Turkish Journal of Botany

Volume 48 | Number 6 Article 3

11-13-2024

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TAŞKIN, ERGÜN; GÜREŞEN, AYSU; and BİLGİÇ, FURKAN (2024) "Implementation of a new Non-destructive Phytobenthic Index (NPI) with the Posidonia Biotic Index (BiPo) to evaluate the ecological status of the Turkish Aegean coasts (Eastern Mediterranean)," *Turkish Journal of Botany*: Vol. 48: No. 6, Article 3.
https://doi.org/10.55730/1300-008X.2818
Available at: https://journals.tubitak.gov.tr/botany/vol48/iss6/3



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Research Article

Turk J Bot
(2024) 48: 296-307
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doi:10.55730/1300-008X.2818

Implementation of a new Nondestructive Phytobenthic Index (NPI) with the *Posidonia* Biotic Index (BiPo) to evaluate the ecological status of the Turkish Aegean coasts (Eastern Mediterranean)

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Received: 19.04.2024 • **Accepted/Published Online:** 22.10.2024 • **Final Version:** 13.11.2024

Abstract: The ecosystem status of the Aegean Sea coasts of Türkiye (Eastern Mediterranean) was assessed using the Biotic Index based on *Posidonia oceanica* (BiPo) and a newly proposed Nondestructive Phytobenthic Index (NPI), according to the requirements of the Water Framework Directive (WFD 2000/60/EC). In addition, their relationships with the Macroalgae-Land Uses Simplified Index (MA-LUSI) were evaluated. The descriptors measured through the NPI included the shoot density, cover, depth and lower limit type of the *Posidonia* meadows and cover of the other macrophytic communities; *Cymodocea/Zostera*, canopy-forming brown, coralligenous, opportunistic, and alien macroalgae. The good status was expressed by the mean value of the BiPo (0.69) at 20 sites, while the moderate status was expressed by the NPI (0.59) at 25 sites. Simultaneous implementation of the biotic indices proved their consistency (r = 0.745), while negative relationships between the MA-LUSI and the BiPo (r = –0.243) and NPI (r = –0.450), underlined their capability to assess the degradation of macrophytic communities in anthropized regions.

Key words: *Posidonia* biotic index, nondestructive phytobenthic index, ecological status, *Posidonia oceanica*, Eastern Mediterranean

1. Introduction

The implementations of the European Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC) have been essential for monitoring biological quality elements in order to assess water status and indicate environmental alterations in coastal ecosystems (EC, 2000; Hemminga and Duarte, 2000; Romero et al., 2007; Marbà et al., 2012; Gerakaris et al., 2017). Marine macrophytes, including the common representative angiosperm *Posidonia oceanica* (Linneaus) Delile, are used as specific biological quality elements in the monitoring programs executed by the WFD and the MSFD due to their sensitivity to pressures and effective application capacity in a wide geospatial extent (Balestri et al., 2004; Martínez-Crego et al., 2008; Lopez y Royo et al., 2010; Med-GIG, 2011; Boudouresque et al., 2009).

The endemic *P. oceanica* is the leading seagrass species spreading across large areas and forming habitats in the Mediterranean Sea and its distinctive reactions to environmental alterations are already known (Pergent et al., 1995; Pergent-Martini et al., 2005; Lopez y Royo et al., 2009; Boudouresque et al., 2012). Moreover, macroalgal communities associated with *P. oceanica* beds have a wide distribution along the Eastern Mediterranean from pristine to urbanized sites and are subjected to significant impacts that cause progressive regressions simultaneously, as in the Western Mediterranean (Ruiz and Romero, 2003; Montefalcone et al., 2007; Bonacorsi et al., 2013; Blanco-Murillo et al., 2022).

Human pressures, such as pollution, destructive fishing methods, mooring, the invasion of alien species, and rapid urbanization resulting from various forms of land use, generally lead to major alterations in the habitats of the Mediterranean Sea ecosystem (Ardizzone and Pelusi, 1984; Boudouresque et al., 2006; Coll et al., 2012; Giakoumi et al., 2013; Halpern et al., 2015; Sini et al., 2017). Environmental impacts have been clearly identified as direct irreversible degradation of macrophytic communities and habitat heterogeneity (Montefalcone et al., 2007; Montefalcone et al., 2010; Pergent et al., 2013; Telesca et al., 2015). Therefore, seagrass beds (*Posidonia*, *Cymodocea*, and *Zostera*), macroalgal forests (*Cystoseira*, *Sargassum*), and coralligenous algae in the Mediterranean Sea, are included as Priority Habitats in the Convention on the Conservation of European Wildlife and Natural

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Habitats, European Union's Habitats Directive (92/43/EEC) (EEC, 1992) and the Mediterranean Action Plan for the Conservation of Marine Vegetation (UNEP-MAP).

