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A Biotic Index (Λ) for Measuring the Ecological Quality of Mediterranean Lagoons

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Abstract: This study presents a biotic index (Λ) for measuring environmental quality in the coastal lagoons of the Mediterranean. Index Λ considers combined anthropogenic (pollution) and natural factors (prohibitive salinity, anoxia, toxic blooms, isolation from sea, etc.) of deterioration. The method is based on the principle of indicator species and on the conceptual scheme developed by Frisoni et al. (1984) according to which there are six possible sub-assemblages (Zones) of benthic macrofauna, each indicating a different level of environmental quality. The procedure requires defining the relative extent of the Zones in the lagoon under study, and the number of species and the mean biomass of benthic macrofauna present in each. The three metrics are applied in the index formula and the resulting number from one to ten indicates increasing environmental quality. The authors have validated the index by applying it to two lagoons, Lesina and Varano (S.Adriatic, Italy).

Key words: Mediterranean, coastal lagoons, quality assessment, biotic index, benthic macrofauna.

1. Introduction

Coastal lagoons are a favourite object of scientific studies. At the same time they are considered valuable territories by large sections of the general public (nature-lovers, conservationists, birdwatchers, environmentalists, sightseers, fishermen, aquaculturists, sportsmen and open-air people generally), and this has moved governments to enact measures for their conservation. To what extent are the studies of the scientists useful in assessing the environmental value of lagoons according to this conservation policy? One type of study is purely descriptive [1-2] and cannot by its intrinsic reason generate a criterion of quality. The research which does face the problem of environmental quality tends to concentrate on the pollution factor [3-5]. But can itconceptually reduce environmental quality in a lagoon to being simply a function of pollution?

The Ramsar (Iran) Convention (1971), undersigned by many countries, recommends the conservation of wetlands for their function as "regulators of water regimes and as habitats supporting a characteristic flora and fauna, especially waterfowl". It stresses their "great economic, cultural, scientific and recreational value". More recently, Directive 2000/60/EC of the European Parliament and of the Council, of October 23, a2000, establishing a framework for Community action in the field of water policy, also has a special word for coastal lagoons, termed "transitional waters", at n 17 of the preliminary statements of intent. "An effective and coherent water policy must take account of the

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vulnerability of aquatic ecosystems located near the coast and estuaries or in gulfs or relatively closed seas, as their equilibrium is strongly influenced by the quality of inland waters flowing into them. Protection of water status within river basins will provide economic benefits by contributing towards the protection of fish populations, including coastal fish populations".

The values expressed in these policy directives come within the concepts of biodiversity, biomass and productivity, where biodiversity is related to the cultural and aesthetic values of taxonomic richness and landscape variety; biomass relates to the quantity of organisms present at one time and place, which is a cultural value if related to wildlife in general but is a commercial value if the fishery is in mind; productivity, the rate of organic turnover, is particularly relevant in the case of the fishery, translating into a high sustainable yield.

Although pollution can certainly affect biodiversity, biomass and productivity, yet in coastal lagoons these parameters do also vary from purely natural mechanisms quite independent of human causes. It is possible to find a lagoon with no pollution yet having low environmental quality. Excessive fluctuations in salinity, harmful microalgal blooms, anoxic crises, too much or too little marine penetration and excessive turbidity may have an anthropogenic origin (e.g. domestic sewage, agricultural fertilisers, dredging and embanking, etc.) but they may also derive from purely natural causes. Over the course of years the authors have developed a method that measures the overall environmental quality, whether it be determined by the natural processes of the ecosystem or by anthropogenic influence. The method consists in a relatively simple biotic index (Λ) based on the principle of indicator species [6]. After investigating the lagoons and fish-raising meres ("valli da pesca") of Italy, Ref. [7-8] was the first to correlate positive environmental quality, essentially interpreted as the natural capacity for fish production, with the characteristics of the benthos. Later and independently Ref. [9, 10] arrived at the same conclusions as the result of a study of fifteen lagoons in S. France, Greece, Morocco and Tunisia.

