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| **Allowable Zones of Effect for Mediterranean marine Aquaculture (AZE)** |

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**ABSTRACT**

Sustainability of Mediterranean aquaculture will be focus regarding to the environmental dimension of minimize the local impact on environmental conditions and biodiversity and respect the ecological services of the ecosystem. The development of floating cages on coastal systems needs to develop a regulatory framework for offshore aquaculture, considering important aspect such as permitting and site selection because the potential harmful effects on marine environment. For management purposes, the concept of AZE, area of sea-bed in which competent authority will allow to aquaculture some figures exceeding the relevant environmental quality standard (EQS), producing some non-permanent damage to the environment, can provide a degree of flexibility in the regulation of farms effects and recognises that it is quite impossible to cause no environmental effects from intensive fish production in the immediate surrounding area. Monitoring the environmental affection should be necessary for ensure sustainable aquaculture production, and three spatial scales may be considered: immediate vicinity of farm (AZE), to monitor that EQSs sampled around the AZE comply with the EQSs set for the medium field and to evaluate how much EQS at the regional scale differ from the reference sites.

## 1. Marine Spatial Planning: need of definition of Allowable Zone of Effect for aquaculture activities.

### 1.1 Mediterranean Sea: marine aquaculture in oligotrophic waters.

Mediterranean Sea, as an enclose sea with a high continental influence, present an idiosyncratic combination of characteristics which make them very different from other marine regions, for example, the existence of a tidal range very reduced, which limited the washing up of nutrients as happen in open oceans. Karakassis (2001) enumerated the characteristics that affect both the fish farming industry and the ecological processes determining the fate of aquaculture wastes:

a) High temperature (annual minimum of 12ºC, reaching up to 25ºC during summer) induces high metabolic rates, thus affecting both the production of the farmed fish and the activity of microbial communities.

b) The microtidal regime (tidal range is typically less than 50 cm) reduces the potential for dilution and dispersion of solute and particulate wastes particularly in enclosed bays were wind-driven currents are relatively weak.

b) Oligotrophy: low nutrient content, low primary production, and low phytoplankton biomass are typical of most Mediterranean marine ecosystems, particularly in the Eastern Basin. Low phytoplankton biomass induces high transparency of the water and light penetration deeper in the water column thus allowing photosynthesis at a greater depth.

c) Primary production is considered to be phosphorus limited as opposed to nitrogen limitation in the Atlantic and in most of the world's Oceans. In this context, eutrophication could be expected only when phosphate is released in adequate quantities.

d) The biotic component of the ecosystem, i.e. the fauna and flora, is highly diverse particularly in the coastal zone and consists of a large proportion of endemic species as a result of the dynamic geological past of the Mediterranean. It is typically of low abundance and biomass as a result of the prevailing oligotrophic conditions.

e) The morphology of coastal bays where most of the aquaculture is practiced is also very different from that of Scottish lochs and Norwegian fjords. They are typically not associated with permanent freshwater supply nor do they have a sill impeding the subsurface exchange of water masses.

Additional to the traditional Mediterranean extensive aquaculture, with a multitrophic production on natural wetlands, producing mollusc, crustaceans and/or several species of fish with a low trophic level, using the natural primary and secondary production from marine ecosystem, intensive production of fin fish has been developed on coastal areas. Mediterranean aquaculture produces mainly carnivorous species because the request of the market, using additional food. The intensive production is carried out mainly in floating cages. Cage aquaculture needs of high rich protein food for feeding these species with a high trophic level such as the sea bream and sea bass, which provide a large source of nutrients inputs to coastal areas.

It is significantly demonstrated that this intensive development of aquaculture industry produce an increase of nutrient load to marine environment which can exceed the assimilative capacity of marine environment, producing situation of eutrophication (Naylor et al., 2000). Depending on environmental management and total production, fish farms produce a magnitude of diverse types of effluents, such as wasted feed and faeces, dissolved organic matter, nutrients as ammonium, drugs and pesticides, which can pollute the marine environment with several negative impacts on ecosystem (Holmer et al., 2008).
Sustainability of Mediterranean aquaculture will be focus regarding to the environmental dimension of minimize the local impact on environmental conditions and biodiversity and respect the ecological services of the ecosystem; therefore the protection of the environment (waste management) conservation of habitats and singular species, maintaining the local ecological biodiversity and water quality will improve the sustainability in Mediterranean aquaculture (GFCM, 2011; InDAM project). Also the Mediterranean is the area of competence of two marine environmental convections: i) The Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area, of which the European Union is not a member, and ii) The Barcelona Convention or Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and the Mediterranean Action Plan (MAP) which is linked to it.

### 1.2. Aquaculture and spatial planning.

The development of floating cages on coastal systems needs to develop a regulatory framework for offshore aquaculture, considering important aspect such as permitting and site selection because the potential harmful effects on marine environment. It is important to establish a regulatory process that clearly identifies where aquaculture facilities can be located and for how long. Also, Integrating coastal zone management should be used to analyse the potential interactions among aquaculture and other activities, with the aim to integrate the spatial use of coastal areas minimizing the negative impacts.

Following the rules of the Location theory, which is concerned with the geographic setting of economic activity, location of aquaculture facilities should address the questions of what kind of aquaculture activities will be located, where and how. Thus companies will choose locations that maximize their profits and administration should regulate the use of space for maximize their utility by society, in terms of environmental, social and economical sustainability. In this situation marine spatial planning should bring together multiple users of the ocean – including energy, industry, government, conservation and recreation – to make informed and coordinated decisions about how to use marine resources sustainably. Spatial planning of aquaculture should be a public process of analyzing and allocating the spatial and temporal distribution of aquaculture in marine areas to achieve ecological, economic, and social objectives that usually have been specified only through an administrative process, incorporating a participatory approach. Essentially, spatial planning will help to a site selection that enables integrated, forward-looking for regulating, managing and protecting the marine environment, including through allocation of space, that addresses the multiple, cumulative, and potentially conflicting uses of the sea (Nath et al. 2000). Effective marine spatial planning has essential attributes (Joint Marine Programme Marine, 2007):

- Multi-objective. Marine spatial planning should balance ecological, social, economic, and governance objectives, but the over riding objective should be increased sustainability.
- Spatially focused. The ocean area to be managed must be clearly defined, ideally at the ecosystem level - certainly being large enough to incorporate relevant ecosystem processes.
- Integrated. The planning process should address the interrelationships and interdependence of each component within the defined management area, including natural processes, activities, and authorities.

