# Methodological approach to the study and "follow-up" of an Environmental Impact Study (EIS) of aquaculture in the open sea

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# Methodological approach to the study and "follow-up" of an Environmental Impact Study (EIS) of aquaculture in the open sea

***A. Belmonte, **J.M. Ruiz, ***A. Uriarte and ****F. Giménez**
*Freelance. Avda. Infante Juan Manuel, 4, 2º Esc., Murcia 30011, Spain
**Spanish Oceanographic Institute, Oceanographic Centre of Murcia, Apdo. 22, 30740 San Pedro del Pinatar, Spain
***Instituto Tecnológico Pesquero y Alimentario (AZTI), Dept. of Oceanography and Marine Environment, Avda. Satrústegui, 8, 20008 San Sebastián, Spain
****Department for Environmental Sciences and Natural Resources, Faculty of Biologic Sciences, University of Alicante, Campus de S. Vicente de Raspeig, P.O. Box 99, 03080 Alicante, Spain

**SUMMARY –** The present study aims to explain the methodology used in an EIS (Environment Impact Study) of several Mediterranean aquaculture projects (mainly relating to red tuna). The form of pollution caused by this activity has been studied; it is classified into biotic pollution (the introduction of exotic species) and abiotic (organic material particles, inorganic solids, metabolic products and products caused by the handling of installations and structures). Moreover, the type of projects (protected floating cages, in the open sea) and the environment where the activity is to take place are also studied. The relevance of the vertical impact on land is much higher than in marine habitat, where horizontal impacts should also be taken into account. In the latter case, it is necessary to have control stations far enough from the focus of the disturbance, but having as many similar characteristics as possible. It is also important to be able to differentiate changes caused in the environment, by a disturbance from changes caused by the seasonal conditions of the different communities. Consequently, previous knowledge of the environment where the project is to be developed is essential. One of the most important points to be considered, regarding the methodology applied, is undertaking a study on the local currents, with the aim of modelling pollutant dispersion. In this way, we can locate the sampling stations involved in the Environment Control Program (ECP), operating during the activity development. Basically, the objective of an ECP is to check if the EIS predictions on a particular project are fulfilled. Likewise, whether taking the proposed corrective steps, disruptions caused by impacts can be minimised. Therefore, information collected from the environment impact control is the empirical base, to acquire the necessary knowledge to make estimations about the environmental effects of future projects.

**Key words:** Aquaculture, impact, tuna, modelling.

***RESUME –** "Approche méthodologique à l'étude et suivi d'une étude d'impact sur l'environnement (EIE) de l'aquaculture en mer ouverte". Cette étude vise à expliquer la méthodologie utilisée dans une EIE (étude d'impact sur l'environnement) de plusieurs projets aquacoles méditerranéens (notamment concernant le thon rouge). On a étudié le type de pollution produite par cette activité ; on l'a classée en pollution biotique (l'introduction d'espèces exotiques) et abiotique (particules de matière organique, solides inorganiques, produits métaboliques et produits de la manipulation des installations et des structures). On a étudié également le type de projets (cages flottantes protégées, en mer ouverte) et l'environnement où l'activité sera développée. L'intérêt de l'impact vertical sur le terrain est plus important que sur l'habitat marin, où les impacts horizontaux doivent aussi être considérés. Dans le dernier cas, il est nécessaire d'avoir des stations de contrôle suffisamment éloignes du centre de perturbation, mais avec des caractéristiques les plus similaires possibles. Il est important également d'être en mesure de différencier des changements causés sur l'environnement par une perturbation des changements causés par les conditions saisonnières des différentes communatés. En conséquence, il est essentiel d'avoir une connaissance préalable sur l'environnement où le projet sera développé. Un des points les plus importants à considérer, en ce qui concerne la méthodologie appliquée, est de faire une étude des courants locaux dans le but de modéliser la dispersion de polluants. De cette façon, on peut localiser les stations d'échantillonnage participant au programme de contrôle de l'environnement (PCE) et fonctionnant pendant le développement de l'activité. L'objectif fondamental d'un PCE est de vérifier si les prédictions de l'EIS dans un projet particulier ont été réalisées. Egalement, voir si en adoptant les mesures de correction proposées on peut minimiser les perturbations provoquées par les impacts. Par conséquent, l'information collectée à travers le contrôle de l'impact sur l'environnement est la base empirique pour acquérir la connaissance nécessaire afin d'estimer les effets sur l'environnement de projets futurs.*