Over the last decade, a variety of macrophyte biotic indices have been developed in order to assess the ecological quality that compares the status of a biological quality element, both in a particular body of water and in a pristine area (EC, 2000) (Cartography of Littoral (CARLIT): Ballesteros et al., 2007; Rapid Quality Index (R-MaQI): Sfriso et al., 2007; *Posidonia oceanica* Multivariate Index (POMI): Romero et al., 2007; INTERREG *Posidonia* Programme (POSID): Pergent et al., 2007; Valencian CS: Fernandez-Torquemada et al., 2008; *Posidonia oceanica* Rapid Easy Index (PREI): Gobert et al., 2009; Biotic Index based on *Posidonia oceanica* (BiPo): Lopez y Royo et al., 2010; Ecological Evaluation Index continuous formula (EEI-c): Orfanidis et al., 2011; CymoSkew Biotic Index: Orfanidis et al., 2020; Marine Floristic Ecological Index (MARFEI): Taşkın et al. 2018, 2020b and Benthic Ecological Assessment Rapid Index (BEARI): Taşkın, 2020). The abovementioned ecological indices have been successfully applied mainly in the Western Mediterranean and should be tested in various coastal regions along the Mediterranean Sea at a more spatial scale in order to construct regular classifications in relation to the WFD.

Assessing anthropogenic disturbances in coastal waters provides a functional tool in terms of determination of potential threat spots and land use management implementations (Borja et al., 2011; Flo et al., 2019). Therefore, anthropogenic indices with feasible methodologies (Land Uses Simplified Index (LUSI): Flo et al., 2011; Macroalgae-LUSI (MA-LUSI): Taşkın et al. 2020b; Pressure Impact Analysis (PIA): Tan et al., 2017) are used in the evaluation of environmental impacts.

From this perspective, the present study aimed to 1) introduce a new Nondestructive Phytobenthic Index (NPI), 2) assess the coastal ecosystem status of 25 sites along the Turkish coasts of the Aegean Sea (Eastern Mediterranean) using the BiPo and NPI, 3) test the relationship between the biotic indices (BiPo and NPI) and MA-LUSI, and 4) evaluate the implementation consistency of these indices throughout the Eastern Mediterranean. Consequently, this study contributes to the construction of a long-term data series beneficial for monitoring the marine macrophytes and *P. oceanica* meadows as a functional ecosystem service (Vassallo et al., 2013) in a spatially extensive area.

2. Materials and methods

2.1. Study area

Turkish coasts of the Aegean Sea (Eastern Mediterranean) comprise specific hydrological characteristics when put together with the Western Mediterranean Sea due to the Turkish Straits Current System. Since the Black Sea waters and freshwaters flow to the Aegean Sea, the salinity in the surface waters fluctuates between 32.5 and 37.0‰ (Ignatiades, 2005; Siokou-Frangou et al., 2009).

2.2. Assessment of the anthropogenic pressures

The MA-LUSI (Taşkın et al. 2020b) was applied considering the direct (mariculture, sewage outfall, sediment nutrient release, and harbor) and indirect (urban, industrial, and agriculture) impacts along with confinement and the background trophic status as stated by the Mediterranean Intercalibration Group (MED-GIG) (EC, 2013). Pressure data (MA-LUSI) were obtained from the land use map data of the CORINE Land Cover 2000 database covering a 1.5-km buffer zone around the sampling sites.

2.3. Development of the NPI

In order to fulfill the requirements of the WFD, the new NPI was developed based on the accessible data for benthic macrophytes along the Turkish coasts. Since *P. oceanica* meadows comprise high biodiversity with the coexistence of macroalgal groups, relevant descriptors were integrated into the procedure to evaluate the functioning of the coastal ecosystems along the region.

During the assessment of the ecological quality ratio (EQR), benthic macrophytes were classified as the representatives of different ecological conditions due to the expert judgement and spatial assessment of anthropogenic pressures (Orfanidis et al., 2003; Med-GIG, 2011). Accordingly, the presence of seagrasses and late-successional canopy-forming brown algae and coralligenous macroalgae, represented reference conditions, whereas the presence of opportunistic and alien macroalgae with high growth rates, represented anthropized conditions.

A model was designed using a set of nine descriptors of the main community groups (G) observed on the line transects a depth between 0 m and 40 m: lower limit type (GIa), shoot density (shoots m^{-2}) (GIb), lower limit depth (m) (GIc) and cover (%) (GId) of *P. oceanica* (GI), and cover (%) of the other groups: *Cymodocea nodosa*/*Zostera* spp. (GII), canopy-forming brown (GIII), coralligenous (GIV), opportunistic (GV), and alien (GVI) macroalgae (Table 1).

Aiming to demonstrate the grades of pressures (from pristine–high to anthropized–bad status) (EC, 2000) at each site with the NPI, each descriptor was evaluated through scoring (from 4 to 0) based on the available literature and statements of experts (Orfanidis et al., 2003; Gobert et al., 2009; UNEP-MAP-RAC/SPA, 2011; Taşkın et al., 2018, 2020b; Taşkın, 2020). The results based on the ecological groups (GI, GII, GIII, and GIV), representing a recent disappearance or nonexistence, corresponded to a bad/poor ecological status. Ranking for five ecological status classes: bad (0–0.2), poor (0.2–0.4), moderate (0.4–0.6), good (0.6–0.8), and high (0.8–1), was identified as proposed by the WFD (EC, 2000). An EQR between 0 and 1 was obtained according to the following formula:

Table 1. Evaluation and harmonization of the main community categories for the NPI.

