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An insight to the ecological evaluation index (EEI)

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Abstract

The ecological evaluation index (EEI) was designed to estimate the ecological status of transitional and coastal waters. Marine benthic macrophytes (seaweeds, seagrasses) were used as bioindicators of ecosystem shifts due to anthropogenic stress, from the pristine state with late-successional species (high ecological status class (ESC)) to the degraded state with opportunistic species (bad ESC). The relation of EEI to function and to resilience of the marine ecosystem, and its possibility for comparing and ranking at local, national and international levels are some of its main management implications.

Keywords: Water quality; Benthic macrophytes; Functional groups; Ecosystem function; Ecosystem resilience; Water Framework Directive

1. Introduction

Central issue in the management of "high" valued transitional and coastal ecosystems (Costanza et al., 1997) is the identification of key signals that indicate the degree of human impact or ecological status (Crooks and Turner, 1999). Regarding the ecosystems as dynamic open systems with multiple stable equilibrium states (Holling, 1973) further strengthens the need for ecological assessment, because the restoration of desired states may require drastic and expensive intervention (Maler, 2000).

Communities are often used in ecological assessment as bioindicators of ecological status (Dauer, 1993; Bricker et al., 1999; Gibson et al., 2000; EEC, 2000), because long-term anthropogenic stress is ecologically relevant investigated at community level (Odum, 1985; Crowe et al., 2000). However, the evaluation of the ecological status is often a difficult task because of spatial and temporal community variability. A more temporally stable and predictable view of community requires a functional approach (Steneck and Watling, 1982).

Marine benthic macrophytes form the structural base (McRoy and Lloyd, 1981) and behave as ecosystem engineers (sensu Jones et al., 1994) of some of the most productive ecosystems of the world. As photosynthetic sessile organisms, they respond directly to the abiotic and biotic aquatic environment, and thus represent sensitive bioindicators of its changes (for a short-review see Orfanidis et al., 2001).

This paper aims to present an insight to the structure and relevance of the ecological evaluation index (EEI). It has been recently introduced by Orfanidis et al. (2001) for the evaluation of ecological status of transitional and coastal waters in accordance to European Water Framework Directive (WFD) (EEC, 2000). For WFD "ecological status" is an expression of the quality (ecological status class (ESC)) of the structure and functioning of aquatic ecosystems.

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2. Why and how to use the EEI

The EEI quantifies shifts in the structure and function of transitional and coastal waters at different spatial and temporal scales by using non-linear and linear relationships.

(a) Shifts in marine ecosystem structure and function are evaluated by classifying marine benthic macrophytes in two ecological state groups (ESGs I, II), representing alternative ecological states, e.g. pristine and degraded. ESG I includes seaweed species with a thick or calcareous thallus, low growth rates and long life cycles (late successionals), whereas the ESG II includes sheet-like and filamentous seaweed species with high growth rates and short life cycles (opportunistic). All seagrasses are included in the first group, whereas Cyanophyceae and species with a coarsely branched thallus are included in the second group. Table 1 shows a provisional list of Greek seaweed genera classified into ESGs.

(b) Spatial and temporal changes of benthic macrophytic communities are identified by seasonal sampling of ecologically uniform non-overlapping permanent-polygons (PPs) or permanent-lines (PLs) of the studied area/coastline (Fig. 1). It is recommended to use PP for well-defined ecosystems, e.g. lagoons, shallow closed bays, and PL for relative open coasts. Sampling can follow a nonaligned block design, in which a sample is located randomly within a representative permanent cell of dimensions $10\,\text{m} \times 10\,\text{m}$. The absolute abundance (%) of each ESG is estimated by coverage (%) in each sample. Three samples per season per cell could be an optimum sampling frequency.

