

## ASSESSMENT OF COASTAL ENVIRONMENTAL QUALITY BASED ON LITTORAL COMMUNITY CARTOGRAPHY: METHODOLOGICAL APPROACH

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### ABSTRACT

In this study we present a new methodology for monitoring water quality based on the cartography of rocky benthic communities in the littoral zone. Littoral communities thriving in the selected coast are cartographed from a small boat and the cartographic information is transcribed to a GIS. With the use of spatial databases and geographic information system technology (GIS) it is possible to know not only the distribution of rocky benthic communities along the coast but also to obtain an environmental quality index giving a "quality" value to every community. This index takes into account the length of the coast covered by each community, a value of ecological quality of each community obtained by expert judgement, and a correction by different parameters other than water quality involved in the distribution of littoral communities (e.g. natural or artificial substrate, type of coast) which has been obtained with an accurate study of the distribution of littoral communities in reference zones. This index, named Ecological Quality Ratio, fulfils the requirements of the Water Framework Directive. (2000/60/EC).

### INTRODUCTION

Littoral benthic communities can be used as biological indicators of environmental changes because (1) they are exhaustively studied, at least in the Western Mediterranean and other European coasts, (2) they integrate the environmental changes occurring in marine ecosystems, and (3) they are strongly affected by pollution.

Amongst the organisms that can be used as bioindicators we can point up the seaweeds, which have some species that are good indicators of the environmental quality (e.g. Levine, 1984). There are some studies that show the effects of industrial and wastewater discharges on the macroalgae, mainly regarding the Fucophyceae, characterized in the Mediterranean Sea by the genus *Cystoseira* (e.g. Bellan Santini, 1968; Soltan *et al.*, 2001). According to Belsher (1977) pollution also affects some red algae, with the disappearance of some species of Gelidiales and Rhodymeniales, and the regression of some Ceramiales, Gigartinales and Cryptonemiales.

We have selected the communities of the littoral zone (mediolittoral and upper infralittoral according to Pérès and Picard, 1964) as biological indicators of the environmental quality of the coastal waters. The community of *Cystoseira mediterranea*

or *Cystoseira amentacea* var. *stricta* has been considered as the most mature community in Mediterranean coastal areas with high to moderate water movement, high irradiance and good water quality. The calcareous formation constituted by *Lithophyllum byssoides* (and other corallines such as *Neogoniolithon brassica-florida*) thriving in waters with very high water movement and relatively low irradiances, does not usually allow the development of the *Cystoseira mediterranea/stricta* community, but this community also indicates a very good water quality. These communities are replaced by other communities dominated by different species of the genus *Cystoseira* or by other brown algae in more sheltered environments. All these communities, that can be considered typical of good-water quality environments are replaced by other communities if water quality decreases. First at all, there is a progressive decrease on the cover of *Cystoseira*, *Lithophyllum byssoides* and other species, which ends in a total replacement of the community. Into moderately to very high hydrodynamic environments the community dominated by *Corallina elongata* (Bellan-Santini, 1968; Ballesteros *et al.*, 1984) and/or mussels (*Mytilus galloprovincialis*) (Bellan-Santini, 1968) is very abundant in waters with a high content of particulate organic matter and nutrients. In some places of the central Mediterranean the simplification of the communities dominated by the genus *Cystoseira* leads to the dominance of another species, *Haliptilon virgatum*. In most jetties and quays with high eutrophication levels, these communities can be present, together with other mediolittoral belts of green and blue-green algae. In other conditions with high nutrient loading (even of natural origin, e.g. very dense seagull colonies) the macroalgae of the genus *Ulva* (Golubic, 1970; Rodríguez-Prieto and Polo, 1996), *Cladophora* (Belsher, 1977) and *Enteromorpha* (Ballesteros *et al.*, 1984) appear, which can finally substitute the belts of *Cystoseira* or even *Corallina*. The replacement of all these communities by species of blue green algae (*Oscillatoria*, *Lyngbya*, *Phormidium*) or *Derbesia* indicates extremely high-degraded environments (Golubic, 1970; Littler and Murray, 1975).