EG	Descriptor	Scoring				
		0	1	2	3	4
GIa	Lower limit type of *P. oceanica*	none	Regressive	Sparse	Sharp	Progressive
GIb	Shoot density of *P. oceanica* at 15 m (shoot m^{-2})	none	0–150	150–300	300–450	> 450
GIc	Lower limit depth of *P. oceanica* (m)	none	0–15	15–20	20–30	> 30
GId	Cover of *P. oceanica* at 15 m (%)	none	0–25	25–50	50–75	75–100
GII	Cover (%) of *Cymodocea nodosa*/*Zostera* spp.*	none	1–25	25–50	50–75	75–100
GIII	Cover (%) of canopy-forming brown macroalgae (*Cystoseira*, *Sargassum*) *	none	1–25	25–50	50–75	75–100
GIV	Cover (%) of coralligenous macroalgae (i.e. *Mesophyllum*, *Lithothamnion*, *Titanoderma*) *	none	1–25	25–50	50–75	75–100
GV	Cover (%) of opportunistic macroalgae (i.e. *Ulva* spp., *Cladophora* spp., filamentous) *	none	1–25	25–50	50–75	75–100
GVI	Cover (%) of alien macroalgae (i.e. *Stypopodium schimperi*, *Caulerpa* spp., *Codium fragile*, *Asparagopsis* spp.) *	none	1–25	25–50	50–75	75–100

EG: Ecological group, *if present, the highest cover value (%) at 7 depths (0, 5, 10, 15, 20, 30, and 40 m) was taken as the total coverage.

EQR_{NPI} = (GIa + GIb + GIc + GId + GII + GIII + GIV) / [(GIa + GIb + GIc + GId + GII + GIII + GIV) + (GV + GVI)].

2.4. Application of the method to the Aegean coasts

Sampling was conducted in June–September 2023 at 25 sites along the Aegean coasts of Türkiye (Figure 1). Scuba diving was carried from the shore up to a depth of 40 m in the aphotic subtidal zone around the steep decline of the seafloor in each site. In order to assess the macrophytic cover (%) for the NPI, nondestructive, photographic samplings were taken throughout the line transect-quadrats (60 × 60 cm) at 7 depths (0, 5, 10, 15, 20, 30, and 40 m) and a distance of at least 5 m was left between the three replicates of the transects per site (Figure 2). PhotoQuad Software (Trygonis and Sini 2012) was used to integrate the field data. Moreover, the main descriptors of *P. oceanica*, including the shoot density (shoots m^{-2}) and cover (%) were recorded and 20 shoots were collected at the intermediate depth (15 ± 1 m) in order to measure the leaf area (cm^2 $shoot^{-1}$) used in the BiPo and depth and type were recorded on the lower limit depth of the meadow.

2.5. Data analysis

Measurements of the main *P. oceanica* descriptors [lower limit depth (m), lower limit type (regressive, sparse, sharp, or progressive), shoot density (shoots m^{-2}) and leaf area (cm^2 $shoot^{-1}$)] were presented and the EQRs of the BiPo were measured by averaging the EQR scores of the four individual descriptors (Lopez y Royo et al., 2010). As for the EQRs of the NPI, they were measured using the formula after averaging the mean cover (%) of the main community groups (GId to GVI) along each transect for the three transects sampled.

In order to verify their implementation capacity to create consistent classifications, the potential relationships between the biotic indices (BiPo and NPI) were tested. Moreover, the efficiency of the biotic indices to reflect the anthropogenic pressures (MA-LUSI), was verified using linear regression analysis. Effects of the anthropogenic pressures on the benthic macrophytes (descriptors of the community groups: GIa to GVI, using the BiPo and NPI) were tested using principal component analysis (PCA). In order to compare the abundances of the benthic macrophytes among the sampling sites, the Bray–Curtis clusters were constructed using the coverage data of the community groups (GI–GVI). All statistical analyses were performed using PAST Software (Hammer et al., 2001).

3. Results

The results of the biotic indices (BiPo and NPI), one of which was newly proposed for benthic macrophytic communities, are given for each site in Table 2. According to the BiPo, the ecological status of the Aegean coasts of Türkiye ranged between high and moderate, with the mean value (0.69) of the good status at 20 sites. As for the NPI, the ecological status ranged between high and bad, with a mean value (0.59) of moderate at 25 sites. The relationship between the BiPo and NPI revealed a significant value of $R^2 = 0.745$, $p < 0.05$ (Figure 3).