### 1.3. Allowable Zone of Effect as mixing zone for aquaculture activities.

Compare to terrestrial spatial planning, marine planning achieve the trouble of the property of space and resources, and the diffuse potential pollution because hydrodynamic, as movement of water bodies could increase across the space the influence of marine aquaculture far away from the source of pollution, affecting e.g. protected habitats or other user interests at scale of hundreds to thousands of meters. Therefore, it is important to define the space where the activity can affect in some ways the environmental conditions. The mixing zone concept has commonly been applied in the environmental management of a wide variety of municipal (sewages, traffic pollution) and industrial discharges, understand as the area of determine terrestrial ecosystem, and/or or volume of atmosphere, within which it is permitted to exceed an environmental quality standard. Marine fish aquaculture, like other human interventions in the marine environment should have an impact in the water body and benthic habitats, because effluent treatment is unavailable, impractical, inadequate or prohibitively expensive and dilution by receiving waters is necessary before water quality standards are achievable. The greater impact is clearly in around the area where the activity is taking place; therefore, many regulatory authorities adopt the term of Allowable Zone of Effect (AZE) as the mixing zone for marine aquaculture. This term has been also used with several synonymous by different organization (Table 1).

| Term | Source of definition | Document |
|---|---|---|
| Mixing zone | GESAMP 1996 | www.fao.org/documents |
| Allowed Zone of Effect | Scotland (SEPA) | www.sepa.org.uk |
| Zone A | Ecasa EU Project | www.ecasa.org.uk |
| Aquaculture Management Areas | New Zealand | www.mfe.govt.nz/issues/aquaculture/faqs/aquaculture-management-areas.html |
| Local impact Zone | Croatia | http://ccrm.vims.edu/publications/pubs/aquaculture%20guidelines.pdf |

Table 1. Example of several terms synonymous for AZE used by different organizations.

An AZE, generally may be spatial, as defined by a fixed area of the seabed or a fixed volume of the water column beneath or around the aquaculture facility. But also it may be considered temporal, as defined by a measurement at a fixed point so many hours after an event. Application of this terminology has used in early by some countries such as Scotland. The Scottish Environment Protection Agency (SEPA) regulates the marine cage fish farming industry in Scotland through the exercise of its powers and duties under the Control of Pollution Act 1974. SEPA regulates the emission of pollutants through a system of discharge consents, which contain limits and conditions relating to their release. In the absence of practical methods to collect and treat waste products arising, the industry relies on natural environmental processes to render them harmless in the waters around the fish farms. An 'Allowable Zone of Effect' is used, which is defined as " The area (or volume) of seabed or receiving water body in which SEPA will allow some exceedance of the relevant environmental quality standard or some damage to the environment" (www.sepa.org.uk). SEPA accepts that a certain area immediately below and around the cages may experience carbon accretion to a level which may change the community structure of sediment fauna but within this AZE quality standards should ensure a minimum number of sediment re-workers, which will be available to breakdown wastes and prevent total anoxia developing. Based on that, a more general definition can be "The area of sea-bed or volume of the receiving water body in which competent authority will allow to Mediterranean aquaculture producers some figures exceeding the relevant environmental quality standard (EQS) that might be defined for the different Mediterranean region by experts, producing some non-permanent damage to the environment". Acceptation of AZE around fish farm provides a degree of flexibility in the regulation of farms effects and recognises that it is quite impossible to cause no environmental effects from intensive fish production in the immediate surrounding area. This concept may become fundamental to the system of environmental management within the Mediterranean region. It follows that any modelling approach used in regulating effluent discharges must allow appropriate boundaries to be set defining where the Mediterranean environmental managers expect the EQS to be achieved, taking account of natural processes of dispersion and degradation of the various types of organic and chemical wastes. It is sometimes argued that if culture practices and environmental conditions permit, use of an AZE should be avoided since it implicitly allows localised changes in the quality of water and/or sediments (GESAMP, 1996). However that is a very unusual situation, and it will happen for very low annual production (100 - 300 tons) at very exposed locations. An AZE, consequently, may be a necessity in coastal aquaculture. Management based on AZE approach does provide some controls on the extent of coastal degradation. For example, AZE for two or more discharges of pollutants should not overlap and, thus, the delineation of a mixing zone precludes additional development nearby. For example, if an upland aquaculture facility along an open coast is given a mixing zone extending 1 km along the shoreline in both directions, a second farm of comparable size would have to be at least 2 km distant in order to avoid overlapping mixing zones. In practice the actual separation would likely be even greater since subdividing a water body into abutting but non-overlapping mixing zones would not be prudent (GESAP, 1996). In this sense, AZE concept can be very useful for matching with some European legislation such as the Water Framework Directive. Five main environmental issues that Europeans are worried about, averaged results for the EU25 show that nearly half of the respondents are worried about "water pollution" (47%), with figures for individual countries going up as far as 71%. This demand by citizens is one of the main reasons why the Commission has made water protection one of the priorities of its work. The new European Water Policy will get polluted waters clean again, and ensure clean waters are kept clean (ec.europa.eu/environment/water/water-framework). In response to this, Water Framework Directive has been implemented with the following with key aims such as the expanding the scope of water protection to all waters, surface waters and groundwater achieving "good status" for all waters by a set deadline. It is proposed that WFD poor status can be equated with an undesirable disturbance to ecosystem health. Good health corresponds either to high status (when no disturbance can be detected against a background of natural variability) or good status (when disturbance is just detectable). WFD moderate status does not correspond to an undesirable disturbance or to poor ecosystem health; indeed, system vigour might be optimal as defined above. However, an ecosystem in this state, albeit only moderately altered from reference conditions, could be on the brink of rapid change if its resistance is about to be overwhelmed. Thus a trend from good to fair status may give cause for concern by suggesting that an ecosystem is tending towards (although has not yet reached) dystrophy, poor health and undesirable disturbance (Tett, 2004). Therefore, if aquaculture is acting in coastal waters, this activity can produce a water body with poor status, which will be against the WFD principles. Definition of AZE for aquaculture facilities regarding the WFD requirement will help to avoid uncertainties for coastal managers since coastal aquaculture may produce undesirable disturbance to ecosystem health.

## 2. Spatial allocation of allowed zone for aquaculture.

It is important to remark that, spatial planning for site selection of aquaculture facilities will be necessary for a correct displacement of AZE because space is a finite resource. The availability of suitable areas for aquaculture in the Mediterranean region is becoming a major problem for the development and expansion of the activity. At local level the emerging issues, which need to be addressed within the concept of sustainable aquaculture, are, among others, site selection and site allocation (GFCM, 2011). There is a need for AZE with appropriate environmental characteristics and good water quality. In addition to these natural limiting factors, the social aspects of interactions with other human activities or conflicts over the use and appropriation of resources in the much-exploited coastal zone are constraints to be considered when aquaculture facilities are set up (IUCN, 2009). For integrating Mediterranean marine fish farming into coastal space, a correct management of the potential interactions with other users and with environment should be considered by: 1) planning regarding the positioning of aquaculture sites, 2) application of Environmental Impact Assessment, and 3) monitoring of the installations (Figure 1). Therefore a site selection process should be carried out, for defining properly the geographical position and extent of aquaculture in a determine region. For that, ecological and socio-economical criteria should be taken into account, and then aquaculture can search for suitable space that minimizes conflict with the myriad of other uses and users of coastal waters, such as shipping, fishing, recreational activities and industry (Dempster and Sanchez-Jerez, 2008).

