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RESEARCH ARTICLE

A new non-destructive method for the assessment of the ecological status of coastal waters by using marine macrophytes

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Abstract

The EU Water Framework Directive (WFD 2000/60/EC) declared the benthic macrophytes (macroalgae and angiosperms) as biological quality elements to assess the ecological status of coastal and transitional waters. In the present paper, Benthic Ecological Assessment Rapid Index (BEARI) is proposed as a new non-destructive method to assess the ecological quality of coastal waters. The data was obtained by photographic sampling at 9 different sites in the Sea of Marmara (3 sites) and the coasts of Aegean Sea (6 sites) of Turkey. Macrophytes were classified into two benthic ecological groups: BEGI (late-successional taxa) and BEGII (tolerant and opportunistic taxa). By this new non-destructive method, it was found out that 3 sites had "high" ecological quality, 3 sites "good" quality, 1 site "moderate" quality, and 2 sites "bad" quality. The relationship between the pressure index MA-LUSI and new index (BEARI) was also tested and a strong negative correlation was found.

Keywords: Angiosperms, BEARI, ecological status, MA-LUSI, marine algae

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Introduction

The EU Water Framework Directive (WFD 2000/60/EC) requires that the ecological status of surface waters will be "high/good" by 2015. Macroalgae and angiosperms were declared as one of the biological quality elements to assess the ecological status of coastal and transitional waters by the WFD such as phytoplankton, macroinvertebrates, and fish.

Several non-destructive [the CARtography of LITtoral (CARLIT) (Ballesteros *et al.* 2007)] and destructive [the Ecological Evaluation Index (EEI) (Orfanidis *et al.* 2001, 2011), the *Posidonia oceanica* multivariate index (POMI) (Romero *et al.* 2007), the Macrophyte Quality Index (MaQI) (Sfriso *et al.* 2007, 2009), the *Posidonia oceanica* Rapid Easy Index (PREI) (Gobert *et al.* 2009), CymoSkew index (Orfanidis *et al*. 2010), the Alien Biotic Index (ALEX) (Çınar and Bakır 2014; Piazzi *et al.* 2015), Marine Floristic Ecological Index (MARFEI) (Taşkın *et al.* 2018)] indices have been developed and used for the assessment of the ecological status classes of the coastal and transitional waters of the the Mediterranean and the Sea of Marmara.

The aim of this study is to improve a non-destructive method by using marine macrophytes. In the present study, Benthic Ecological Assessment Rapid Index (BEARI) is proposed as a new non-destructive method to assess the ecological status of coastal waters. This new index was tested to assess the ecological status classes of the Sea of Marmara and the coasts of Aegean Sea of Turkey. The relationship between the pressure index MA-LUSI and BEARI was also investigated.

Materials and Methods

Study Area and Sampling

Sampling was only made once at each of nine localities in the Sea of Marmara and the Turkish coasts of the Aegean Sea in May, June or July between 2015 and 2019 (Figure 1). Sampling was made in spring and summer seasons for the pressures (i.e. tourism, nutrients) and macroalgal growth. To compare EEI index results by Integrated Marine Pollution Monitoring Programme of Turkey conducted by the Ministry of Environment and Urbanization with the new index BEARI the same stations were selected. The photographic samplings were made from hard and soft substrates between 0 and 5 m depths by using underwater camera (Olympus and GoPro3^{+}) by quadrats (20x20 cm) for ten replicates per station. At least 5 m distance was replaced between two replicates.

Pressure data

Land Uses Simplified Index (LUSI) was developed and used for the assessment of eutrophication (Flo *et al.* 2011, 2019), and it is based on the anthropogenic land uses and the coastline morphology. The Macroalgae-Land Uses Simplified Index (MA-LUSI) has been suggested to be applied for shallow water macroalgae communities disturbed with mariculture activities, sewage outfalls, harbor facilities, irregular freshwater inputs, urban, commercial and industrial, agricultural inputs by the Mediterranean Intercalibration Group of macroalgae (MEDGIG; EC, 2013). The pressure index MA-LUSI data was obtained from the Corine land cover map affect a 1.5 km buffer zone around the sampling sites.