2. Materials and Methods

Guelorget and Perthuisot (1992) [10] distinguished different sub-assemblages within the general bionomic category of Mediterranean coastal lagoons as defined by Perès and Picard (1964) [11] ("Biocoenose lagunaire euryhaline et eurytherme"). They identified six possible benthic sub-assemblages (Zones) which succeed one another along the gradient of marine penetration into the basin (Table 1).

Biodiversity diminishes proceeding from Zone I nearest the sea channel, to Zone VI ecologically the farthest from the sea. Biomass and productivity reach the maximum halfway along the gradient, in Zones III and IV. Zones III and IV thus present the most favourable combination of biodiversity biomass and productivity, and are considered the most productive in terms of extensive aquaculture and fishery.

The lagoons with the highest environmental quality are, therefore, those in which Zone III and/or Zone IV occupy the greatest possible area. The authors' index incorporates these concepts and quantifies them by means of data gathered in sampling operations conducted on the benthos. After two initial trials in Lesina lagoon (Jan. 1993, Nov. 1995) to run in the method, in 1997 the author commenced a regular monitoring programme in order to have a time series for Lesina and Varano lagoons. These two basins are on the Adriatic coast of S. Italy (Fig. 1), covering 6,000 and 6,500 ha respectively and lie only 10 km apart.

They share the same climate and general geographical position but Varano is significantly deeper (5 m) than Lesina (1 m). Each basin has two permanent channels communicating with the sea. Most of the input of freshwater derives from perennial karst springs around the shores but also from the sewage treatment plants of towns within the drainage basin. The salinity of Varano tends to be homogeneous and

Table 1 The species which typify each one of the six Zones according to the bionomics of a paralic ecosystem as defined by Frisoni et al. (1984).

Species	Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
Marine biocenoses S.F.B.C.*	x					
Mollusca						
Hydrobia acuta (Draparnaud, 1805)				x	x	
Pirenella conica (Blainville, 1826)					x	
Abra segmentum (Récluz, 1843)				x		
Acanthocardia echinata (Linné, 1758)		x				
Cerastoderma glaucum (Poiret, 1789)				x		
Corbula gibba (Olivi, 1792)			x			
Donax semistriatus Poli, 1795		x				
D. trunculus Linné, 1758		x				
Dosinia exoleta (Linné, 1758)		x				
Gastrana fragilis (Linné, 1758)			x			
Loripes lacteus (Linné, 1758)			x			
Mactra glauca Von Born, 1778		x				
Mactra stultorum (Linné, 1758)		x				
Paphia aurea (Gmelin, 1791)			x			
Scrobicularia plana (Da Costa, 1778)			x			
Tapes decussatus (Linné, 1758)			x			
Tellina tenuis Da Costa, 1778		x				
Annelida						
Akera bullata (Müller, O.F.,1776)			x			
Audouinia tentaculata (Montagu, 1808)		x				
Glycera convoluta Keferst, 1862			x			
Magelona papillicornis (F. Müller, 1858)		x				
Nereis diverticolor (O. F. Müller, 1776)				x	x	
Nephthys hombergi Savigny, 1818			x			
Owenia fusiformis (Delle Chiaje, 1841)		x				
Pectinaria koreni (Malmgren, 1866)		x				
Phyllodoce mucosa (Oersted, 1843)		x				
Crustacea						
Corophium insidiosum Crawford, 1937				x	x	
Gammarus aequicaudi (Martynov, 1931)				x		
Gmmarus insensibilis Stock, 1966				x	x	x
Idotea baltica (Pallas, 1772)					x	
Portumnus latipes (Penn, 1777)		x				

* Pérès and Picard, 1964.