The pressures assessed at each site are given in Table 2. İzmir was recorded as the most impacted site subjected to anthropogenic activities with the highest (11.25) MA-LUSI value, followed by Karaburun (6.25) and Çandarlı (5.63), while Gökçeada Island (0.94), Bozburun-2 (0.94), Yeniköy (1.13), Bozcaada Island, Kuşadası, and Gökova Bay (1.88) were the least anthropized sites. The relationships between

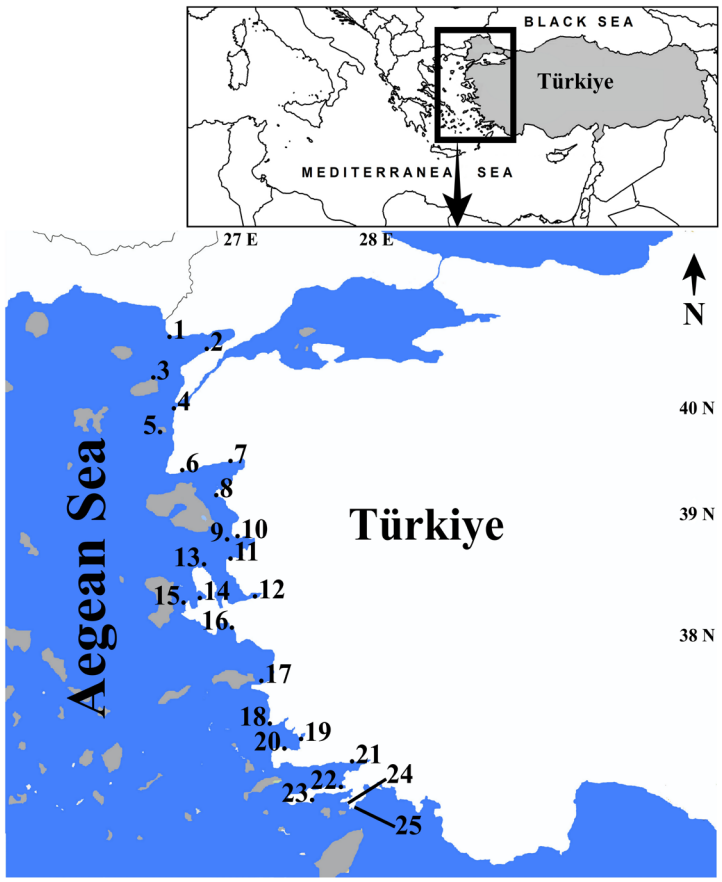


Figure 1. Sampling sites on the Aegean coasts of Türkiye (1: Enez, 2: Saros Bay, 3: Gökçeada Island, 4: Yeniköy, 5: Bozcaada Island, 6:Babakale, 7: Altınoluk, 8: Ayvalık, 9: Dikili, 10: Çandarlı, 11: Foça, 12: İzmir, 13: Karaburun, 14: Ildır, 15: Çeşme, 16: Seferihisar, 17: Kuşadası, 18: Didim, 19: Güllük, 20: Bodrum, 21: Akyaka, 22: Gökova Bay, 23: Datça: 24: Bozburun-1, 25: Bozburun-2).

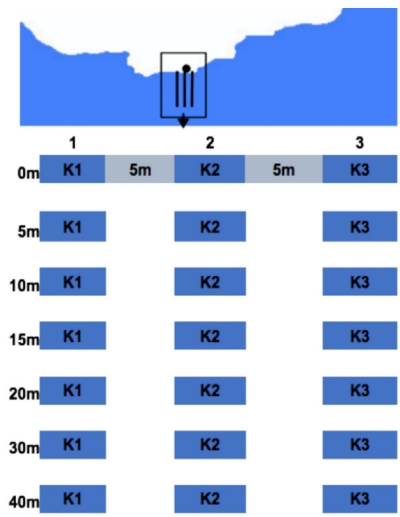


Figure 2. Line transect-quadrat results for the photographic samplings.

Table 2. Ecological status (with the BiPo and NPI), descriptors of *P. oceanica* (GIa-GId), and coverages (%) of other macrophytes (GII-GVI) and anthropogenic pressure data (MALUSI) at the sites.