Data analysis

Macrophytes (macroalgae and angiosperms) were classified into two benthic ecological groups, BEGI (late-successional taxa such as *Cystoseira* spp., angiosperms, *Padina* spp., calcareous red algae, *Halimeda tuna*, *Acetabularia acetabulum*), and BEGII (tolerant and opportunistic taxa such as filamentous and sheet-like green algae, blue green algae) (Table 1) based on Orfanidis *et al.* (2011) and Taşkın *et al.* (2018).

The coverage of the macroalgae and angiosperms data was obtained from ten photographic samplings per station by using the photoQuad software (Trygonis and Sini 2012). The photoQuad software is the visual method in the digital domain, providing a versatile, fast, and semi-automated approach, and the grid cell count method in photoQuad can be used to quickly estimate percentage coverage of organisms and associated substrate (Trygonis and Sini 2012) (Figure 2).

$$BEARI_{EQR} = (\%BEGI) / (\%BEGI+\%BEGII)$$

Ecological quality ratio (EQR) between 0 and 1 was obtained by the above formulation (bad=0-0.20; poor=0.20-0.40; moderate=0.40-0.60; good=0.60-0.80; high=0.80-1). The relationship between pressures and $BEARI_{EQR}$ values were calculated using the MA-LUSI index.

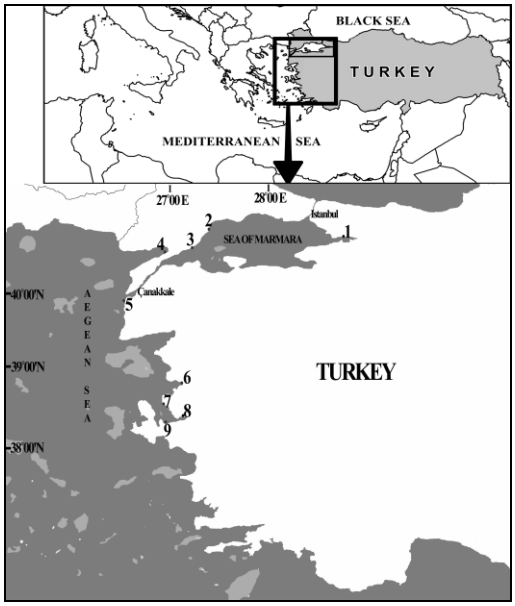

Figure 1. Sampling stations in the Sea of Marmara and the Turkish coasts of the Aegean Sea (1: Hereke; 2: Tekirdağ; 3: Şarköy; 4: Saros, 5: Yeniköy; 6: Yenişakran; 7: Foça; 8: Bostanlı, İzmir inner Bay; 9: Urla)

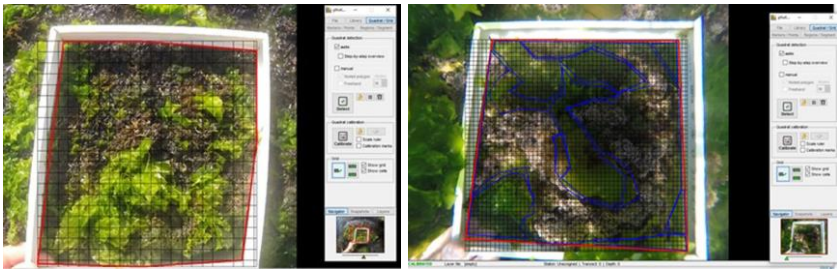

Figure 2. An example for the calculation of coverage (%) of the benthic macrophytes by using the photoQuad software

Table 1. The Benthic Ecological Groups (BEG) of marine benthic macrophytes (macroalgae and angiosperms)