Most studies devoted to determine the environmental quality of an area using communities as indicators use samples that are classified and quantified in the laboratory, or use lists of species with semiquantitative estimates of abundance that are directly obtained in the field. Nevertheless, cartographic methods have also been used in the study of littoral communities. First, cartography was used in marine reserves and other protected areas as a tool to know the distribution of the different communities in order to look for long-term changes (Bianconi *et al.*, 1987; Meinesz *et al.*, 1999). The incorporation of GIS methodology in this kind of studies has allowed more accurate cartographies and has made easy the data analysis in order to correlate the extension of the communities with other data (e.g. geomorphology, pollution...) (Mangialajo, 2000; Soltan, 2001). The establishment of a reference network of high status sites permits to estimate the ecological status and adjust this methodology to the Water Framework Directive (2000/60/EC).

## DESCRIPTION OF THE METHOD

Sampling is performed in the totality of the rocky areas present in the selected coast. Sedimentary areas are not considered in this methodology if they are devoid of any apparent animal or vegetal coverage, as it is usually the case (with the exception of extremely sheltered environments and coastal lagoons where seagrasses or certain species of seaweeds can be abundant). We do not take into account highly man-modified water environments such as the inner part of harbours and marinas, which do not reflect the environmental quality of the adjacent coast.

The dimension of the sector of the coast to be used as a unit is difficult to precise because of the different coastal morphologies and of its fractal structure. However, and according to the length of the coast where we have applied this methodology, we have estimated this unit as 50 meters of coast length smoothed to the course of a pneumatic boat at a distance of 3 meters of the coastline. Therefore, the whole coast is surveyed with a pneumatic boat and the different units (communities or combination of communities) that are observed are directly indicated in aerial photographs, nautical charts or ortho-photographs. This graphic support has to be of an appropriate scale (in our case enough to differentiate the 50 meter sectors, that is 1:10.000 or 1:5.000) and suitable to be easily used in a small boat. Most of the sampling should be performed in a rather reduced time scale (e.g. one to two months) in order to avoid the great seasonal variability that is usually associated to these littoral communities. In the Northwestern Mediterranean the best months to make this kind of study are May and June, but this may vary when considering other geographical areas.

In our study we have differentiated the following units:

- Cystoseira 5: The belt of *Cystoseira mediterranea* / *stricta* is continuous, with a high density of *Cystoseira* plants.
- Cystoseira 4: The belt of *C. mediterranea* / *stricta* is continuous only in the places that are most suitable for this species.
- Cystoseira 3: The belt of *C. mediterranea* / *C. stricta* is not continuous, and density of *Cystoseira* is only high in the places that are most suitable for this species. There are some small sectors that can be devoid of *Cystoseira* or, if present, it is represented by isolated plants.
- Cystoseira 2: *C. mediterranea* / *C. stricta* never attains high densities and, therefore, a clear belt of this species is inexistent (with the possible exception of some isolated and small patches in very few places very suitable for this species). The isolated plants are usual, even abundant.
- Cystoseira 1: Only scattered plants of *C. mediterranea* / *C. stricta* are present, growing inside other communities. There are no patches, even of very small size, where a *Cystoseira* belt can be described.

*Lithophyllum byssoides* – formation ("trottoir"): Present in places with high hydrodynamism and steep slope. The growth of *Lithophyllum byssoides* creates an overhang in the upper infralittoral level that prevents the growth of *Cystoseira*.

*Cystoseira* spp. (sheltered environments): Mainly characterized by *Cystoseira crinita*, *C. brachycarpa*, *C. elegans* but also by other species of the same genus. The same categories used for *C. mediterranea* can be used.

*Cystoseira compressa*: Belt of *Cystoseira compressa*, it can also be distinguished in the 5 categories we have used for *C. mediterranea* / *C. amentocea* var. *stricta*.

*Posidonia oceanica*: Barrier reefs of *Posidonia oceanica*, whose leaves attain the water surface can be observed in sheltered environments, usually together with *Cystoseira* spp.

*Cymodocea nodosa*: Meadows dominated by this species in very sheltered environments, over sand, mud or gravel.

*Zostera noltii*: Meadows dominated by this species in extremely sheltered environments, usually over muddy and silty bottoms.

*Corallina elongata*: This unit is characterized by the dominance of this species, which is widespread in the Northwestern Mediterranean, but always with the absence of *Cystoseira*. In fact, the categories 1 and 2 of *Cystoseira* should be usually attributed to this or other communities with the presence of some *Cystoseira* individuals.