relatively stable. At Lesina the annual salinity variations are more pronounced and there is a permanent E-W gradient due to the fact that all the freshwater input occurs at the eastern end. Both lagoons may be defined polyhaline [1]. The annual temperature cycle has extremes of about 5 ℃ and 30 ℃ but Varano has a slightly narrower range. Varano is often the seat of summer dinoflagellate blooms which cause a general crisis of the ecosystem. Both lagoons are the seat of commercial fisheries; Lesina is famous for its eels (*Anguilla anguilla* Linné, 1758) and bivalve farming (*Mytilus galloprovincialis* Lamarck, 1819; *Tapes decussatus* Linné, 1758) is practised at Varano. The procedure for applying the index requires defining the relative extent of the Zones, and the number of species and the mean biomass (g wet weight/m^2) of benthic macrofauna present in each. A box-corer with an opening 15 × 15 cm (225 cm^2) was used to gather the sampling units, and the material was sorted on a 1 mm mesh. Each sample consisted in at least 50 sampling units taken from as many stations [12-13] distributed according to a systematic grid (Fig. 1).

The plan was to take two samples a year, one in spring and one in autumn, in order to register the effects of the two critical seasons of winter and summer, but this has not always been possible. The spring sample proposes to reveal the effects of low salinity resulting from the Mediterranean season of rains. The autumn sample carries the signs of the summer when blooms, anoxia and H_2S sometimes kill off the benthic assemblage from large areas. Having obtained the three metrics, the index was then calculated by applying them in the following formula.

$$\ln\left(\sum_{i=1}^{6}\frac{n_i}{N}\bullet b_i\bullet S_i\right)=\Lambda$$

Where, i identifies the Zone (I, II, III, IV, V, VI)

n_i is the number of sampling units belonging to Zone I;

N is the total number of sampling units comprising the sample;

b_i is the mean biomass (g ww/m^2) in Zone I;

S_i is the number of species in Zone I.

Λ expresses the ecological state of the lagoon according to a scale of increasing quality from 1 to 10.

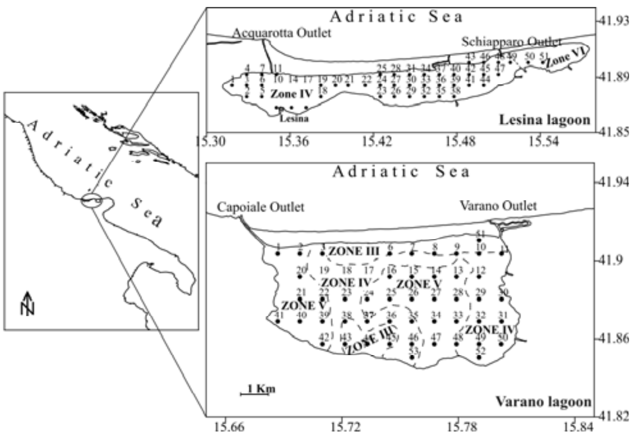

Fig. 1 Varano and Lesina lagoons showing sampling stations. The zonation of benthic macrofauna (Frisoni et al., 1984) refers to year 2003.

Values above 6.50 indicate good environmental status.

The authors thought it unnecessary to include productivity in the formula. Taken as the ratio between biomass produced and standing biomass, the rate of productivity of the benthic fauna of coastal lagoons, typically showing r-strategy, is about 1 [14] and therefore would not influence the value of the index.

3. Results

In the years immediately preceding the authors' monitoring programme dark red summer blooms of dinoflagellates were a regular feature of Varano. Dead fish would be noticed and the mussel farmers had to forcibly sell out their stock to avoid losing it. By September the ecosystem would have returned to good condition, allowing the fishermen and aquaculturists to resume their activity till the subsequent summer crisis. The authors' first assay in Jan. 1997 gave Λ at 6.61 (Fig. 2).