Taxa	BEG
Brown algae	
Cystoseira spp. (*C. crinita, C. compressa, C. barbata, C. spinosa, C. foeniculacea, etc.*)	I
Padina spp. (*P. pavonica, P. pavocanoides, etc.*)	I
Sargassum spp. (*S. acinarium, S. vulgare, etc.*)	I
Cutleria/Aglaozonia	I
Taonia atomaria	I
Ralfsia verrucosa	I
Angiosperms/Seagrasses	
Posidonia oceanica	I
Cymodocea nodosa	I
Zostera spp. (*Z. marina, Z. noltei*)	I
Ruppia spp.	I
Red Algae	
Corallina spp.	I
Ellisolandia elongata	I
Halopitys incurva	I
Amphiroa spp. (*A. rigida, etc.*)	I
Haliptilon attenuatum	I
Hydrolithon farinosum	I
Jania spp. (*J. rubens, etc.*)	I
Lithophyllum spp. (*L. cystoseirae, etc.*)	I
Melobesia membranacea	I
Peyssonnelia spp. (*P. dubyi, P. squamaria, etc.*)	I
Phymatolithon spp.	I
Sahlingia subintegra	I
Pneophyllum spp.	I
Ganonema farinosum	I
Lithothamnion spp.	I
Mesophyllum spp. (*M. expansum, etc.*)	I
Other calcareous red algae	I

Table 1. Continued

Green Algae	
Halimeda tuna	I
Acetabularia acetabulum	I
Flabellia petiolata	I
Anadyoemen stellata	I
Brown algae	
Dictyota spp. (*D. dichotoma, etc.*)	II
Colpomenia spp.	II
Halopteris spp.	II
Sphacelaria spp. (*S. cirrosa, S. rigidula, etc.*)	II
Acinetospora crinita	II
Ectocarpus spp. (*E. fasciculatus, etc.*)	II
Feldmannia spp.	II
Myrionema spp.	II
Cladosiphon spp.	II
Petalonia spp.	II
Scytosiphon spp.	II
Stilophora tenella	II
Red Algae	II
Laurencia spp.	II
Chondracanthus acicularis	II
Chondria capillaris	II
Chylocladia verticillata	II
Gelidium spp.	II
Gelidiella spp.	II
Gracilaria spp.	II
Gigartina spp.	II
Dermocorynus dichotomus	II
Halymenia spp.	II
Hypnea musciformis	II
Palisada spp.	II
Pterocladiella capillacea	II
Acrochaetium spp.	II
Callithamnion corymbosum	II
Ceramium spp.	II
Dasya spp.	II
Falkenbergia rufolanosa	II
Polysiphonia spp.	II
Vertebrata spp.	II
Green Algae	II
Bryopsis spp.	II
Chaetomorpha spp.	II
Cladophora spp.	II
Codium spp.	II
Caulerpa spp.	II
Ulva spp.	II
Valonia spp.	II
Blue-Green Algae	II
All Cyanophyta taxa	II

Results and Discussion

Benthic Ecological Assessment Rapid Index (BEARI) is proposed as a new non-destructive method to assess the ecological quality of coastal waters, and it has been tested at 9 stations from the coasts of Aegean Sea and the Sea of Marmara, Turkey. The study revealed high ecological status class for 3 sites, good for 3 sites, moderate for 1 site, and bad for 2 sites (Table 2). Hereke (Sea of Marmara) and Bostanlı (İzmir, Aegean Sea) were fairly impacted by the anthropogenic activities and the highest values of MA-LUSI index were found at Bostanlı (11.25) and Hereke (8.75) sampling sites. The relationship between the pressure MA-LUSI index and $BEARI_{EQR}$ was tested and a negative linear relationship was found (Table 2, Figure 3).

The Marine Floristic Ecological Index (MARFEI) had been developed and tested at 25 sites in the Sea of Marmara by Taşkın *et al.* (2018), who reported that Şarköy, Tekirdağ and Hereke were, respectively, found at "moderate", "poor" and "bad" ecological quality status. In the present study, these stations have been evaluated as "good" (at Şarköy), "moderate" (at Tekirdağ) and "bad" (at Hereke).

The ecological status of Ayvalık (the Aegean coasts of Turkey) had been assessed at two sites by using the Ecological Evaluation Index (EEI) (Taşkın 2015) and the station at the inner bay of Ayvalık was reported at "moderate" quality while the station at the outer bay was at "high" ecological quality status.