*Halimtilon virgatum*: Community dominated by this species, sometimes with *Dictyota fasciola* and *Laurencia microcladia*. Absence of *Cystoseira* plants.

*Mytilus galloprovincialis*: Mussel beds, without *Cystoseira*.

Green algae: Green littoral belts dominated by *Ulva*, *Cladophora* without *Cystoseira*.

Encrusting corallines : Belts dominated by the encrusting corallines *Lithophyllum incrustans*, *Neogoniolithon brassica-florida*, and, even, crusts of *Corallina elongata*.

Blue green algae: The dominant species are blue green algae, perhaps with some ulvacean algae and *Derbesia tenuissima*.

The presence/absence and abundance of every community is determined not only by pollution or other anthropogenic disturbances but also by the natural environment. Therefore, different geomorphological parameters that most probably are involved in the establishment and/or development of the communities have to be evaluated in order to account for this natural variability. The geomorphological factors that we have considered are the following:

- Coastline morphology: continuous rock, blocks, stones...
- Substrate constitution: calcareous, basaltic, granitic...
- Coastline slope
- Coastline orientation
- Natural\Artificial
- Degree of wave exposure
- Height of the sea-cliffs

Based on the previous knowledge (expert judgement), obtained by other methods or by the available literature, and for every community or unit we have established a direct correspondence between units and quality based on the vulnerability in front of natural or anthropic disturbances. Each unit or combination of units must have a "quality" value. In our first approach we established a scale from 1 to 20 (table 1), but is possible to use any other scale. Thus, the assessment of the environmental quality of a concrete sector of coastline can be estimated as:

$$EQV = \frac{\sum (l_i * x_i)}{\sum l_i}$$

where,

- EQV: Environmental Quality Value of a stretch of coastline.
- Li: length of the coastline occupied by the unit i.
- Xi: assessment of the quality value of the unit.

Table 1: Examples of quality values for different communities found in the coasts of Catalonia.

UNIT(i)	VALUE(xi)
Cystoseira 5	20
"Trottoir" <i>L. lichenoides</i>	20
Cystoseira 3	15
<i>Corallina elongata</i>	8
<i>Mytilus galloprovincialis</i>	8
<i>Lithophyllum incrustans</i>	6
Green algae	3
Blue-Green algae	1

The cartographic information obtained has to be transcribed, as accurately as possible, to a GIS. This GIS must have a geo-referenced graphical support (e.g. orto-photographs), and the coastline must be generated over this graphical support. The coastline has to be divided in sectors, and we assign a community category and the values of the different parameters for every single sector of coast.

The Mediterranean coastline is, in some places, subject to great anthropogenic modifications. Thus, coastlines coming from different graphical supports can be different and even have strong changes from one year to another (creation of new harbours or jetties, dredging, beach regeneration). These changes have to be taken into account when transcribing the data and the graphical support has to be modified accordingly from year to year.

As established by the WFD (2000/60/EC) in order to ensure comparability between the values obtained by different monitoring systems an ecological quality ratio (EQR) has to be calculated. These ratios represent the relationship between the values observed in the study site and the values observed in the reference sites.

$$\text{EQR} = \frac{\text{Relation of observed values of biological parameters}}{\text{Reference values of the biological parameters}}$$

The reference sites have to be selected based on 1) their undisturbed or very minor disturbed state and 2) their similar physico-chemical and hydrogeomorphological conditions with the valuated site. In our case, the reference network for the Catalan coast is formed by three different high status sites: 1) Façade maritime du Parc Naturel Régional de Corse, 2) Reserva dels Freus de Formentera i Eivissa and 3) Reserva del Nord de Menorca. These three reference sites were cartographed in 2001.

The comparison between the Catalan coast and the reference sites has to be made sector by sector. First at all, it is important to assess which are the geomorphological factors that affect the presence/absence or dominance of the different communities. A MDS analysis was performed in the reference sites regarding all the different situations (e.g. 174 in our study) resulting from all the combinations of the geomorphological variables considered and the percentage of coast occupied by each community for each situation.

