23]. Among 27 algal taxa with noticeable presence only three were classified as ESG I (*Acetabularia acetabulum*, *Padina pavonica* and *Fosliella farinosa*). The reason for low presence of late successional ESG I taxa could be the short period of immersion (less than one year).

Although found dominant taxa are very adaptive and represent typical fouler in the Adriatic [45], numerous authors pointed out that macrolagae of genus *Ulva* [46–48] and Cladophora [49] appears in conditions with high nutrient loading [26,46]. The massive presence of the green algae *Ulva* sp. and *Cladophora* sp. along the European coastline is considered to be a reliable indicator for nutrient enriched seawater [50]. Chlorophytes are favoured by an increase of nutrients, and genera such as *Cladophora* and *Ulva* are usually abundant in eutrophicated areas due to their great reproductive capacity and their rapid growth rate [44].

Low diversity and species richness together with massive presence of the green algae (as *Ulva* sp.) and negligible presence of ESG I taxa, may lead to erroneous conclusion that Vela Luka Bay is eutrophicated area. Nevertheless, similar situation may occur in non-polluted environments [13,51,52], e.g. due to short period of immersion. Low values of biomass and *R/P* Index together with dominance of Phaeophyta also support conclusion that there is no negative impact of nutrient enrichment on macrophyta fouling community in Vela Luka Bay.

Conclusions

(***i***) Low biomass, diversity, species richness, *R/P* Index, dominance of Phaeophyta, together with massive presence of green algae (as *Ulva* sp.) and negligible presence of ESG I taxa can result from nutrient enrichment in Vela Luka Bay, but also from short immersion period.

(***ii***) A possibility of wider application of the presence and the abundance of benthic macrophytes for the classification of the Ecological Status is shown.

(***iii***) The analysis of macrophyta fouling communities (functional-form classification, EEI) on artificial test panels obtains simple, cost-effective, non-destructive monitoring system that covers the demands of Water Frame Directive (2000/ 60/ EC).

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