Table 2. The average coverage (%) of the benthic ecological groups (BEGI, BEGII), the ecological quality ratio by $BEARI_{EQR}$ and pressures data (MA-LUSI index) of the research sites from Turkey

Stations	Benthic ecological groups (%)		$BEARI_{EQR}$	Ecological Status	MA-LUSI
	BEGI	BEGII			
Şarköy	57.44	33.79	0.61	Good	3
Tekirdağ	25.63	34.76	0.50	Moderate	7
Hereke	0	85.29	0	Bad	8.75
Saros	70.47	0.58	0.99	High	2.81
Yeniköy	46.64	21.90	0.65	Good	1.125
Yenişakran	55.08	4.11	0.94	High	4.5
Foça	50.71	0.32	0.98	High	3
Bostanlı (İzmir Inner Bay)	0	74.73	0	Bad	11.25
Urla	55.21	19.90	0.72	Good	6.25

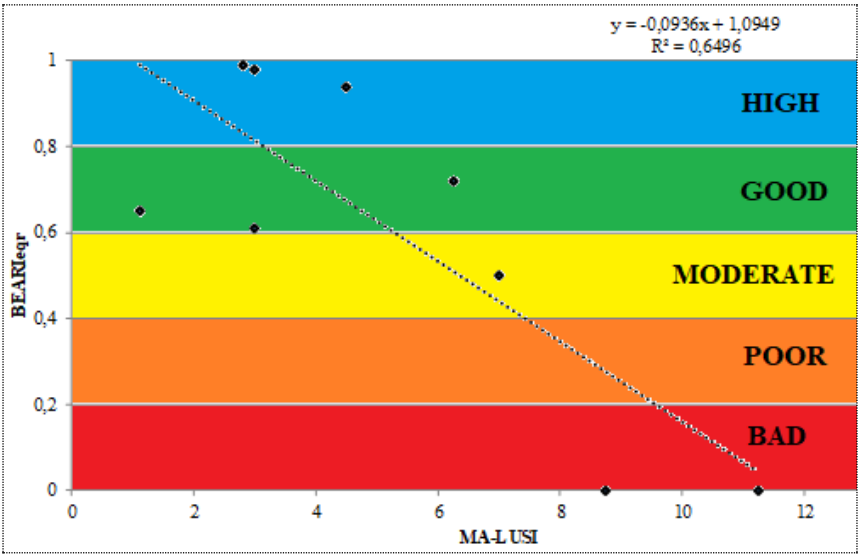

Figure 3. Relationship between BEARI$_{EQR}$ and pressure data (MA-LUSI index) of the research sites from Turkey

Marine benthic macrophytes (macroalgae and seagrasses) are a good bioindicators to assess for the ecological quality status of the coastal and transitional waters. Marine benthic macrophytes are split into two groups by several biotic macrophytes indices, generally (Ballesteros *et al.* 2007; Orfanidis *et al.* 2001, 2011; Sfriso *et al.* 2007, 2009; Taşkın *et al.* 2018). The first group sensetive, late-successional macroalgae (*Cystoseira* spp., *Sargassum* spp., *Padina* spp., calcareous red algae, etc.) and seagrasses (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera* spp.) are found common in pristine waters (Boudouresque 1969; Ballesteros 1990; Pergent 1991) while the second group the tolerant and opportunistic algae (filamentous *Cladophora*, *Ceramium*, *Ectocarpus*, *Polysiphonia*, sheet-like *Ulva*, blue green algal layer, etc.) are commonly distributed in the human-impacted coastal waters (Orfanidis *et al.* 2003). In the present study, marine benthic macrophytes were also classified into two benthic ecological groups, BEGI (the late-successional, sensitive taxa) and BEGII (tolerant and opportunistic taxa).

Ecological quality status of the Turkish coastal waters by using marine macroalgae and marine angiosperms were studied by Taşkın *et al.* (2020). They used a destructive method Ecological Evaluation Index (EEI) to assess the coastal waters. In the present study, seven sampling sites (Şarköy, Tekirdağ, Hereke, Saros, Yeniköy, Bostanlı, Urla) were selected from the same sites of the Integrated Marine Pollution Monitoring Programme of Turkey (Ministry of Environment and Urbanization of Turkey) (Taşkın *et al.* 2020) to compare destructive (EEI) and non-destructive (BEARI) methods. The relationship

between the destructive index EEI and new non-destructive index BEARI results was tested and a good correlation (R^2= 0.94, p= 0.0018) was found (Figure 4).