This mediocre level of quality was expected as there had been a bloom during the preceding summer. A surprise came in July 1997 when the authors registered 8.12 in full summer. The expected bloom had not taken

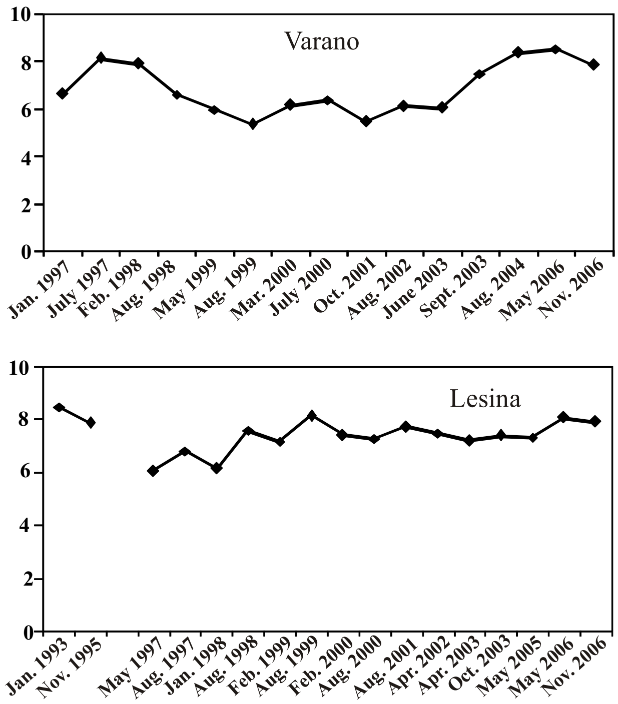

Fig. 2 Variations over the years of the value of Index Λ in Varano and Lesina lagoons.

place and the environment had markedly improved. In Feb. 1998 the index level remained high with 7.89. The decline to 6.58 in Aug. 1998 was considered normal, due to the effects of the warm season, but the subsequent further drop to 5.93 in May 1999 was quite unusual. The authors had presumed the environment to recuperate during winter and spring. Now, in fact, Varano had entered a critical phase because a stable green bloom had developed, and for the next three years Λ would not rise above 6.33. Only just recently the water has become clear again and quality has rebounded, rising to 7.45 in Sept. 2003 and reaching an unprecedented 8.42 in Aug. 2004. The most recent sample of May 2006 shows that the index has remained high at 8.65. Lesina presented quite different dynamics during the same period (Fig. 2). In 1997 the lagoon was suffering from a dense green microalgal bloom, possibly triggered by the quite extraordinary heavy rain of the preceding summer. From May 1997 to January 1998 the index stayed below 7.00 due to the persistence of the bloom. In August 1998 the bloom had disappeared, as a result the quality had risen to 7.59. Feb. 1999 registered a slight dip to 7.17 but then in the subsequent Aug. the index rose to 8.15, it is high. In Feb. 2000 the index decreased somewhat to 7.42, but which is still good. The lagoon stayed around these values to Oct. 2003. In 2004 the authors did not take samples. When the authors resumed the work in 2005 the index registered 8.15 in May, showing that the quality had gone up. The sample of May 2006 revealed that the quality has maintained its high level of quality with the index at 8.35.

4. Discussion

Although close to each other and sharing the same general climate and geographical position, the two lagoons present quite different environments. The quality of Varano is influenced negatively by two large areas of Zone V (Fig. 1) which cover from a quarter to a third of the area of the basin, varying from year to year. Harmful dinoflagellate blooms often develop here in summertime, causing anoxia and consequent mortality at benthos level. The rest of Varano is Zone IV except for the strip along the northern shore and an area in the southern part which is Zone III. In Lesina the index showed less pronounced variations in the course of the years (Fig. 2). After recovering from the bloom in 1998, the quality remained consistently high. Being a very shallow basin (< 1 m deep), oxygen diffuses readily preventing anoxic conditions even in the warmest time of the year with water temperatures reaching 30 ℃. During the period of the bloom from 1996 to May 1998, 90% of the lagoon presented the characteristics of a Zone V. The biomass of the benthic macrofauna was low and contained no bivalves. The remaining 10% was a Zone VI at the eastern extremity consisting of a freshwater area covered with reeds (*Phragmites australis* (Cav.) Trin. ex Steud.). The sample of Aug. 1998 revealed that the situation had improved: the Zone V had disappeared and a Zone IV had taken its place. The bivalves *Abra alba, Cerastoderma glaucum* and *Mytilaster minimus* had densely colonised all the lagoon except for the persistent Zone VI at the eastern end. The record over the years shows that the bionomics of the two lagoons are not stable. The variations appear to be oscillations around a typical modal state to which the ecosystem always tends to revert to. In the case of Varano it would seem that the basin is mostly comprised of Zones IV and V and only to a lesser extent of Zone III, with Λ value at 6.00 (Fig. 2). Those times when values of Λ approached 8.00, with the entire lagoon classifiable as a Zone III, appear to be exceptional, explained by the non-occurrence of dinoflagellate blooms in summer. This situation at Varano was registered only four times out of 14 controls. The modal condition of Lesina may be described as a homogeneous Zone IV having a limited freshwater Zone VI at the eastern extremity, with Λ consistently above 7.00 (Fig. 2). The drop of Λ to values below 7.00 from May 1997 to Jan. 1998 appears as a passing phase, due to a lingering dinoflagellate bloom that developed during the very rainy summer of