As aquaculture is the ‘new kid on the block’ in terms of its use of space, in many coastal areas it will struggle to obtain suitable sites that do not conflict with pre-existing users that may be more important to the economics of the region (Starasinic & Popovic 2004). In this case, integrated coastal zone management may be relevant, as is indicated by the Council decision of the European Community (2010/631/EU) concerning the conclusion of the Protocol of Integrated Coastal Zone Management in the Mediterranean to the Conservation for the Protection of the Marine Environment and the Coastal region of the Mediterranean. The Recommendation of the European Parliament and of the Council of 30 May 2002, concerning the implementation of Integrated Coastal Zone Management in Europe, and in particular Chapter V thereof, encourages the implementation by the Member States of integrated coastal zone management in the context of existing conventions with neighbouring countries, including non-Member States, in the same regional sea.The shared use of Public Domain areas and the conservation policies for the Mediterranean Sea reduce the availability of sites. At the same time, however, demand for aquaculture products is increasing, especially because industries such as that in the Mediterranean can supply a constant stream of quality products at stable prices. Further efforts are still required to ensure the sustainable development of aquaculture in the Mediterranean; to this end, site selection and site management are important processes that need to be implemented in a sustainable manner (IUCN, 2009). For example in Spain, many regional governments tried to reduce the procedures and improve their efficiency by designing coastal zone plan for aquaculture. With planning as a tool for managing aquaculture, the administration defines and sets up maritime and coastal zones designated for aquaculture activities. In the last decade, some of these regional governments started to define these “interested zones for aquaculture” described by Law 23/1985, as “those zones that because of their optimum conditions for aquaculture need official protection”. After this scenario, of multiple uses of coastal spatial resources, and with the aim of giving a space to marine aquaculture, avoiding environmental degradation and negative interaction with other traditional users, the concept of Allowed Zones for Aquaculture (AZA) can be developed, and should be defined for Mediterranean countries, included in national and regional administrative levels, serving as a tool for the integration of aquaculture into the coastal zone management (Chapela Pérez, 2009).

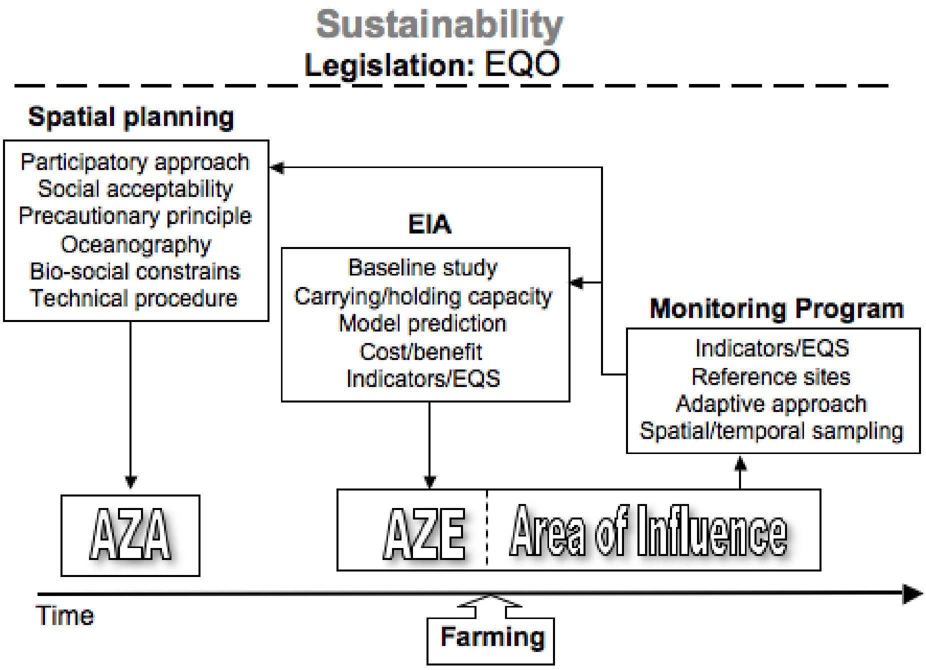


Figure 1. Administrative process for developing aquaculture on coastal zones. Under the umbrella of sustainability, national and/or regional legislation should define the Environmental Quality Objectives (EQO). A technical procedure of site selection must define the Allowed Zone for Aquaculture (AZA). For each AZA, an Environmental Impact Assessment will define the spatial magnitude of the Allowed Zone of Effect (AZE) for a determinate level of production. When farming start, monitoring programs should check that the Environmental Quality Standard (EQS) are under optimal levels.

A definition of AZA could be the next: "a marine area where the development of aquaculture has priority over other uses, therefore will be primarily dedicated to aquaculture". This area will be the result of a zoning process by means of spatial planning, in which a determine proportion of the region would be legally recognized by administrative bodies that would be considered it as a priority for local aquaculture development. A technical procedure, using geographical information systems, should be used for determining the AZAs, using objective information on environmental and oceanographic conditions and uses. As IUCN (2009) recommends, the selection of AZAs should be based on a participatory approach, promoting the social acceptability, by means of a precautionary principle and thinking on a potential adaptive management. In such instances, political decisions on the use of coastal space may be the only way aquaculture gains access to coastal waters. The GIS-based model will be useful in its identification of areas where the sustainability of AZAs may be maximised. Within this areas assigned to aquaculture, where aquaculture has priority in front of other users, AZE can be implemented reducing conflicts because the negative interaction with other users and the unacceptable degradation of priority habitats. At these two spatial levels, AZE within AZA, environmental monitoring programs should be performed, with the aim of avoiding unacceptable ecological impacts such as low oxygen concentration, eutrophication, or exceeding the EQS. One example of this kind of spatial management is the definitions of Aquaculture Management Areas (AMAs) in New Zealand. Aquaculture industry has recently experienced a period of rapid growth in this country with more than 500 greenshell mussel farms totalling 30 km2. Rapid growth of the aquaculture industry coupled with the near saturation of traditional sites and recent advances in culture technologies, has led the industry toward alternate environments; notably offshore locations. The industry's desire to explore these areas, together with recent central government requirements, has created the need for environmental managers to prescriptively zone for aquaculture through the creation of AMAs (Longdill et al., 2008). The authors present novel concepts to GIS-based assessments of aquaculture suitability in the form of layers representing marine productive regions and long-term shore-normal components of residual velocities assisted the identification of productive and sustainable offshore AMAs.Other example is from Tasmanian (Australia; Crawford, 2003). The government legislation requires that Marine Farming Development Plans (MFDPs) are prepared for each aquaculture growing area. Each plan details areas that are zoned for marine farming, and within each zone are allocated leases, which are the actual areas to be farmed (i.e. the area of sea bottom and water above which is leased from the Government for marine farming activities).One issue regarding to spatial planning and allocation of AZE inside predefine AZAs is the need of spatial accuracy for the mooring of fish farm. Companies or administrative bodies involve in developing and using GIS for spatial management of aquaculture could paid little attention to the problems caused by error, inaccuracy, and imprecision in spatial datasets and spatial localization in the field using GPS systems. With an error of tens of meter, the baseline studies and modelling for defining the holding and carrying capacity, taking onto consideration the habitat distribution, optimal depth, etc, may be useless. Therefore, accuracy (degree to which information on a map or in a digital database matches true or accepted values) and precision (level of measurement and exactness of description in a GIS database; Foote and Huebner, 2000), as well as good practice of the company undertaking the fish farm mooring are necessary during spatial allocation of fish farms.