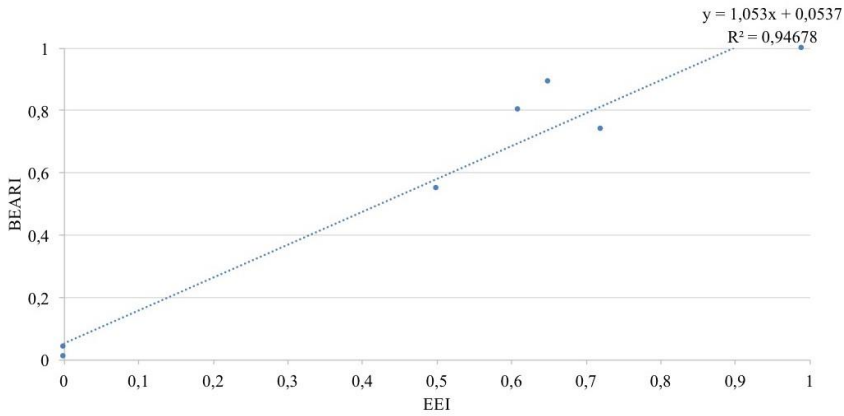

Figure 4. Relationship between BEARI and EEI index of the several sampling sites from Turkey

In conclusion, a new method, Benthic Ecological Assessment Rapid Index (BEARI) being a non-destructive, rapid and easily implemented one, was used for the coastal waters of the Sea of Marmara and Aegean Sea. BEARI could be used for the assessment of the ecological quality status of the benthic communities (i.e. coralligenous habitats) from shallow and deep waters.

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Deniz makrofitleri kullanılarak tahribatsız yeni bir metot ile kıyı sularının ekolojik durumunun belirlenmesi

Öz

AB Su Çerçeve Direktifi'nde kıyı ve geçiş sularının ekolojik durumunun değerlendirilmesi için bentik makrofitler (makroalgler ve angiospermler) biyolojik element olarak önerilmiştir. Bu çalışmada, tahribatsız yeni bir metot, Bentik Ekolojik Değerlendirme Hızlı İndeks (BEDHİ), deniz sularının ekolojik kalitesinin değerlendirilmesi için önerilmiştir. Marmara Denizi'nden 3 ve Ege Denizi kıyılarından 6 farklı noktasından fotoğrafik örneklemeler gerçekleştirilmiştir. Makrofitler, BEGI (geç gelişimsel gösteren taksonlar) ve BEGII (toleranslı ve fırsatçı taksonlar) olmak üzere iki ekolojik gruba ayrılmıştır. Bu çalışmada, 3 nokta için çok iyi, 3 nokta için iyi, 1 nokta

için orta ve 2 nokta için kötü ekolojik durum sınıfında bulunmuştur. Baskı indeksi MA-LUSI ile yeni indeks BEDHİ arasındaki ilişki test edilmiş ve negatif bir doğrusal ilişki tespit edilmiştir (R^2=0.649).

Anahtar kelimeler: Angiosperm, BEDHİ, ekolojik durum, MA-LUSI, deniz algleri

References

Ballesteros, E. (1990) Structure and dynamics of the *Cystoseira caespitosa* (Fucales, Phaeophyceae) community in the North-Western Mediterranean. *Scient Mar* 54: 155-168.

Ballesteros, E., Torras, X., Pinedo, S., García, M., Mangialajo, L., de Torres, M. (2007) A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive. *Marine Pollution Bulletin* 55: 172-180.

Boudouresque, C.F. (1969) Etude qualitative et quantitative d'un peuplement algal à *Cystoseira mediterranea* dans la région de Banyuls sur Mer. *Vie et Milieu* 20: 437-452.

Çınar, M.E., Bakır, K. (2014) ALien Biotic IndEX (ALEX) – a new index for assessing impacts of alien species on benthic communities. *Marine Pollution Bulletin* 87: 171-179.