***Mots-clés :** Aquaculture, impact, thon, modélisation.*

## Introduction

An Environment Impact Study (EIS) is a procedure by which prediction of the impact (i.e. degree of anthropogenic disturbance) that the intervention of a certain activity or understructure may have on the environment, will determine the suitability of that intervention. Logically, there are no essential differences between the prediction and verification of the impact. Both tasks are based upon a comparison between a "normal" state of the ecosystem (not disturbed) and a disturbed state, as a consequence of the intervention (García Charton, 1997). When an impact is predicted, the normal state can be known in detail; however when verifying an impact, only the disturbed state is generally known. The prediction procedure and verification of the impact aim to: (i) detect the named impact (can it happen?); (ii) identify it, i.e. describe the kind of physico-chemical and biological mechanisms intervening in the disturbance; and (iii) provide an estimation of the magnitude of the effects and their relative importance within the ecosystem.

Using a medical analogy, an expert on the environment may, starting from a "symptom", diagnose the ecosystem's "physical condition" and determine the environmental "health" deterioration that the intervention of an activity may involve (Rapport *et al.,* 1985; Shrader-Frechette, 1994). Environmental stress symptoms usually appear in a group (being "syndromes"), simultaneously acting at several levels (breathing, feeding, growing, reproduction, etc.) in response to alterations in concrete levels (organs, tissues, cells or subcell level); these provoke successive effects in the general levels (population, community, ecosystem).

Since September 1995, a group of Spanish professional individuals, with different areas of expertise including geologists, civil engineers, chemists, biologists, etc., have been working jointly on EISs into the fish farming of gilthead (*Sparus aurata*), red tuna (*Thunnus thynnus*) and sea bass (*Dicentrarchus labrax*).

The present study explains the methodological concepts used to evaluate the environmental impact caused by the above activities, specifically in the case of tuna farming in the area around Tiñoso Cape, within the coast of Murcia (SE Spain). We have carried out an EIS regarding the location of two floating cages, situated on the east and west side of the Cape (Figs 1 and 2) (Belmonte and Ruiz, 1996; Belmonte *et al.,* 1997).