Results of this MDS analysis shows that "Coastline morphology" (Fig. 1) and "Natural\Artificial" (Fig. 2) are the most important parameters in the determination of the littoral benthic communities in the reference sites. The combination of these parameters permits to define six different "geomorphological relevant situations" (table 2). The value of EQV has been calculated for everyone of these situations (table 2).

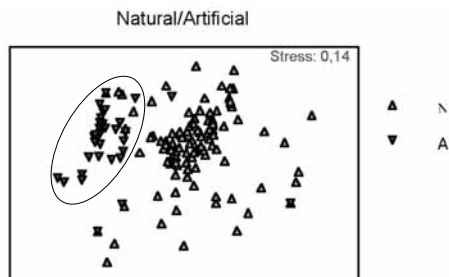


Fig. 1 : MDS analysis: distribution of the 174 different situations resulting from all the available combinations of the geomorphological variables considered in reference sites according to the percentage of coast occupied by each community for each situation. Artificial and natural substrates are indicated with different symbols.

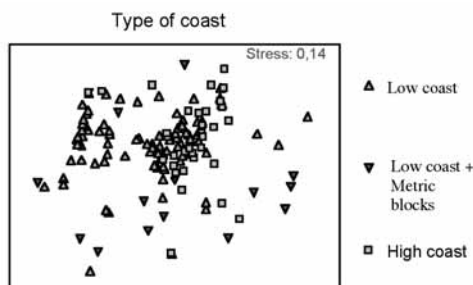


Fig. 2 : MDS analysis: distribution of the 174 different situations resulting from all the available combinations of the geomorphological variables considered in reference sites according to the percentage of coast occupied by each community for each situation. Decimetric blocks, low coast and high coast are indicated with different symbols.

Table 2: Ecological quality values calculated for the six geomorphological relevant situations in reference conditions

Situation	Type of coast	N/A	EQV
1	Decimetric blocks	Artificial	12,06
2	Low coast	Artificial	11,86
3	High coast	Artificial	8,00
4	Decimetric blocks	Natural	12,20
5	Low coast	Natural	16,61
6	High coast	Natural	15,25

The EQR of every sector of coast to be evaluated was calculated based on the relation between the EQV obtained in the study site and the EQV in the reference sites corresponding to the same "geomorphological relevant situation". Therefore, the EQR of a coast is calculated according to the following formula:

$$EQR = \frac{\sum \frac{EQV_{ss_i} * l_i}{EQV_{rs_i}}}{\sum l_i}$$

where:

i : situation

EQV<sub>ss</sub>i: EQV in the study site for the situation i

EQV<sub>rs</sub>i: EQV in the reference sites for the situation i

li: Coastal length in the study coast for the situation i

The EQR is a value quoted from 1 to 0. We classify the range of values in 5 categories of disturbance and status (table 3) that are expressed in five different colors in the maps: blue for high, green for good, orange for moderate, yellow for poor and red for bad ecological status

Table 3: Degree of disturbance and ecological status for different intervals of the Ecological quality ratio

EQR	Disturbance	Status
>0,75 - 1,00	No or very minor	High
>0,60 - 0,75	Slight	Good
>0,40 - 0,60	Moderate	Moderate
>0,25 - 0,40	Major	Poor
0,0 - 0,25	Severe	Bad

### EXAMPLE

This methodology has been applied to the coast of Catalonia. Data was collected in spring 2002. The geomorphological parameters were evaluated in year 2001, together with the geomorphological and community cartography of the reference sites. Here, we present the EQR corresponding to different regions, although it can also be obtained for municipalities or other geographical or management-based units (Fig. 3).

The result of the EQR for the littoral regions in Catalonia in year 2002 shows that the ecological status of the northern coast is high, while the center and the south coast have a moderate status, except for the region of "Tarragonès" with a good status. The region "Baix Llobregat" has not been evaluated since its shoreline is completely sandy.



### CONCLUSIONS

The cartography of the littoral communities permits to know the distribution of these communities along the coast and the monitoring of the ecological status of coastal waters within the WFD monitoring programs. The sampling of data is relatively quick and, as a visual method, it is non destructive. It is also important to point out that is continuous and every piece of rocky coast can be evaluated. Nevertheless, coasts devoid of any kind of macroscopic vegetation cannot be evaluated (e.g. sandy shores).



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