## 3. Establishment and sizing of AZE around the immediate vicinity of the farms.

Spatial definition of AZE has been performed using different perspectives. Summarily, administrative process or dispersion modelling can be used to define the extent of the AZE (Figure 2).

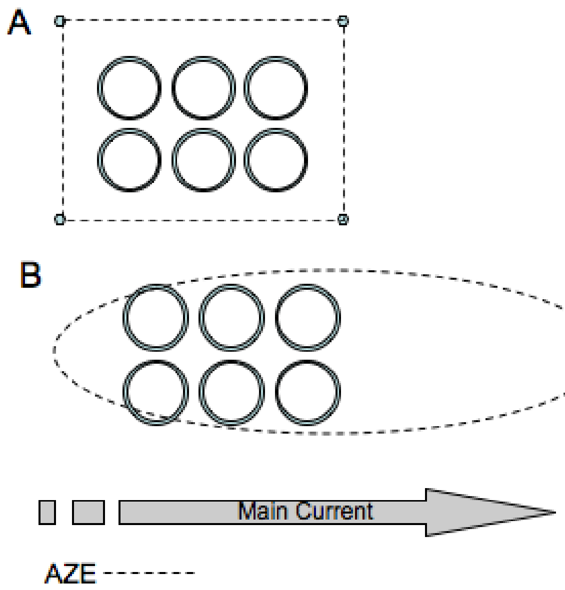


Figure 2. (A) Administrative licence or (B) dispersion modelling may be used to define the extent of the AZE.

Regarding to the administrative process, commonly, companies are required to apply for a licence to use privately a public space and discharge wastes into the sea. AZE can correspond exactly with the surface of marine space and the match volume of water body where the farmer has applied for a licence related to the regulatory framework to allow commercial aquaculture production in a determinate country or region. The existing regulatory process should be complex and multiple permits must be obtained from several different administrative bodies, before a facility can begin operation. After this process, this location can hold a fish production and generally it is delimitated by floating boys, normally with a rectangular shape, and have a temporal caducity (5 to 10 years, Chapela

Pérez et al., in press). Definition of the spatial licence will be according to the result of the Environmental Impact Assessment, which will evaluate the potential impact depending on the species to be produced, size of production and the carrying or holding capacity of the receiving body of water. Because the farmer will be the "owner" of this space for a period of time, generally of public access, and will be paid taxes for using the marine environment for developing aquaculture, AZE may well correspond exactly with this administrative area. Around this AZE, an area of influence can be defined, as an extension of the potential impact. Other option is the use of modelling for defining the extent of AZE. It is generalized the use of mathematical models to determine the extension and magnitude of the environmental impact that fish farming will have on a water body. These models will help to the process of authorisation of fish farms taken into consideration the environmental sensitivity of an area to aquaculture development with regard to nutrient input and benthic impact. One very well established process, using mathematical modelling for defining AZE, is established by Scottish Environmental Protection Agency. Licenses of the Control of Pollution Act (1974), also known as discharge consents, are given using site-specific models: i) dissolved nitrogen above background levels within a marine location (Equilibrium Concentration Enhancement), ii) benthic impact model uses a combination of equations to calculate the size and dimensions of the area covered by solid waste fall-out from the fish farm (waste food and faeces). The results are presented as a percentage of the whole surface area of the location that are either impacted or degraded by carbon deposition. Both these models are run within a database that contains the hydrographical information on all the marine regions. These details are then used to run a particle tracking ('random-walk') model which simulates the dispersion of particulate waste from the farm and its subsequent settlement onto the seabed. The results from the model are presented as the total area that is either impacted (>0.02KgC/m 2/yr) or degraded (>0.7KgC/m 2/yr) by waste fall-out from the farm. The model is re-run, using different released quantities of medicine, until the predicted concentration fields after the stipulated time do not breach the Maximum Allowable Concentration (MAC) and Allowable Zone of Effect (AZE). Modelling (AutoDEPOMOD) is used to determine maximum holding biomass, size of AZE, monitoring positions and in-feed sea lice treatment quantities. The Scotties legislation provide very well specified definition of the area of seabead within the immediate vicinity of sea cages which should exhibit some deterioration in the physio-chemical properties of the sediment and/or resident flora. The extent is determined by a deposition of 191.8 g m2 y-1 and an infaunal trophic index (ITI) of 30 (http://www.sepa.org.uk/water/water_regulation/regimes/aquaculture/marine_aquaculture/modelling/technical_guidance_notes.aspx ; Black et al., 2008).

In the same way, TROPOMOD modelling approach has been also used for defined how severe is the impact of fish farming of tilapia and milkfish in Philippines (EU FP6 PHILMINAQ), what is the maximum impact underneath cages and how far to the boundary of the impact. With the modelling result, it is defined the Allowable Zone of Effect and define how can husbandry practices be optimised to use the zone most productively. MERAMOD modelling has been applied to Eastern Mediterranean conditions for seabass and seabream production (MERAMED project, EU FP5). A resume of the application of these modelling methods can be found in the toolbox of the European project ECASA (www.ecasatoolbox.org.uk).