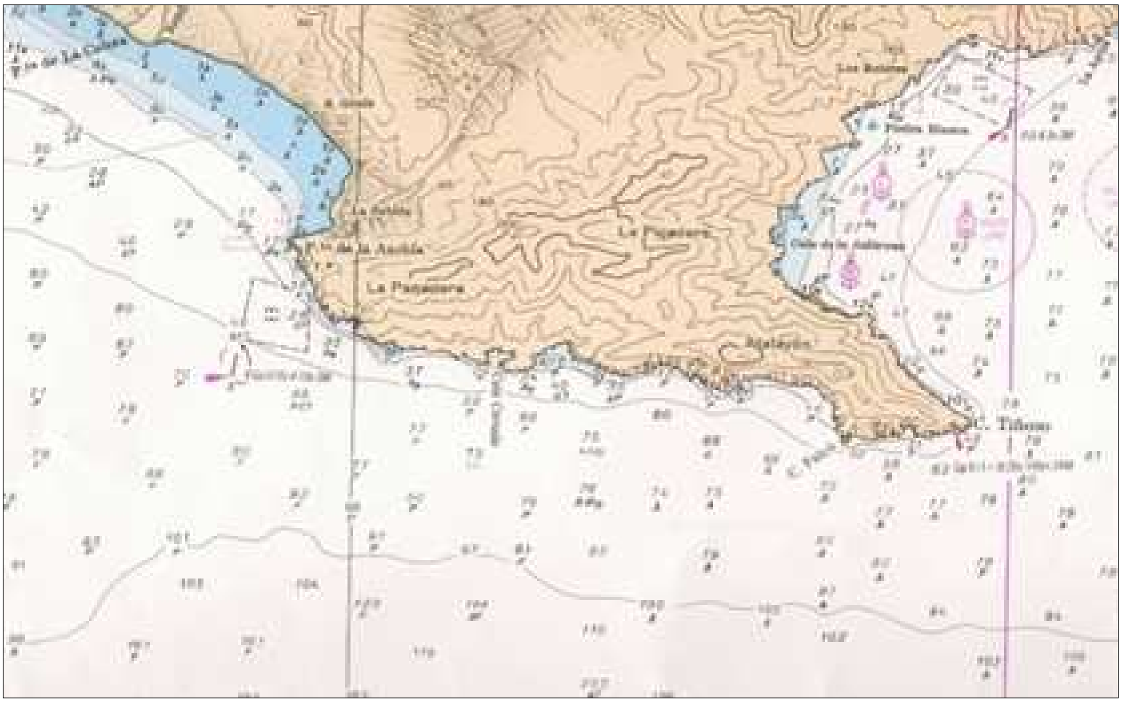

Fig. 1. Tiñoso Cape, coast of Murcia (SE Spain). Location of two floating cages, situated on the east and west side of the Cape. (Note: bathymetry in metres.)

Fig. 2. Tiñoso Cape, the south and east sides; for location see Fig. 1.

## Ecosystems heterogeneity

Firstly, in terms of the methodology, it is important to establish the "normal" state of the ecosystem, with which the present or future disturbed state has to be compared in order to define the scope and relevance of the impact. A characteristic of ecosystems, which makes the answer to these questions extremely complicated, is their heterogeneity (Kolasa and Pickett, 1991; Levin, 1992).

Ecological heterogeneity can be defined intuitively as a change in space and time, at multiple and simultaneous scales, of organisms and their physico-chemical living conditions. This change results from interaction between the space-time variations of environmental conditions (temperature, salinity, light, nutrient concentrations, habitat physical structure, etc.) and the organisms' different reactions to these conditions. Moreover, the maintenance of the marine habitat creates a new difficulty; this consists of defining the scope of the impact provoked by the disturbance or, in another words, the environment of the project. Such a definition will, undoubtedly, influence the studies' conclusions. Similarly, the three-dimensional aspect of the problem needs to be considered. Overall, there is a need to differentiate the changes in the ecosystem provoked by the disturbance, from the changes caused by the ecological heterogeneity. Hence, there is a need to identify control stations far enough from the disturbance focus, but still having as many similar characteristics as possible.

In summary, the better our knowledge of the environment where the project is to be developed, the easier it will be to reach any conclusions. Therefore, in our opinion, it is essential to obtain the most detailed information about the so-called "pre-operational" state in an EIS.

## Definition and description of the project environment

The selection of the scale at which the project will operate has to be undertaken on an objective basis (Raimondi and Reed, 1996). Such an approach should start with the use of previous scientific and technical information, the collection of meadow data on physical processes that could define the area of study (sea currents, sediment dynamics) and carrying out pilot studies. Such preliminary sampling has as its aim, the definition of the space distribution of organisms of interest, together with their variations in time.

Geomorphologically, the coast is oriented to the south; therefore, it is predominantly exposed to winds and swells in 2nd and 3rd quadrants. Generally the water masses associated with the coast of Murcia are: "Mediterranean" coastal mass, warm and salty, and "Atlantic" mass, located far from the coast). This general pattern changes in the area around Tiñoso Cape, where the appearance of deep waters has been detected, this is caused by the presence of large submarine valleys cutting trough the continental slope. Such morphology/bathymetry causes the presence, next to the coast, of cooler and nutrient-rich waters, compared to the general oligotrophic conditions of the region.