(c) To evaluate the ecological status of PPs or PLs the mean absolute abundance (%) of ESGs I and II sampled in PPs and PLs is non-linearly corresponded to five different ESCs (Table 2). The ESCs are related linearly to the EEI at PP or PL scale (Fig. 2). The surface area of each PP or the length of each PL is multiplied by their EEI and then divided by the sum of surface areas of PPs or lengths of the PLs. The area- or length-weighted values are then summed to estimate the spatial scale weighted EEI and the equivalent ESC (Table 2).

Table 1
Classification of Greek seaweed genera into ESGs

Genus	ESG
Acetabularia	I
Acanthophora[a]	II
Amphiroa	I
Anadyomene	I
Antithamnion	II
Bryopsis	II
Calithamnion	II
Caulerpa	II
Ceramium	II
Chaetomorpha	II
Champia[a]	II
Chondria[a]	II
Cladophora	II
Codium	II
Colpomenia	II
Corallina	I
Cystoseira	I
Dasya	II
Dermatolithon	I
Dictyopteris	II
Dictyota	II
Ectocarpus	II
Enteromorpha	II
Erithrotrichia	II
Flabellia	I
Fosliella	I
Gelidiella[a]	II
Gelidium[a]	II
Gigartina[a]	II
Gonyotrichum	II
Gracilaria[a]	II
Griffithsia	II
Halimeda	I
Halopteris[a]	II
Herposiphonia	II
Hypnea[a]	II
Jania	I
Laurencia[a]	II
Lithothamnion	I
Lomentaria[a]	II
Lophosiphonia	II
Padina	I
Petalonia	II
Peyssonelia	I
Polysiphonia	II
Pseudochlorodesmis	II
Sargassum	I
Scytosiphon	II
Spermothamnion	II
Sphacelaria[a]	II
Taonia	I
Ulva	II
Valonia[a]	II

Data were adopted from Orfanidis et al. (2001).
[a] Indicate provisional classification.