Additional to spatial magnitude, estimation of carrying/holding capacity of AZE should very relevant, despite of technical difficulty. An example of modelling carrying/holding capacity is given by Stigebrandt et al. (2004). This model try to define, in terms of maximum fish production per month, the holding capacity, regarding to three basic environmental requirements: (i) the benthic fauna at a farm site must not be allowed to disappear due to accumulation of organic material; (ii) the water quality in the net pens must be kept high; (iii) the water quality in the areas surrounding the farm must not deteriorate. The model comprises four sub-models which, for a given set of local environmental parameters, compute holding capacity according to these basic requirements. Given the feeding rate, feed composition and water temperature, a general fish sub-model adapted for domesticated Atlantic salmon computes the metabolism, growth and feed requirement of a specified fish stock. The fish model also computes emissions of particulate organic matter, i.e., uneaten feed and faeces. A dispersion sub-model computes the distribution of particulate matter from the net pens on the bottom for various sizes of pens and distances between them. A benthic sub-model computes the maximum rate of particulate matter sedimentation that will not result in the extinction of the benthic macro infauna. Water quality in the net pens is expressed as the lowest concentration of oxygen and the highest concentration of dissolved substances potentially harmful to the fish. These are computed by the water quality sub-model that needs input from the fish sub-model concerning the emission of dissolved substances and the consumption of oxygen due to respiration. Generally the spatial scale of AZE delimitation from the cages system is of ten's of meters. For example, with respect to sea floor impacts, SEPA is currently adhering to an early recommendation that calls for a 25 meter AZE in all directions beyond the net-pen structures (Tlusty et al., 2001). SEPA, however, recognizes the inadequacies of this definition in view of the potentially disproportionate level of impact in any given direction due to the dynamic nature of the receiving waters and is considering alternative approaches. One alternative approach that has been proposed would allow extension of the AZE in one direction, with a compensating reduction in the AZE in another direction, e.g. an elliptical AZE of 75 meters in one direction and 0-5 meters in all others instead of 25 meters in all directions. Definition of an appropriate site-specific boundary, however, requires sufficient information to predict the rate of deposition in various directions. A predictive deposition model, DEPOMOD, has been developed to assist in this effort. The model outputs a predicted plume, or footprint, the outer boundary of which defines the AZE (Cromey et al., 2002). In EEUU net-cage culture, for example, regulatory authorities may designate a mixing zone for solid wastes as the area directly beneath the farm or as the total area of the lease, typically many times the size of the actual net-cages. A mixing zone for dissolved wastes may be established at some arbitrary distance from the farm as in Washington State (USA) where, for some farms, compliance with water quality standards is determined by sampling 30 m from the net-cages. Mixing zones for dissolved wastes from aquaculture may attain a size of over 1 km2 (AECOS, 1991). The Salmon Aquaculture Dialogue (2010) define AZE under the use of determine standard as 30 meters. In Tasmania, general management controls are listed in Marine Farming Developed Plans and for finfish farming zones stipulate ''there must be no unacceptable environmental impact 35 m outside the boundary of the marine farming lease area. Relevant environmental parameters must be monitored in the lease area, 35 m from the boundary of the marine farm lease area and at any control site(s) in accordance with the requirements specified in the relevant marine farming licence.'' The 35-m point from the boundary was based on studies from Europe where farm wastes were generally found to be concentrated within 35 m of the edge of the cage (Crawford, 2003). Practical applications of AZE concept in Mediterranean countries are scarce. In Croatia, a Local Impact Zone is defined, as equivalent to AZE, defined as the area under and near a fish farm where most of the larger particles are deposited, and normally does not extent beyond 15 m form the fish farm. In Mediterranean practice regulators have tended to specify a maximum AZE, typically a radius of 25 or 50 m from the cages or the licensed surface area (Katavić et al., 2005; Table 2). Andalucia (Spain) has a regional spatial planning for aquaculture where are defined the "suitable areas for aquaculture" where do not exist administrative limitation for marine aquaculture (Macia et al., 2005).

| Country | Distance from farm |
|---|---|
| Tasmania (Australia) | 35 m |
| Washington State (USA) | 30 m |
| Scotland (UK) | 25 m |
| Croatia | 15 m |
| Average | 26.25 m |

Table 2. Examples of spatial impact of fish farming from AZE to the area of influence.

One aspect to be take into account for monitoring AZE is the management of continues discharges, such as organic matter due to feaces and rest of food sedimentation, and sporadic spills (e.g chemical use for external parasites). Again, SEPA has been pioneer and the Scottish regulation distinguishes between continuous and intermittent discharges and SEPA has established a separate AZE for each. The AZE for continuous net-pen discharges is 100 meters from the net-pen structure, similar to the AZE for all other marine discharges. SEPA acknowledges that, given the nature of these discharges, the AZE for intermittent discharges, such as those associated with sea lice treatment, cannot be realistically defined by a standard measured distance. Site-specific 3-hour and 72-hour dispersion modelling is being employed to predict dispersion to determine an appropriate AZE based on environmental quality standards. The regulations state that, after 72 hours "...residual concentrations of the substance should comply with the corresponding 3-day EQS and the area of the AZE should not exceed 0.5 km2 or 2% of the system (whichever is the least).