The area where the two installations are located consists of two distinct settings; namely, the eastern and western part of Tiñoso Cape (Figs 1 and 2). The limit between the two sections would be Punta de la Azohía (Fig. 1). Such a division is made on the basis of land roughness, the type of seabed and the geomorphology of the bed (defined on the basis of the bathymetric profiles).

The western area of the Cape, Mazarrón's Bay (Fig. 3), is characterised by a low-lying coast with some medium high cliffs, a gently sloping offshore bathymetric profile, a seabed of sand and pebbles, and extensive beaches. Some watercourses do empty into this area. These are excellent conditions for the development of *Posidonia oceanica* meadows (Belmonte *et al.,* 1997).

Fig. 3. Mazarrón's Bay.

The eastern area of the cape (Cartagena's Bay) is characterised by high and steep cliffs that extend vertically into the sea. Hence, this is an area of substantial coastal and seabed roughness, with only a few small beaches of alluvial origin. The sedimentary seabed material is less muddy than in the previous location.

The continental shelf over the whole of the area is relatively narrow, with a higher slope than average for SE Spain.

In the ecological assessment of the area, where a predetermined activity is to be developed, it is particularly useful to know the "quality" of the environment and, therefore, the possible disturbance effects on the environment caused by the particular activity. The marine ecosystem assessment is determined by representation and structural and space development of the benthic communities level in the area, or the natural level; this is clearly dependent upon the sediment and water quality (Belmonte *et al.,* 1997).

Waters in the area of the location at the installations are oligothrophic, poor in nutrients, transparent and free from industrial waste. The only nutrients and cloudiness variations are caused by natural processes: the emergence of deep waters, vertical water exchange and the casual contribution of land materials (Belmonte *et al.,* 1997).

The coastal area of study is characterised by vertical cliffs, large rocks and small beaches: these relate to a high diversity of rock substratum habitats. Within this types of habitats, almost all the Mediterranean biocenosis are represented, such as photophyl seaweeds, pre-coral photophyl communities, hollows and overhangs. Further, the high quality waters have favoured the development and conservation at a high level of benthic communities (Belmonte *et al.,* 1997).

There is little knowledge available, at present, concerning the processes implied in the management of marine environment. At the same time, information about the different biotic and abiotic components is very scarce, especially relating to the coast of Murcia. In an attempt to be precise concerning the ecological assessment of the area of study, it was decided to study the *Posidonia oceanica* meadow; it is, together with the rock substratum communities, the most representative and extensive benthic community of the region. Therefore, the study of spatial variations (bundle density) was the first approach utilised for the ecological assessment of this particular community (Belmonte *et al.,* 1997).

The importance of *Posidonia oceanica* in the Mediterranean coastal ecosystem is based upon:

(i) Being responsible for a large amount of benthic production in coastal areas.

(ii) Hosting a large number of animal and floral species.

(iii) Serving as refuges, reproduction and feeding places for various species of commercial interest.

(iv) Playing a very important role in: the stabilisation of coastal sediments, the maintenance of physico-chemical characteristics of the water column, and the protection against erosion processes related to the littoral dynamics.

Hence, the local and regional administrations supported by the Spanish government are promoting a protocol aiming to protect these communities (artificial deterrent reefs).

In the area of study two different areas can be identified, as outlined below:

(i) The Azohía meadow. This meadow is characterised by a high structural and spatial development, providing the location with a high/very high ecological value. Only the inferior limit presents an alteration of the space structure acting on the vertical sheaf growth on the meadow. This alteration is consequence of the silt accumulation in the deepest zones. Silt coming from the next littoral streams (Belmonte *et al.,* 1997).