No	Station	MALUSI	GIa (LLT)	GIb (SD-15 m)	GIc (LLD)	GId (Cover %-15 m)	LA (-15 m)	EQR' type	EQR' density	EQR' depth	EQR' surface	GII (%)	GIII (%)	GIV (%)	GV (%)	GVI (%)	EQRNPI	EQRBiPo
1	Enez	4.00	Sp	150 ± 13.2	20.0 ± 0.3	50	201 ± 50.3	0.44	0.35	0.55	0.76	20	0	0	10	1	0.82	0.52
2	Saros Bay	2.81	Sp	192 ± 8.2	18.0 ± 0.6	100	243 ± 62.1	0.44	0.44	0.49	0.92	10	24	9	61		0.75	0.57
3	Gökçeada	0.94	Sp	304 ± 24.0	19.0 ± 0.5	60	263 ± 52.4	0.44	0.70	0.52	1.00	12	0	95	66	8	0.80	0.66
4	Yeniköy	1.13	Sh	432 ± 56.8	25.0 ± 0.3	100	197 ± 44.8	0.66	0.99	0.69	0.75	20	20	0	20	27	0.82	0.77
5	Bozcaada	1.88	Sh	336 ± 57.2	30.0 ± 0.2	100	150 ± 37.4	0.66	0.77	0.82	0.57	0	23	7	51	15	0.79	0.71
6	Babakale	3.00	R	0	5.0 ± 0.0	0	0	0.21	0.00	0.52	0.00	10	45	0	2	81	0.44	0
7	Altınoluk	3.00	R	256 ± 15.1	18.0 ± 0.5	80	200 ± 49.9	0.21	0.59	0.49	0.76	10	11	5	28	1	0.79	0.51
8	Ayvalık	4.50	R	192 ± 7.9	12.0 ± 1.0	40	192 ± 52.2	0.21	0.44	0.33	0.73	10	1	0	55	40	0.64	0.43
9	Dikili	4.50	none	0	none	0	0					0	10	26	35	80	0.33	0
10	Çandarlı	5.63	S	181 ± 23.5	22.5 ± 0.4	100	149 ± 63.7	0.44	0.42	0.62	0.57	1	0	0	40	20	0.80	0.51
11	Foça	5.00	S	288 ± 27.1	32.0 ± 0.5	100	176 ± 47.7	0.44	0.66	0.88	0.67	0	5	20	43	1	0.82	0.66
12	İzmir	11.25	none	0	none	0	0					0	0	0	10	0	0.00	0
13	Karaburun	6.25	Sh	336 ± 30.5	35.0 ± 0.3	100	190 ± 57.3	0.66	0.77	0.96	0.72	0	10	20	30	1	0.83	0.78
14	Ildır	4.68	R	250 ± 32.8	21.0 ± 0.5	90	156 ± 47.0	0.21	0.58	0.58	0.59	8	0	0	29	30	0.69	0.49
15	Çeşme	5.00	Sp	336 ± 30.4	35.0 ± 0.3	100	163 ± 65.3	0.44	0.77	0.96	0.62	5	50	5	10	30	0.74	0.70
16	Seferihisar	3.75	Sp	320 ± 32.2	34.0 ± 0.5	100	187 ± 58.9	0.44	0.74	0.93	0.71	20	90	1	75	5	0.83	0.70
17	Kuşadası	1.88	Sp	208 ± 29.1	27.0 ± 0.2	100	175 ± 72.0	0.44	0.48	0.74	0.66	30	100	70	58	2	0.84	0.58
18	Didim	4.50	R	75 ± 18.9	15.0 ± 0.5	100	146 ± 34.2	0.21	0.17	0.41	0.55	15	0	0	55	85	0.53	0.34
19	Güllük	5.00	R	0	5.0 ± 0.0	0	0					16	0	10	27	1	0.50	0
20	Bodrum	4.50	R	0	2.0 ± 0.0	0	0					5	0	10	2	30	0.50	0
21	Akyaka	4.70	Sp	288 ± 32.5	17.0 ± 0.5	100	195 ± 49.6	0.44	0.66	0.47	0.74	30	0	10	28	55	0.72	0.58
22	Gökova Bay	1.88	Sp	240 ± 46.7	25.0 ± 0.2	100	105 ± 40.4	0.44	0.55	0.69	0.40	10	0	0	5	2	0.86	0.52
23	Datça	3.00	Sp	320 ± 62.7	30.0 ± 0.5	100	147.6 ± 30.	0.44	0.74	0.82	0.56	0	20	5	32	1	0.83	0.64
24	Bozburun-1	3.75	Sp	101 ± 28.5	22.5 ± 0.5	100	110 ± 49.5	0.44	0.23	0.62	0.42	0	40	0	55	15	0.69	0.43
25	Bozburun-2	0.94	Sh	240 ± 41.3	36.5 ± 0.2	100	156 ± 53.8	0.66	0.55	1.00	0.59	0	0	60	27	15	0.84	0.70

*Not calculated, LLT: lower limit type, R: regressive, Sp: sparse, Sh: sharp, SD: shoot density (shoot m^{-2}), LLD: lower limit depth (m), LA: leaf area (cm^2 $shoot^{-1}$).

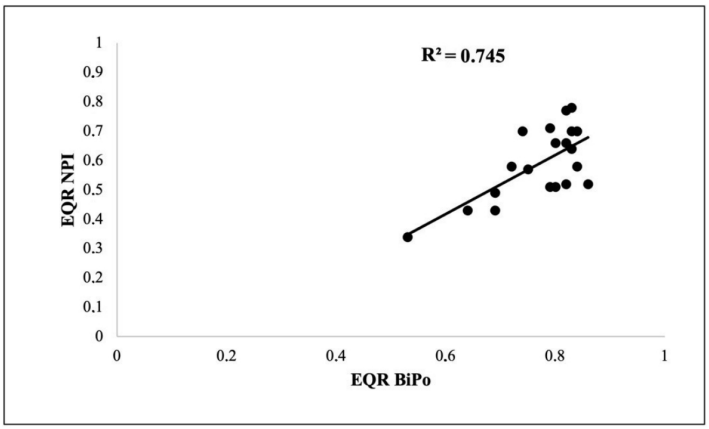


Figure 3. Relationship between the BiPo and NPI indices for the Aegean coasts of Türkiye.

the MA-LUSI and NPI ($R^2 = 0.450$, $p < 0.05$), and the BiPo ($R^2 = 0.243$, $p < 0.05$) were recorded along the coasts of the Aegean Sea (Figure 4).