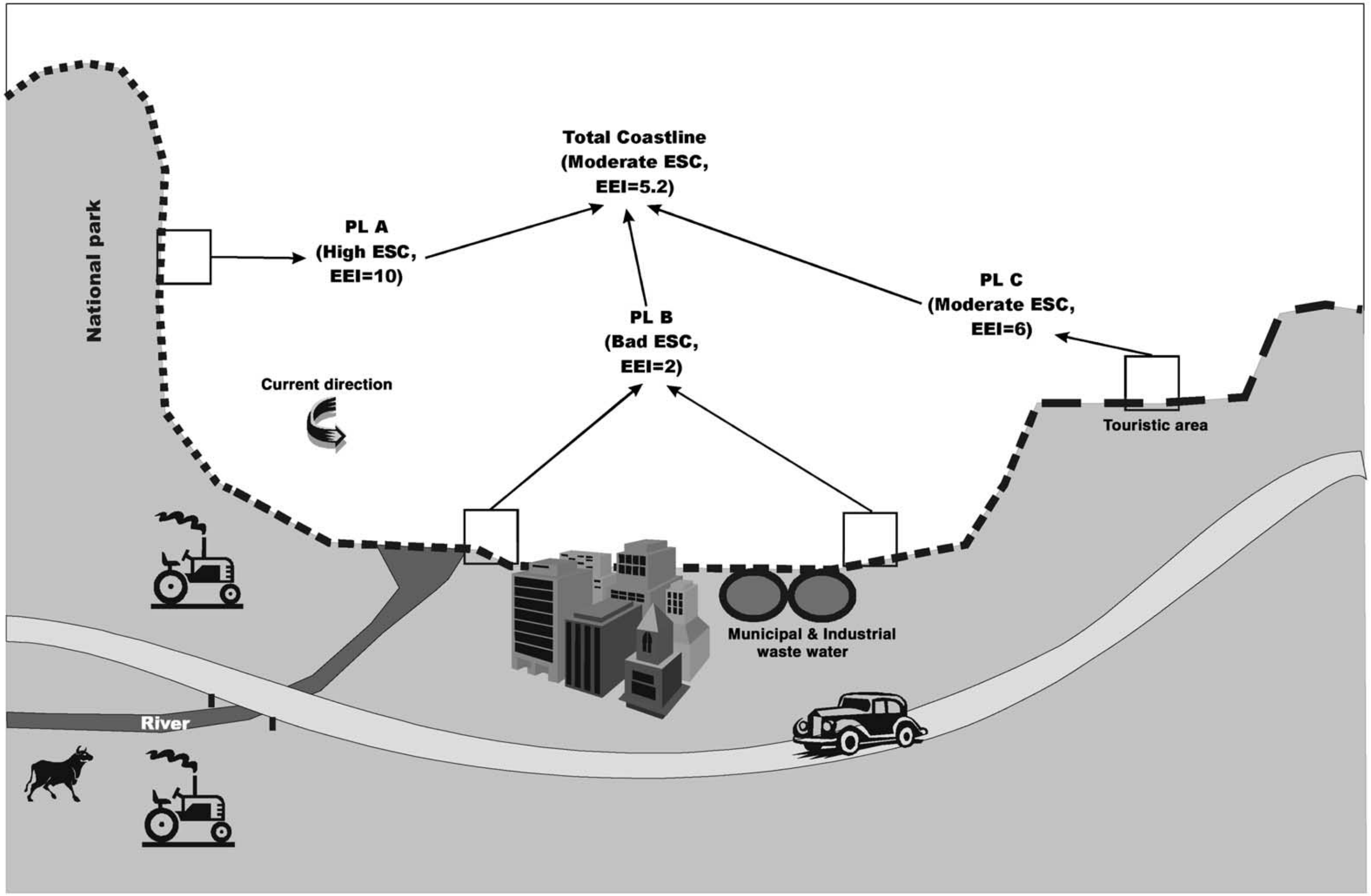

Fig. 1. A hypothetical coastal ecosystem including coastlines (PL) of different ESCs. Rectangles show PL representative permanent vegetative areas (cells) for sampling.

Table 2
Estimation of EEI and the equivalent ESCs from the abundance of ESGs

Mean coverage of ESG I (%)	Mean coverage of ESG II (%)	ESC	EEI at PP or PL	Spatial scale weighted EEI and equivalent ESCs
0–30	0–30	Moderate	6	≤6 to >4 = Moderate
	>30–60	Low	4	≤4 to >2 = Low
	>60	Bad	2	2 = Bad
>30–60	0–30	Good	8	≤8 to >6 = Good
	>30–60	Moderate	6	≤6 to >4 = Moderate
	>60	Low	4	≤4 to >2 = Low
>60	0–30	High	10	≤10 to >8 = High
	>30–60	Good	8	≤8 to >6 = Good
	>60	Moderate	6	≤6 to >4 = Moderate

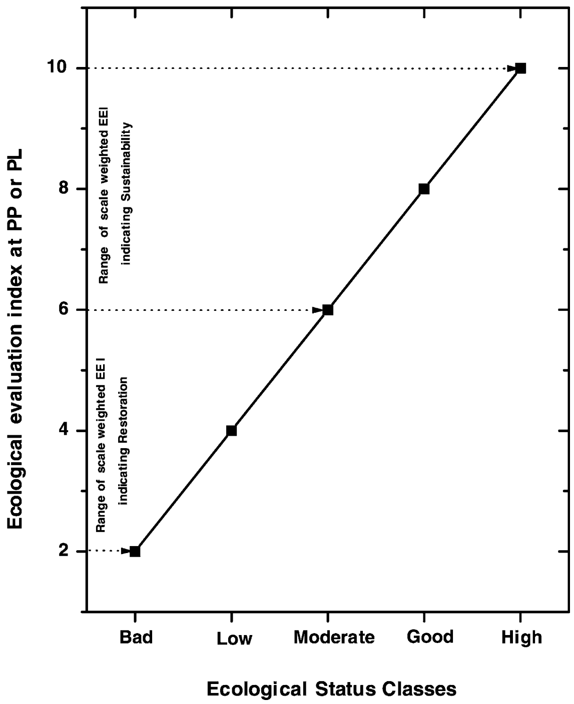

Fig. 2. The linear relationship between EEI and the ESC. EEI ranges for restoration and sustainability.