## 4. Monitoring of the environment surrounding the aquaculture facilities.

### 5. 4.1 Needs of monitoring programs

After the selection of a specific area for developing aquaculture on coastal areas, specific monitoring for aquaculture within this AZE should be carried out in order to ensure that this zone will not be degraded to a point beyond which the services provided by the ecosystem will be severely or irreversibly compromised (FAO, 2008). Effective environmental management of aquaculture requires constant research into a better understanding of associated environmental process and change, which will depend on monitoring programs. The data provide by monitoring may be essential for identification of impacts and decision making. Holmer et al. (2008) summarize the environmental impact of fish farming on marine ecosystem and the most commonly used indicator for monitoring programs in Europe. Spatial and temporal monitoring is a common tool in Mediterranean Aquaculture, generally a compulsory process for many Mediterranean countries (Chapela et al., in press), understanding for monitoring as "the regular collection, generally under regulatory mandate, of biological chemical or physical data from pre-determined locations such that ecological changes attributable to aquaculture can be quantified and evaluated" (GESAMP, 1996). But guidelines and specifications of the monitoring program is very diverse depending on the national o regional legislation, with several administrative bodies involves within. Early reports, as the produced by GESAMP (1996), give recommendation for the implementation of monitoring programs for aquaculture. This report indicate that soluble inorganic and particulate waste from coastal aquaculture farms can result in organic enrichment of the local aquatic environment and to prevent unacceptable changes to the environment, an environmental management framework should be established as a means of regulating development and evaluating potential impacts before permission to develop is granted. Many Mediterranean countries have included into their legislation that, before to start the activity, an Environmental Impact Assessment should be undertaken to predict significant potential impacts, and this EIA has included a monitoring program to be carried out (once production has begun) to detect and evaluate the scale of impact (Chapela et al, in press). Monitoring is therefore part of the regulatory process that ensures that ecological change associated with aquaculture waste is kept within pre-determined, acceptable levels. Monitoring programmes may provide the information base for decisions to allow for further expansion of the AZE or development should measured levels prove that observed ecological change is below unacceptable limits within the AZE or its surroundings. Monitoring program should be adapted to the particular features and issues of each location, and therefore may be site and species-specific. Anticipated and actual impacts will have to be assessed on a case-by-case basis but can follow general recommendations. Aquaculture practices in marine waters can generate environmental impacts as a function of 1) the applied technique, 2) site location, 3) size of production, and 4) capacity of the receiving body of water (Treece, 2011). The magnitude and features of environmental change in an AZE will differ firstly according to the type or class of aquaculture activity (fish farms vs long lines); it will differ according to the rearing and management practices that might produce a perceived pollutant and the release event. For example, the monitoring for permanent process, such as the accumulation of organic waste on the substrate or release of nutrients into the water column, will be different from intermittent events such as the use of antibiotics or the release of water containing a therapeutant after an immersion treatment for external parasites. Furthermore, assessments of environmental impact related to the AZE need to be made at several stages in the process of planning, permitting and executing aquaculture development. In any case, it should be implemented a monitoring program, using appropriated indicators, to assess impacts within and outside the AZE.Standardization of monitoring programs for Mediterranean aquaculture can be quite complex, and maybe not recommended, because the high variability of environmental conditions and different intensity of production, from family to multinational owners of farm facilities. However, many other studies have tried to define optimal environmental monitoring programs for Mediterranean aquaculture. The European project MERAMED (Modelling Environmental Response to Aquaculture in the MEDiterranean; meramed.akvaplan.com) has attempted to develop and establish a model based control system for the environmental monitoring of fish cage farms in the eastern Mediterranean, creating an appropriate set of protocols, monitoring systems and techniques for the control of such farms in Mediterranean conditions.Monitoring programs should be adaptive, and related to EQS goals and farm size. A clear example of adaptive programs is showed in Katavić et al. (2005) for Croatian aquaculture. The type of monitoring will change depending of acceptability for EQS. For a small farm (<100 ton/year) a simple descriptive monitoring program (Type A) will be carried out annually, but if unacceptable conditions are found outside AZE, the monitoring program is extended to Type B (semi-quantitative survey/rapid assessment techniques).

### 4.2. Spatial and temporal extend of monitoring plan.

Extension of the AZE and spatial magnitude of the monitoring program is other aspect to be taken into consideration. European project ECASA define three levels of scales in the type of environmental management:

Zone A - farm scale - this is where obvious impacts from aquaculture occurs; in some jurisdictions farmers are required to manage and monitor impacts themselves, in their own interests and to present themselves well to environmentally aware members of the public; public environment management can in these cases confine itself to a licensing and auditing role. AZE will be at the same spatial scale that this zone or at lest within it.

Zone B - water body scale - pressures may result from several sources and impacts may not be obvious until ecosystem resistance has been overwhelmed; public environmental management needs to play a more active role in estimating assimilative and carrying capacities and policing their use by the multiplier users; there may be possibilities for synergy, with shell-fish or seaweed aquaculture benefiting from nutrients input by finfish farms;

Zone C - regional scale - issues are those of planning for multiple types of use, of monitoring conditions for their own sake and to provide reference values for zone B water bodies, and making regulations for the management of the smaller scales.

Fernandes et al (2001) define that the fundamental aims of monitoring programs should be related to the scale of influence of farming, checking what are the environmental impacts in the near-field, and how large an area is affected. These three spatial scales should be considered, namely, for monitoring programs: (i) to monitor the situation in the immediate vicinity of, or directly below, and control that the operation comply with the criteria set for the near zone of impact, AZE; (ii) to monitor that EQSs sampled outside the AZE comply with the EQSs set for the medium field and, if not, how large is the deviation and; (iii) to evaluate how much, if any, the EQS in the middle/far field differ from the ones sampled at the reference sites. For this last large scale, it is important to take into account the multiple users that can be affecting to benthic and pelagic systems in the Mediterranean Sea, producing cumulative impacts. Mediterranean sea is a closed sea, bordered by heavily populated and industrialised coastlines that are visited by millions of tourists, crossed by intense maritime traffic and fed by urbanised river basins that are industrialised and farmed intensively (Ebro, Rhone, Po, Arno, Tiber, Nile), and coastal areas are subject to cumulative impacts from a variety of pollutants—from near and far, and from point, nonpoint, and airborne. Normally, fish farm would be allocated in areas near of harbours, with conurbations that can produce sewages of not well-treated domestic and industrial water or where maritime shipping occurs (Dempster and Sanchez-Jerez 2008). Stormwater runoff can be also affecting to water quality at scale of kms and local fisherman can operated bottom trawling, legally or illegally, in the middle/far field or even around fish farms, which will affect to benthic communities (Sanchez-Jerez and Ramos-Esplá 1996). These cumulative impacts are also important for the geographical selection of reference sites that should be chosen to give information on normal condition at the area of fish farming, and may affect the interpretation of fish farming effects. For that, association of EQS deviation with fish farming activities at this large scale should be considered very carefully for decision-making and ICZM will be relevant for a proper environmental management of multi-user marine space.