PCA with 46.24% total variance represented by the first two axes, reveal the effects of the anthropogenic pressures (MA-LUSI) on the vitality of benthic macrophytes (Figure 5). Eight sites (Bozburun-2, Karaburun, Datça, Foça, Bozcaada, Seferihisar, Çeşme, and Gökova Bay) were characterized by the cover, shoot density, and lower limit depth of the *P. oceanica* meadows, canopy-forming brown (GIII) and opportunistic (GV) macroalgae, and the BiPo, while four sites (İzmir, Bozburun-1, Çandarlı, and Ildır) were affected by anthropogenic pressures (MA-LUSI). The other sites were characterized by the leaf area of *P. oceanica*, *Cymodocea nodosa* (GII), coralligenous macroalgae (GIV), and NPI results (Saros Bay, Enez, Akyaka, Altınoluk, Yeniköy, Kuşadası, and Gökçeada Island), and alien macrophytes (GVI) (Didim, Güllük, Bodrum, Babakale, and Ayvalık).

P. oceanica meadows showed distribution at 23 sites, except in İzmir and Dikili. Moreover, small patches were observed in shallow waters in Babakale, Güllük, and Bodrum. The maximum lower limit depth (36.5 m) of *P. oceanica* was recorded in Bozburun-2, followed by Karaburun (35 m), Çeşme (35 m), and Seferihisar (34 m). The lower limit types of the meadows were regressive at 7 sites, sparse at 12 sites, and sharp at 4 sites (Table 2). The highest recorded shoot density was 432 shoots m^{-2} at Yeniköy, while the lowest was 74.67 shoots m^{-2} at Didim. The highest recorded leaf area at a depth of 15 m was 262.9 cm^2 $shoot^{-1}$ on Gökçeada Island, whereas the lowest was 105.2 cm^2 $shoot^{-1}$ in Gökova Bay.

The seagrass *Cymodocea nodosa* (Ucria) Ascherson (GII) was observed at all the sites except 7 (Bozcaada, Dikili, Foça, İzmir, Karaburun, Datça, and Bozburun-2). Six canopy-forming brown algal taxa (GIII), *Cystoseira foeniculacea* (L.) Greville (Babakale), *Ericaria corniculata* (Turner) Neiva & Serrão (Saros, Kuşadası, Bozburun-1), *Ericaria crinita* (Duby) Molinari & Guiry (Bozcaada, Seferihisar, Kuşadası), *Gongolaria montagnei* (J.Agardh) Kuntze (Datça), *Gongolaria montagnei* var. *compressa* (Ercegović) Verlaque, Blanfuné, Boudouresque & Thibaut (Bozburun-1, Kuşadası), and *Sargassum acinarium* (L.) Setchell (Babakale), were recorded at several sites. Coralligenous macroalgae (GIV) *Mesophyllum alternans* (Foslie) Cabioch & M.L. Mendoza was recorded at depths of 10 and 15 m at Gökçeada Island, while *Lithothamnion* sp. at a depth of 5 m in Bozburun-2. The highest cover (%) of the opportunistic *Ulva* and *Cladophora* species (GV), was recorded in İzmir. Five alien macroalgae (GVI); red alga *Asparagopsis armata* Harvey (Dikili), brown alga *Stypopodium schimperi* (Kützing) Verlaque & Boudouresque (Didim), green algae *Caulerpa cylindracea* Sonder (Saros, Yeniköy, Bozcaada, Babakale, Ayvalık, Ildır, Çeşme), *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini (Bozburun-2), and Spermatophyta *Halophila stipulacea* (Forsskål) Ascherson (Babakale, Ayvalık, Akyaka), were recorded with high cover values at several sites. *C. cylindracea* was recorded at 7 sites (central–northern Aegean), whereas *C. taxifolia* var. *distichophylla* was observed at a depth of 40 m at only one site (southern Aegean), which was also reported recently to have expanded its distribution to the Marmara Sea (Taşkın et al., 2023a).

Abundances of the benthic macrophytes among the sampling sites were gathered under two clusters (26% similarity) using the Bray–Curtis Similarity Index (Figure 6). The first cluster consisted of sites with alien species and with only small patches of them (Babakale, Dikili and Bodrum). The second cluster was grouped under two clusters, and first one consisted of sites (İzmir and Güllük) without/with only small patches of *P. oceanica* meadows

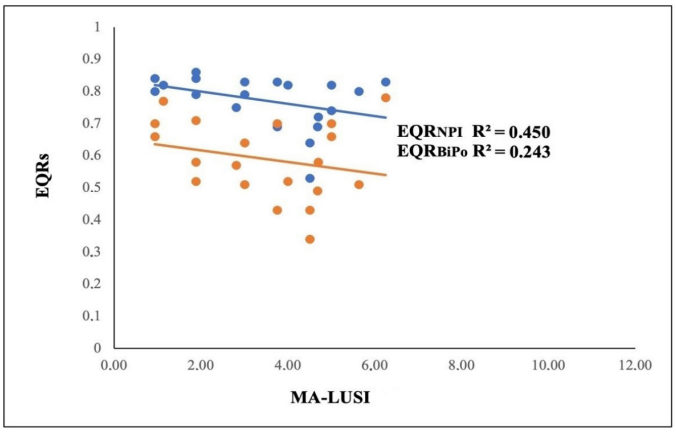


Figure 4. Relationship between the anthropogenic pressures (MA-LUSI) and biotic indices (BiPo and NPI) obtained at the study sites.