(ii) The Cala Salitrona – La Aguja meadow. As a consequence of the platform's high slope, this area consists of a narrow section lying parallel to the coast; this increases somewhat in width in Cala Salitrona. The development level of the meadow is optimal in the surface areas, but reduced in the deeper areas just to the lower limit, in relation to the more developed meadows along the coasts of Murcia; it is more developed in the area of Cala Salitrona (Fig. 1) (Belmonte *et al.,* 1997).

The meadow has a medium ecological value at a regional level, due to its reduced development and extension, especially over the seabed in front of Los Boletes (Fig. 1). However, the area has a high ecological value at a local level, due to its high natural level and its contribution to habitat and benthic community diversification in the area.

Detritivorous communities next to the Azohía area have a very reduced ecological value, as a consequence of sediment accumulation of material supplied by neighbouring watercourses (Belmonte *et al.,* 1997).

Away from Punta de la Azohia, the influence of these sediments from watercourses becomes less important. Hence, around Tiñoso and Falcó Capes surroundings (Fig. 1), there exists a detritivorous biocenosis of optimal development and high representation.

However, in front of Cala del Bolete and Cala Aguilar there is a muddy detritivorous community with a high proportion of land-derived materials; this is of a reduced ecological value.

## Study of local currents

In order to study local currents, two current meters were located in each of the proposed locations for the installations, over the same period of time and during the same season. Speed and (local) current direction were obtained every 10 min. These data were used later in the dispersion modelling of pollution in the water column, caused by materials secreted by the metabolism of fishes and food not ingested.

Within the western area of Tiñoso Cape (Azohia) the currents were more frequently in a NW-SE direction (parallel to the coast). The predominant current was towards the SE, with high speed and lasting approximately 14.7 days (half the lunar cycle), this was interrupted only to change to the NW, with currents of lower intensity, and higher variability (at the same time). Speeds in the SE direction were of the order of 5 cm/sec (0.7 knots), and of less than 3 cm/sec in the NW direction (Belmonte *et al.,* 1997).

Within the eastern area of Tiñoso Cape (Los Boletes), the currents also show high frequencies in both E-NE and SW directions (parallel to the coast). However, in this season currents are considerably lower than in the previous case, with maximum speed in a SW direction: on a particular day, speeds of 16 cm/sec (0.32 knots) were exceeded. Over the reminder of the directions, the highest speed recorded was 10 cm/sec (0.2 knots), whilst a mean speed was of the order of 3 cm/sec (0.06 knots) (Belmonte and Ruiz, 1996).

According to the analyses undertaken the currents had a dominant SW direction, with changes every 24 hours approx. towards the NE. These NE currents are of a lower speed than the SW currents lasting a shorter time.

In terms of directional frequencies, the directions parallel to the coast are dominant. However, over the last period of the analysis, the N component was more important; this relates to transport towards the coast, but at a very low speed. The most frequent current direction was towards the SW, with 4.6% of the recorded values. The less frequently recorded direction was in the offshore direction, i.e. SE, with 9.7% of the values.

## General description of the project

Red tuna is of the genus *Thunnus*, from the family *Scombridae*, existing in the Atlantic Ocean and the Mediterranean Sea; it is one of the most important fishes, in high demand as a food source. This migratory fish is characterised by its high power of movement, being able to make long trips in its reproduction and trophic migrations. Tuna, in its reproduction migration, moves towards the Mediterranean Sea; it is the Balearic Sea which is one of its spawning places.

The tuna is a pelagic and migrating species. It has a spindle-shaped body and widely-forked tail and is extremely large when adult. This species is associated mainly with clean and oxygenated waters; it always avoids sediment in suspension or cloudy waters, since they will impel the brachial gaseous exchange. This limitation is the reason why the selection of the installation location is so important.

The project itself involves the capture of individuals of this species, during June and July, within the Mediterranean Sea. Subsequently, they are put into cages and sent to fixed cages located on both sides of Tiñoso Cape; they are fed with the aim of fattening them until January, when they will be sold. The weight that the fish can reach in these environmental conditions of temperature, hydrodynamism and water quality, will depend on the initial weight. So tunas of 50 kg could increase 65%, while tunas of 175 or 200 kg, could gain between 15 and 20%.