### 4.3. Statistical bases for the design of monitoring programs

Monitoring describes the processes and activities that need to take place to characterise and monitor the quality of the environment. Environmental monitoring of fish farming is used in the preparation of environmental impact assessments, as well as in many circumstances to avoid the risk of harmful effects on the marine environment. Literature on aquaculture monitoring programs shows a variety of approaches, but all monitoring strategies have the objective to establish the current status of an environment or to establish trends in environmental parameters related to farming activity. In all cases the results of monitoring must be analysed statistically. Monitoring program should be adaptive to the size of production and the sensitivity of the surrounding environment. For many types of sampling designs it is critical to take random samples because it makes the data more likely to be independent. Random samples, for monitoring programs, may need to be taken stratified in different areas. Normally this areas can be defines has the AZE (local impact zone), Intermediate Impact zone (transitional zone where the impact can be also detected) and no affected areas far away from fish farms (control location). This kind of stratified sampling is useful because the reduction if the error variance to estimate fish farming effects more clearly. Samples unit must be allocated randomly within different zones and it is recommended that the sampling designs was balance, with used equal number of replicates for each zone. Another important aspect is to considered use a nested or hierarchical design, with the aim to dealing with spatial and temporal variation on several scales. Sedimentation of organic matter within the AZE could show a very patchly distribution regarding to the spatial distribution of cages and hydrodynamic, affecting to chemical features of sediment. It is also very well know that there is a great natural variation in abundance of benthic fauna link to soft sediments (Fernandez-Gonzalez and Sanchez-Jerez, 2011). Therefore, within each sampling zone, it is necessary to considered random sites where samples will be token randomly. Nested, or hierarchical designs are very common in environmental effects monitoring studies, in a common sense, there are several “impacted” and several “control” zones. The nested design allows us to test two things: (i) difference between “impact” and “control” zones, and (ii) the variability of the sites within areas. If it is not possible to find a significant variability between “impacted” and “control” zones, and a significant difference among sites is found, it would suggest that there is a very high spatial heterogeneity that prevents to detect the environmental impact. In other words, the variability is due to differences among sites and not to differences because the effect of fish farming. Even if it should be significant, however, we can still test to see whether the difference between the zones is significantly larger than the variability among the sites with zones. This will mean that the impact of fish farming is so high that, in spite of the high spatial variability, it is possible to detect the environmental effects of fish farming. An example of analysis of spatial variability at different spatial scales for organic matter enrichment can be found in Chapman et al (1995). The success of the monitoring program will be related to have an optimal spatial and temporal replication, the existence of baseline survey and the use of correct control locations. Baseline data, collected to define the present state of a zone before to start the farming activities, will be appropriated to use as reference data against which changes cause by farm waste can be contrasted. In a simple way, measurements on a zone prior to treatment could serve as controls for measurements on this zone following aquaculture production. However it is important that sufficient information is collected to be able to estimate the magnitude of natural fluctuation of physic-chemical and biological variables across time and space (Kingsford, 1998). Therefore baseline studies should have a similar design of future monitoring programs, considering a nested design, sampling at “impacted” zones (AZE and zone of influence) and control zones. One of the best situations is when it is possible to use a BACI design (Before-After-Control-Impact). The design involves sampling the zone that is planned to be affected by fish farming and a control zone. Control can be defined in the most conventional sense as any treatment against which one or more other treatments is to be compared. At least in monitoring of marine ecosystems, controls are required primarily because biological systems exhibit temporal changes. If we could be absolutely certain that a given system would be constant in its properties, over time, in the absence of an experimentally imposed treatment, then a separate control treatment would be unnecessary (Hurlbert, 1984). Each zone is sampled several times, at random, prior to and then after the start of the potential disturbance. The two zones are sampled at the same times (i.e. times of sampling are orthogonal to the two sites), and there are the same numbers of samples taken before and after the planned development. The times of sampling are nested in either the period before or the period after the potential impact starts (Underwood, 1991, 1992). This design can be extended, increasing the number of control zones to be sampled before and after, (currently called M BACI, where M denotes the inclusion of multiple control); in this situation the power of the evaluation of the impact of fish farming will increase (Keough and Mapstone, 1995). Other authors have also recommend the use of at least two reference sites for monitoring fish farming (Fernandez et al. 2001). The design is an asymmetrical one, using replicated control sites but a single impact site (fish farm), similar to that described by Underwood (1993, 1994). This asymmetrical design has been already applied to fish farming but are relative scarce compared with the evaluation of the environmental impact of other environmental problems (Tuya et al., 2006).

### 4.4. Applied Monitoring designs.

The most important environmental impacts should be produced around the cages, which will be corresponded with the Zone A, within the administrative concession, and where AZE should be also located. All this three concepts, Zone of local impact, administrative concession and AZE can be spatial superimposed, or differ at some level, depending on the management decision explaining in the text above. It will assume that this impacts in this zone, such as the discharge of nutrients and particulate matter, result of the physiological processes of farmed fish, which are inevitable, and therefore must be monitored. Following this premise, different countries has applied diverse designs of monitoring programs, which can be resume on two options: i) use of perpendicular transects (Figure 3) and ii) random stratified sampling (Figure 4). One example of use of perpendicular transect is the recommendation for monitoring Irish fish farms. The report “Irish Focus Area Reports (FARs) on Aquaculture, Introductions and Transfers, and Transgenics (based on CNL(09)15 and incorporating the elements from the Guidance on Best Management Practices, SLG(09)5)” indicates that through each array of cages, two transects (perpendicular to each other) shall be run with each incorporating sites, directly beneath the cages, at the edge of the cages, and 10m, 20m, 50 m and 100m in the direction of the prevailing current or seaward direction from the cages and at 10m, 20m, 50m in the opposite direction (Figure 3). In the case of single cages set apart from each other (as experienced in more exposed locations) a pair of transects shall be run through one of the cages (involved in the production cycle). This will be taken to be representative of the others. In addition, a control station must be situated at least 500 m away from the cage sites and show similar benthic and hydrographical characteristics as the farm location.

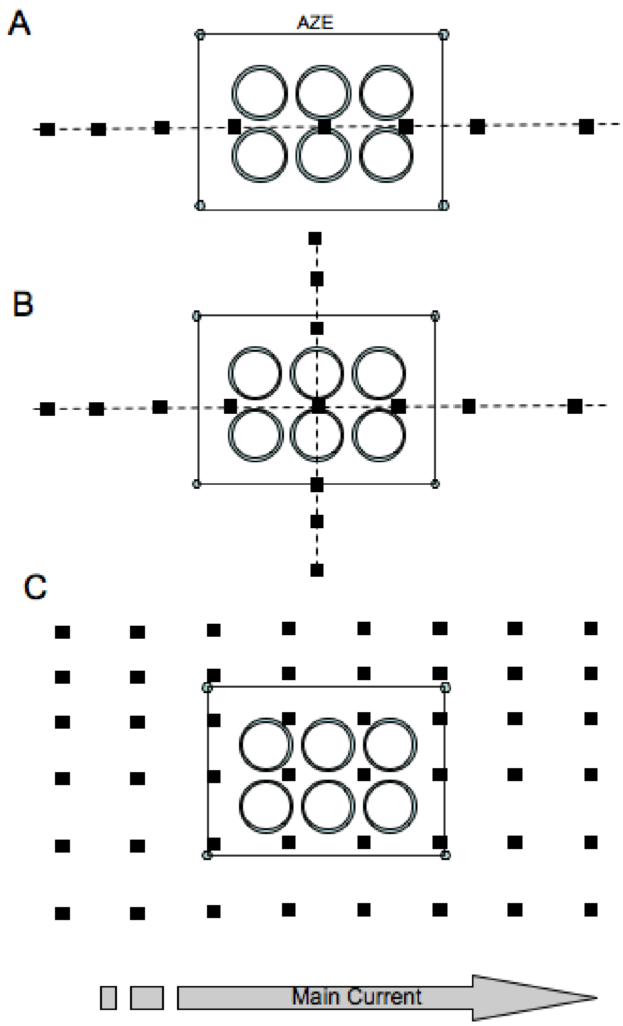


Figure 3. Examples of monitoring programs based on transects across the AZE. A) Simple design using a single transect following the direction of the main current. B) Two transects crossed at the centre of AZE. C) Several perpendiculars transects to AZE, with the aim of applying spatial statistics as Kriging. At each sampling site, one or several samples can be taken.