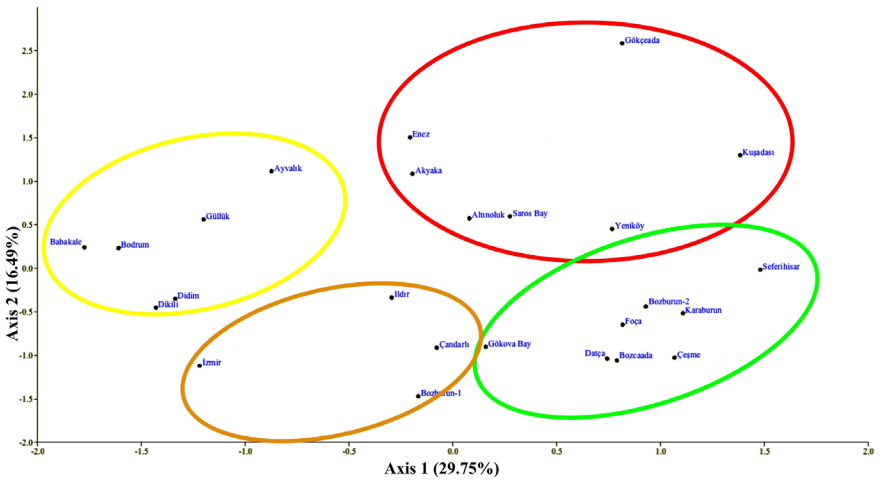


Figure 5. PCA plot showing the four distinct clusters (indicated with ellipses).

and the highest cover of the opportunistic macroalgae, the second cluster consisted of sites (Saros Bay, Gökçeada Island, Yeniköy, Bozcaada Island, Çeşme, Datça, Karaburun, Bozburun-2, Ildır, Çandarlı, etc.) with the highest cover (%) of *P. oceanica*, canopy-forming brown algae, coralligenous macroalgae, and alien macrophytes.

4. Discussion

It is critical to evaluate the ecosystem status with synchronized application of various indices with several biological descriptors (Marba et al., 2013) to provide ecological integrity. The biotic (BiPo and NPI) and anthropogenic pressure (MA-LUSI) indices applied in this study presented suitable data on the ecological quality of the Aegean coasts of Türkiye (Eastern Mediterranean). The good status was expressed by the average EQR value of the BiPo (0.69), while the moderate status was expressed by the NPI (0.59). The Ecological Evaluation Index (EEI) indicating the ecological quality of coastal waters (Orfanidis et al., 2011), tested at 19 sites along the Aegean coasts of Türkiye (Taşkın et al., 2023b) had a relationship with the NPI ($R^2 = 0.402$).

Sensitive macrophytes (seagrass meadows, canopy-forming macroalgae, and coralligenous macroalgae), considered as key habitats of the Mediterranean Sea (Boudouresque et al., 2012), were observed in pristine waters, whereas opportunistic macroalgae (filamentous, sheet-like, invasive, etc.) were observed at the anthropized sites (Orfanidis et al., 2003; Taşkın and Çakır 2022). Therefore, evaluating the anthropogenic impacts on benthic macrophytic communities is of great importance to strengthen management and conservation efforts, since they are assumed as functional bioquality elements (Boudouresque, 1969; Ballesteros, 1990; Pergent, 1991).