Tuna is a highly voracious fish: adult migrations, following reproduction, are undertaken with the aim of feeding. It has been established that tuna does not eat during the trip, as has been observed in trap-nettings. The diet consists mainly of mackerel (*Scomber scombrus*), together with different species of low commercial value cephalopods, supplied manually.

Fixed cages are octagonal in shape (Fig. 4), composed of a structure made with an end framework of different compositions (steel wires, floats, rings and shackles) in such a way that net cloths can be hanged upon them.

Fig. 4. Tuna cages.

## Spillage assessment

Taking into account the limitations imposed by natural processes, an EIS should address problems on the basis of a logical process, analogous to any ecological research (Green, 1979; Legendre and Legendre, 1979; Krebs, 1989; Shrader-Frechette and McCoy, 1993; Underwood, 1995a,b; Kingsford and Battershill, 1998). On the basis of an EIS being basically a comparative study, the task to be addressed is to design a method capable of deciding what, how, when and where to compare.

The first requirement in the development of a study is to pose a clear and scientific question. Peters (1991) affirms that these questions should commence with words such as "how much?", "when?" or "where?"; those questions difficult to undertake would start with words like "why?" or "how?". Therefore, the study has to be focused on quantifiable and identified aspects, in time and space.

In the case of the present study, the products of the tuna's metabolism, together with non-ingested foods (less relevant) are the main sources of spillage causing the most important disturbance to the ecosystem. Moreover, the quantity of organic particulate material is not excessive, since they are fed with entire specimens, which are not cut into pieces. In contrast, according to estimations derived elsewhere, some 20% of foods provided to giltheads is not consumed.

Since there is only a limited amount of literature or information available about these farms, spillage is difficult to assess. Commencing with the initial biomass, according to which the cages had been designed, then studying the weight, length and age data of the tuna captured in trap-nettings in southern Spain, an estimation of production can be obtained (Rodriguez-Roda, 1978).

Once data of production and quantity of food were obtained, it was intended to analyse the fish used as food (mackerel) with the aim of knowing its phosphorus and nitrogen content. As tuna fishing was out of season at the time of collecting these data, it was decided to study phosphorus and nitrogen contents in the tuna, since both are from the same family.

The result of all these attempts at assessing the P and N spillage to the environment, was a very high level of food conversion, although not too high if we take into account that the metabolism of pelagic species is very different to that of gilthead or sea bass.

Further, the above calculations of P and N contributions to the environment were not carried out in absolute terms. Rather, these calculations were considered as reference values, to assess the importance of these spillages to water.

The contribution of P and N to the environment is considerable, but its influence on water quality and benthic populations will depend upon two factors, namely:

(i) The frequency, sense and intensity of water currents in the area, i.e. the rate of water mass renovation around the installations.

(ii) The phase of the production cycle; in August, tuna has the highest need for food in the year, hence, the spillage at this time will be higher than in January.

## Modelling of pollutant dispersion

Hydrodynamic modelling was carried out with the use of TRIMODENA program, which is a software developed jointly by the Marine Engineering Laboratory (LIM) of the Barcelona's Technical University and the Technological Institute for Fishing and Nutrition (AZTI).

The two most important wind directions in terms of the incidence of waste materials along the coast, were identified. These were SW winds (with a maximum incidence on the Punta de la Azohía coast) and SE winds (with a maximum incidence over the El Bolete area), with 30 km/h speed (8.3 m/s), i.e. higher than the average.

Only cases in which local winds directly affect a specific area of the coastline have been considered. In this way, the influence of SW winds for Punta de la Azohía and SE winds for the El Bolete area have been analysed.