3. Example

A hypothetical coastal water system (CWS) is divided in three ecologically uniform PLs (A–C) covering 30, 50 and 20% of the total coastline, respectively (Fig. 1). The mean absolute coverage (%) of ESGs I and II of samples in the PL A was 140 and 20, respectively. This corresponds to the high ESC and to EEI 10. The mean absolute coverage (%) of ESGs I and II of samples in the PL B was 10 and 90, respectively. This corresponds to the bad ESC and to EEI 2. The mean absolute coverage (%) of ESGs I and II of samples in the PL C was 45 and 40, respectively. This corresponds to the moderate ESC and to EEI 6. The EEI of the whole CWS is following: EEI = $(10\times 0.3)+(2\times 0.5)+(6\times 0.2) = 3+1+1.2 = 5.2$, which corresponds to the moderate ESC.

4. Discussion

The EEI (Table 2) quantifies shifts in transitional and coastal waters from pristine to degraded state, which is dominated by opportunistic species (Odum, 1985). The latter is a well-known pattern also from the marine environment (Regier and Corwell, 1972; Duarte, 1995; Harlin, 1995; Schramm, 1999), irrespectively of having one or multiple stable equilibrium states (see Scheffer et al., 2001). Coral reefs, for example, shift due to nutrient loading and over-fishing to an alternative stable state, which is characterized by the dominance of fleshy opportunistic macroalgae (McCook, 1999). Similarly, Scheffer et al. (1993) recognizes two alternative stable stages in lakes, the pristine (oligotrophic) state with clear water and rich submerged vegetation and the degraded (eutrophic) with high turbidity and phytoplankton biomass. In intermediate nutrient levels the last two equilibria alternate and their organisms coexist.

The EEI is based on marine benthic macrophytes inhabiting sediment (roots of seagrasses) as well as water column (seaweeds and leaves of seagrasses) of