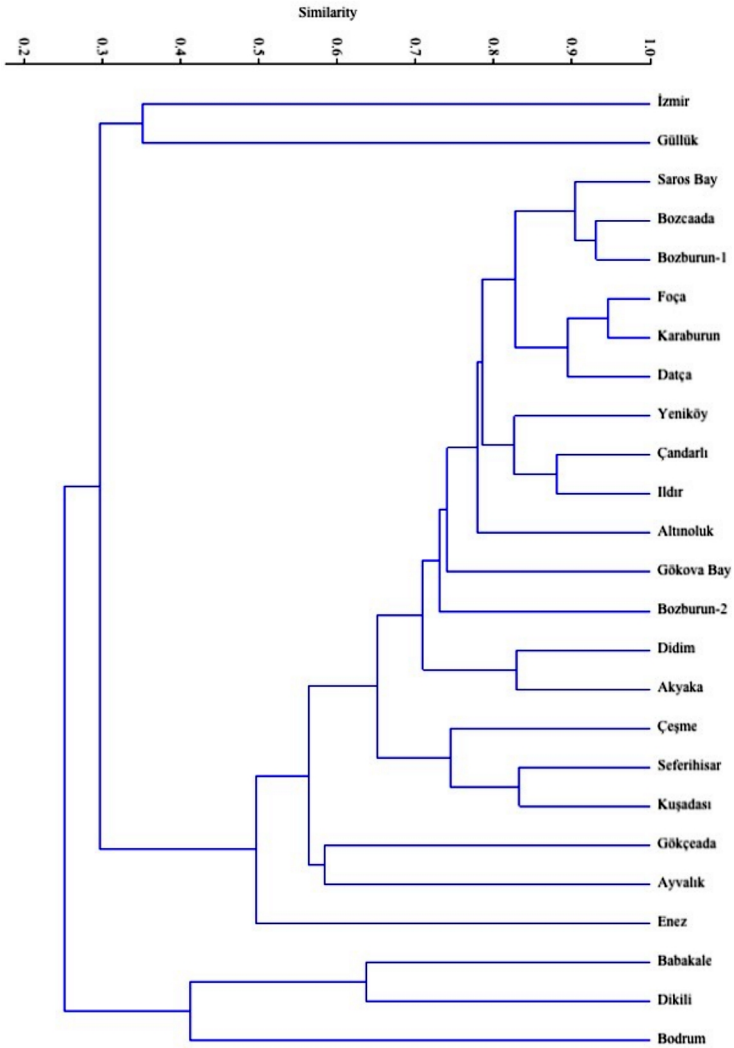


Figure 6. Hierarchical cluster dendrogram based on the Bray–Curtis Similarity Index demonstrating the comparison of the abundances of the main community groups among the sites.

However, there are various impacts that cause the decline of not only seagrasses but also marine forests and coralligenous habitats, such as urbanization, coastal modification, pollution, bottom trawling, anchoring, exotic species, overgrazing, climate change, and sedimentation (Airoldi 2003, Piazzi et al., 2007, Linares et al., 2010, Santos et al., 2019, Çınar et al., 2020, Fabbrizzi et al., 2020, Litsi-Mizan et al., 2023). During the study period, the *P. oceanica* meadows exhibited masses of dead matte, regressions, and heterogeneities at particular sites (İzmir Bay and Edremit Bay) close to these specific pressures. Moreover, barely habitat-forming species, such as seagrass *Cymodocea nodosa* and invasive alga *Caulerpa cylindracea*, were substituted with *P. oceanica* meadows at several sites (İzmir, Gökçeada Island, Babakale, Ayvalık, etc.) since they are more tolerant to pressures (Güreşen et al., 2020a; 2020b). The MA-LUSI and biotic indices (BiPo and NPI) scores verified their efficiency ($p < 0.05$) in determining the degradation of benthic macrophytic habitats at sites (İzmir and Karaburun) affected by anthropogenic pressures, such as territorial discharges at shallow coasts and especially the mucilage phenomenon that occurred in 2020–2021 along the coasts of the Marmara and Aegean seas and settled on the seagrass meadows. Comparable data validated by the implementation of the biotic indices, revealed the functioning of the habitats under threat. Therefore, they are appropriate tools for sustainable conservation and ecological integrity at the regional level.

Taking these things into consideration, it is essential to conduct scientific studies using nondestructive techniques on habitats under protection, such as the *P. oceanica* meadows, *Cystoseira* forests, and coralligenous

algae listed in the Convention on the Conservation of European Wildlife and Natural Habitats, EU Habitats Directive, and UNEP-MAP (Lopez y Royo et al., 2010). Destructive (collection of shoots to be measured in the laboratory) and nondestructive (shoot density, cover, upper, and lower limit depths, lower limit typology, etc., measured in situ) techniques used in the Mediterranean Basin were listed by Montefalcone (2009). Recently, Gobert et al (2020) published a new nondestructive shoot sampling method (NDSM) based on cutting the *P. oceanica* shoot just above the ligula of the outer leaves. The reported potential effects of this methodology were that the sampled shoots grew back to lengths similar to those in the adjacent control meadow within three months. Considering the WFD requirements, nondestructive sampling techniques proved their application capacity to create consistent systematization to construct management plans for sustainability or restoration (Montefalcone, 2009).

Since *P. oceanica* meadows comprise high biodiversity with the coexistence of other groups, various methodologies are necessary during their observations in situ. Herein, a rapid ecological assessment was performed using nondestructive methodology on the basis of an Eastern Mediterranean dataset reinforced by synthetic seascape indices (Montefalcone, 2009) concentrating on the coverage of *P. oceanica* meadows along a deep gradient. The NPI was evaluated at the species, community, and seascape levels from shallow to deep gradients (0–40 m) using sensitive (seagrasses, canopy-forming and coralligenous algae, etc.) and opportunistic and invasive macrophytes based on multiple descriptors, while several biotic indices were focused on bioquality elements with limited descriptors (i.e. depth and species).

5. Conclusion

Considering the NPI reflecting the coastal ecosystem status, it should be applied and intercalibrated throughout the Mediterranean Basin in the future. Hence, it can be assumed as a convenient tool for long-term monitoring of the health of ecosystems and a data collection tool for policy makers in the management of coastal ecosystems.

Acknowledgments

This study was supported by the Scientific and Technological Research Council of Türkiye (Project number: 121Y215). We are grateful to Prof. Dr. Ersin Minareci and Onur Karayalı for their help.

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