1996, out of which the ecosystem emerged in Aug. 1998 to settle in its modal state. Lesina, therefore, presented a consistently better environment, i.e. a higher value of Λ, than Varano. The authors found our assessment of the state of two lagoons to closely correspond to the opinion of the fishermen and aquaculturists whose livelihood depends on the quality of the environment. For Lesina the authors took into consideration the catch of gilt-head seabream (*Sparus aurata* Linné, 1758) which is the least euryoecious of lagoon fishes. It feeds mainly on the benthos, with a preference for bivalves, and it reaches commercial size within one year. In the bad years ($\Lambda < 7.00$) of 1997-1998 only about 20 tonnes/y were caught whereas in the good years ($\Lambda > 7.00$) the catch averaged 100 tonnes/y. In the case of Varano the authors compared Λ with the situation on the mussel farms. When Λ was low, below 6.00, this coincided with the time when the mussel farmers had to remove their stock from the lagoon, a sign that anoxia was impending or that there was a bloom of the wrong sort of phytoplankton. The several biotic indices proposed by various authors [15-19] that use the benthos for assessing the environmental quality of in-shore and estuarine waters are misleading if applied to coastal lagoons.

These indices are aimed at detecting pollution and regard the organic enrichment caused by it to be the key factor influencing the characteristics of the benthic assemblage. The gradual changes observed in in-shore or estuarine benthos determined by increasing levels of organic pollution of human origin [20] are very similar if not identical to the zonation of the lagoon benthos described by Guelorget and Perthuisot (1992) [10], which these authors consider to be the result of the purely natural phenomenon of "confinement", i.e. the degree of marine energy penetrating into the lagoon. The accumulation of dead organic matter in the sediment is, in fact, a natural process in coastal lagoons so that one cannot really distinguish between the organic matter from natural eutrophication and the organic matter generated by pollution from domestic sewage and agricultural fertilisers. Thus, these other indices could erroneously classify a lagoon as polluted when actually it is not affected because the type of benthos observed and thought to be the result of anthropogenic pollution in a particular case could in fact be determined by the purely natural phenomenon of "confinement". On the side, it may be commented that nutrient and organic pollution is not necessarily harmful if it expands Zones III and/or IV at the expense of Zones I and II like in the case of some oligotrophic N. African lagoons (e.g. Nador); but is, of course, deleterious if it creates or increases a Zone V.

5. Conclusions

In conclusion the authors find that the authors' Index L is useful for monitoring the variations in the quality of the environment caused by such factors as excessive fluctuations in salinity, harmful microalgal blooms, anoxic crises, too much or too little marine penetration and excessive turbidity. Such variations may have human causes (e.g. domestic sewage, agricultural fertilisers, dredging and embanking, etc.) but they may also derive from the natural dynamics of the ecosystem, or from both together. The index is not suitable for detecting pollution from toxic substances (heavy metals, pesticides, etc.) at sub-lethal levels where chemical analysis is essential.

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