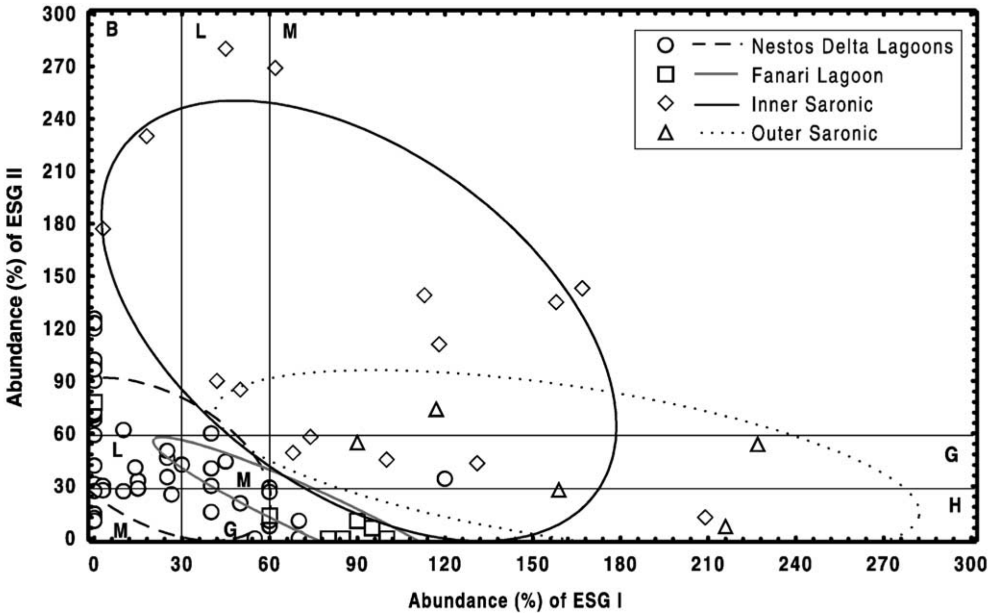

Fig. 3. A categorized scatterplot of abundance (%) of ESGs at different transitional (Delta Nestos and Fanari Lagoons) and coastal (inner and outer Saronic Gulf) ecosystems in Greece. For raw data see Orfanidis et al. (2001). Elliptic areas predict *x*, *y* values with a 60% coefficient. The vertical and horizontal lines divide the scatterplot in five ESCs (B, bad; L, low; M, moderate; G, good; H, high).

transitional and coastal waters. Therefore, it provides a unifying framework (Fig. 3) for an integrated evaluation of ecological status. Because it is based on seasonal sampling reflects the mean of environmental conditions. Seasonal sampling is important because: (1) brackish and polluted waters are unpredictable environments with temporal environmental and thus community changes (Fig. 3), and (2) several opportunistic species existed also in pristine ecosystems by adequate seasonal timing to take full advantages of environmental resources. Examples are the growth of *Scytosiphon* in pristine Helgoland, Germany coasts (Bartsch, 1987) and of *Cladophora* species in oligotrophic Mediterranean coasts (personal observation) during spring.

Marine benthic macrophytes although including evolutionary different groups of plants, such as seaweeds and seagrasses, show adaptive morphologies. For seaweeds Littler and Littler (1980) have proposed a functional-form model, which was tested and verified experimentally: the functional characteristics of plants, such as photosynthesis, nutrient uptake, and grazer susceptibility, are related to morphology and surface area : volume ratios (Littler and Littler, 1980, 1984; Littler and Arnold, 1982). Orfanidis et al. (2001) have included seagrasses in this model and then used it to divide marine benthic macrophytes in two different ecological groups, the late-successional (perennials, ESG I) and the opportunistic (annuals, ESG II). Because the functional groups include considerable variation of forms–functional responses (Littler and Littler, 1984) the classification of certain seaweed genera, e.g. coarsely branched, into ESGs (Table 1) should be regarded as provisional remaining an experimental verification.

The main implication of multiple ecosystem stable states insight is that efforts to reduce the risk of unwanted state shifts due to stochastic events should focus on the gradual changes affecting the ecological resilience of the ecosystem (Holling, 1973) rather than to control disturbances. Ecological resilience typically depends on slowly changing variables, e.g. nutrient, biodiversity, the biomass of long-lived organisms (Scheffer et al., 2001). The latter indicates the relation of EEI to the ecosystem resilience, which is today a key concept in ecological research (Gunderson, 2000). Using EEI one can identify two distinct ecological states, the pristine and the degraded. Both states can be resilient (Carpenter et al., 2001). When EEI approaches 10 the resilience of the pristine state became maximum and of the degraded state 0. The opposite happens when EEI approaches 2.

The EEI is based on absolute abundance of the ESGs and it is closely related to ecosystem function or processes, e.g. nutrient cycling (Asmus and Asmus, 2000), and fish production (Fonseca et al., 1996a,b). High values of EEI indicate the existence of high ecologically and economically valued communities (Costanza et al., 1997).

The EEI was designed to: (1) cover the prerequisites of European WFD, which will be the operational tool setting the objectives for water protection well in Europe (EEC, 2000), and (2) offer to water managers worldwide a tool for comparing, ranking and setting management priorities at different spatial levels, e.g. regional, national, international. EEI values higher than 6 indicate sustainable ecosystems of good or high ESC, whereas EEI values lower than 6 indicate that the ecosystems should be restored to a higher ESC (Fig. 2).

An exact identification of the limits of the ESGs and the ESC could improve the EEI accuracy, whereas the identification of relations of ESGs to different kinds of stress/disturbance or ecosystem states by using a hierarchical approach to the analysis of trait sets (Lavorel et al., 1997) could improve the EEI specification.

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