EC (2013) Commission Decision of 20 September 2013 Establishing, Pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the Values of the Member State Monitoring System Classifications as a Result of the Intercalibration Exercise and Repealing Decision 2008/ 915/EC. Official Journal of the European Union (L 266/1-47).

EU (2000) DIRECTIVE 2000/60/EC of the European parliament and of the council, of 23 October 2000, establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, G.U.C.E. 22/12/2000, L 327.

Flo, E., Camp, J., Garcés, E. (2011) Assessment pressure methodology, Land Uses Simplified Index (LUSI). (Personal communication WFD-CIS- phase II, Technical paper).

Flo, E., Garcés, E., Camp, J. (2019) Land Uses Simplified Index (LUSI): determining land pressures and their link with coastal eutrophication. *Frontiers in Marine Science* 6, 18. doi: 10.3389/fmars.2019.00018.

Gobert, S., Sartoretto, S., Rico-Raimondino, V., Andral, B., Chery, A., Lejeune, P., Boissery, P. (2009) Assessment of three ecological status of Mediterranean

French coastal waters as required by the Water Framework Directive using the *Posidonia oceanica* Rapid Easy Index: PREI. *Marine Pollution Bulletin* 58: 1727-1733.

Orfanidis, S., Papathanasiou, V., Gounaris, S., Theodosiou, Th. (2010) Size distribution approaches for monitoring and conservation of coastal *Cymodocea* habitats. *Aquatic Conserv: Mar Freshw Ecosyst* 20: 177-188.

Orfanidis, S., Panayotidis, P., Stamatis, N. (2001) Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model. *Mediterranean Marine Science* 2: 45-65.

Orfanidis, S., Panayotidis, P., Stamatis, N. (2003) An insight to the ecological evaluation index (EEI). *Ecological Indicators* 3: 27-33.

Orfanidis, S., Panayotidis, P., Ugland, K. (2011) Ecological Evaluation Index continuous formula (EEI-c) application: a step forward for functional groups, the formula and reference condition values. *Mediterranean Marine Science* 12: 199-231.

Pergent, G. (1991) Les indicateurs écologiques de la qualité du milieu marin en Méditerranée. *Oceanis* 17(4): 341-350.

Piazzi, L., Gennaro, P., Ceccherelli, G. (2015) Suitability of the ALien Biotic IndEX (ALEX) for assessing invasion of macroalgae across different Mediterranean habitats. *Marine Pollution Bulletin* 97: 234-240.

Romero, J., Martinez-Crego, B., Alcoverro, T., Perez, M. (2007) A multivariate index based on the seagrass *Posidonia oceanica* (POMI) to assess ecological status of coastal waters under the Water Framework Directive (WFD). *Marine Pollution Bulletin* 55: 196-204.

Sfriso, A., Facca, C., Ghetti, P.F. (2007) Rapid Quality Index, based mainly on Macrophyte Associations (R-MaQI), to assess the ecological status of the transitional environments. *Chemistry and Ecology* 23: 1-11.

Sfriso, A., Facca, C., Ghetti, P.F. (2009) Validation of the Macrophyte Quality Index (MaQI) set up to assess the ecological status of Italian marine transitional environments. *Hydrobiologia* 617: 117-141.

Taşkın, E. (2015) Ecological status of coastal waters of Ayvalık (Aegean Sea, Turkey) by EEI method. *Ekoloji* 24 (95): 10-16.

Taşkın, E., Tan, İ., Minareci, E., Minareci, O., Çakır, M., Polat-Beken, Ç. (2020) Ecological quality status of the Turkish coastal waters by using marine

macrophytes (macroalgae and angiosperms). *Ecological Indicators* 112: 106107.

Taşkın, E., Tsiamis K., Orfanidis, S. (2018) Ecological quality of the Sea of Marmara (Turkey) assessed by the *Mar*ine *F*loristic *E*cological *I*ndex (MARFEI). *J Black Sea/Mediterranean Environ.* 24: 97-114.

Trygonis, V., Sini, M. (2012) photoQuad: a dedicated seabed image processing software, and a comparative error analysis of four photoquadrat methods. *Journal of Experimental Marine Biology and Ecology* 424-425: 99-108.