In conclusion, it was found that the location of cages within the Punta de la Azohía area was more convenient than in the area of El Bolete since, in the first case, there is a higher flow speed at depth. This characteristic ensures improved oxygenation within the cages although, in the area of El Bolete, water flow is rapid enough so as to guarantee the necessary water exchange within the cages.

Spillage towards the coast is not considerable, being only detectable at Cala de la Salitrona under easterly winds and at the extremity of the Azohía, under westerly winds. In the first case, the detected concentrations of spillage represent 0.1% of original concentrations in the surface waters; whilst at Punta de la Azohía, the concentrations can reach 30% of the original concentrations.

The seabed can be affected considerably at El Bolete, in response to minor spillage dispersion. It was observed, in all the simulations, that incidence on the bottom of the sea was limited to less than one kilometre radius, in the case of El Bolete; somewhat higher in Azohía. Although at La Azohía the affected area of the seabed was higher, the concentrations will be more dispersed; therefore, the incidence on the seabed will be less important.

## Environmental Control Programme (ECP)

Basically, the objective of an ECP is to establish if the EIS predictions, on a particular project, are fulfilled. Likewise, whether taking the proposed corrective steps, the disturbances caused by impacts can be minimised. Therefore, information collected from the ECP is the empirical basis to make estimations on the environmental effects of future projects (Belmonte *et al.,* 1997).

The assessment of possible effects caused by an environmental impact on benthic populations must be based upon adequate sampling of the kind of impact, affecting habitat and distribution and the composition of the benthic populations. Moreover, the assessment should be optimal, so to be capable of differentiating changes started by disturbances caused, in turn, by the environment impacts, i.e. exclusively from variations in natural origin. At the same time, an assessment should identify the application of specific statistical methods; these should be capable of defining the magnitude of the changes and, therefore, check the predictions with a minimal margin of error (Belmonte *et al.,* 1997).

When the sampling programme for this particular case study was designed, it was necessary to take into account the following considerations:

(i) The impact had yet not taken place and, as such, the benthic populations before disturbances (provoked by the impact) could be known in advance. This pre-operational state could be compared also in subsequent controls.

(ii) Previous knowledge of the prevailing hydrodynamics and diffusion over the area provided highly important information, in order to assess the sampling (situation and number/location of control stations).

(iii) The parameters should be capable of detecting precisely, in a short time, the effects of disruptions caused on the most relevant benthic populations.

## Descriptive parameters

(i) Water quality: nutrient concentration (nitrites, nitrates, ammonium and phosphates), chlorophyll and material in suspension are indicators of the systems productivity and the phytoplanktonic biomass.

(ii) Sediment quality: granulometry, organic material, organic carbon and microbiology (total and faecal coliform and faecal streptococcus).

## Benthonic communities

(i) Rock substratum: seaweed, molluscs and polychetes, being the most representative groups, were studied.

(ii) Smooth substratum: molluscs and polychetes (as the most representative groups) were studied.

## *Posidonia oceanica* meadows

(i) Bundle density.

(ii) Bundle characteristics.

(iii) Volume and nutrient composition of epiphytes (seaweeds, hydrozoos and briozoos).

## General considerations about the ECP

The difficulties in the control locations are due to the importance of the horizontal impact, since unexpected affected areas appeared during the course of the investigation. On land, this problem does not occur, since horizontal impact is less relevant.

According to the data collected by the samplings carried out during the first year of the Control Programme operations it was identified that, depending upon the parameters of the study, changes took place in a different time interval, i.e. different responses were obtained depending upon the communities. Hence, the smooth substratum benthic communities could be affected rapidly, since the substratum where they live changed. This change was due to the fact that substratum is the first receiver, for example, of the deposited organic materials. Communities living within a rock substratum are not affected by this change, only communities in the water column. In the latter environment, an increase in nutrients is produced almost immediately after the activity starts, as well as a reduction in the original levels when activity is completed and the fishes are recovered from the cages (Aliaga *et al.,* 1996-1997a,b).

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