For random stratified sampling, there are fewer examples but some reports suggest that this approach could be more convenient form the point of view of statistical robustness and cost/benefit. The Spanish project “Selection of Indicators for monitoring marine fish farming” (JACUMAR, Ministerio de Medio Ambiente, Rural y Marino) recommends the use of a hierarchical stratified sampling. Three zones are defined: Zone of impact (AZE), Zone of Influence and Zone of reference. The zone of influence will be selection down in the direction of the prevailing current direction and the control will be located far away from fish farming or other activities. Within each zone, three random sites may be selected. Three samples for monitoring biological, physical and chemical variables will be randomly take within each site (Figure 4).

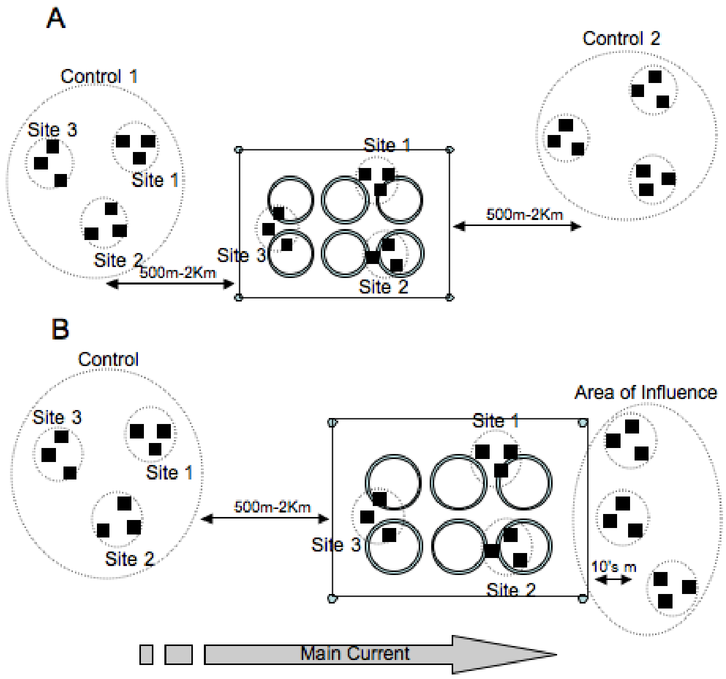


Figure 4. Random stratified sampling considering (A) an Impact zone (AZE) with two control zones far way enough from the aquaculture facilities and (B) three zones: Impact zone (AZE), area of influence and one or several controls. Inside of each zone, several random sites are randomly selected, with three samples of, e.g., Van Veen grabs. On important aspect to be considered is the potential effect around the AZE. Monitoring of AZE is necessary to avoid exceeding environmental quality standards but impact in this area is assumed. However it can be very relevant to check the effect in the immediate vicinity of AZE because it will be a marine space of public domain, where other users such as fishermen or leisure activities can be carried out (Figure 4B). For salmon aquaculture, some indicator with EQS has been defined. For example, the Salmon Aquaculture Dialogue (2010) established quantitative EQS to be measured outside the AZE (Table 3).

| Indicator | EQS |
|---|---|
| Redox potential or sulphide levels in sediment | Redox potential > 0 millivolts (mV) |
| | Sulphide ≤ 1,500 microMoles / l |
| AZTI Marine Biotic Index (AMBI) | AMBI score ≤ 3.3 |

Table 3. Example of indicator and EQS recommended by the Salmon Aquaculture Dialogue to be applied outside the AZE.

Temporal frequency of monitoring sampling programs is also another important aspect to be taken into account for a correct evaluation of potential impacts. In many countries is compulsory to present an annual report, based on the measured of several variable, which can be obtain at different spatial scale. In South Australia, each year, aquaculture licence holders are required to submit an Environmental Monitoring Program (EMP) Report to PIRSA Aquaculture (Primary Industries and Resources), with requirements prescribed within the Aquaculture Regulations 2005. In British Columbia (Canada) the monitoring program should obtain data regarding of production (aquafeed, mortality, biomass) each four months. For farms with more than 680 ton/year, variables in the water column, as oxygen and nutrients, are sampling monthly and benthic variables annually. In Europe, Ireland has been on of the most exigent countries about temporal replication of monitoring water quality, with monthly sampling of water quality (nutrients) and annual sampling of benthos. In other countries, such as Spain, the development of a monitoring program is defined in the EIA for each fish farm, but there is not a common recommendation for spatial and temporal monitoring, depending on the specific recommendation of the EIA and the regional legislations, producing a very diverse collection of monitoring programs. Summarily, frequency of sampling can be adapted to the size of the production, the type of the EQS, and the spatial scale consider. For a complete revision of environmental impact assessment and monitoring in aquaculture around the world see the report of FAO (2009).

## 6. Possibilities of recovery of AZE after aquaculture cessation.

IUCN (2004) indicate in the report “Mediterranean marine aquaculture and environment” that it is necessary support comparative research on recovery of benthos and sites in the Mediterranean. In the same way, CONSENSUS project (www.euraquaculture.info) indicate the necessity of farming cessation for recovery of benthic communities if bottom degradation is quite patent. Very seldom studies on sites recoveries have been realized in the world but in the Mediterranean proper experiments are rare because of lack of example and sites to allow this type of studies. Initiatives are expected in this domain to present better figure of real impact. Avoiding permanent degradation of marine ecosystem is the only way to convince that Mediterranean aquaculture is sustainable and it is not producing a future deprivation of ecosystem services.

### 5.1. Keeping the ecosystem services.

Humans benefit from a multitude of resources and processes that are supplied by marine ecosystems (United Nations 2004 Millennium Ecosystem Assessment). Marine ecosystem services could provide food from local fisheries, support biodiversity and be used for leisure proposals. Consequently, anoxic conditions with severe impact on benthic community, eutrophication of pelagic system or serious affection to wild life attracted to fish cages because abuse of therapeutics should be avoiding. The project InDAM of GFCM (2011) highlights the principle of “respect the ecological service of ecosystem” for developing a sustainable aquaculture in the Mediterranean. Ecological service can be estimated as the changes on water quality, affection to fisheries and nursery areas, and modification of the trophic conditions, and will be strongly correlated with carrying/holding capacity of the ecosystem and the oceanographic conditions. As example, some of the indicator that can be used for estimating the level of maintaining the ecological service are the measure of turbidity, oxygen saturation, use of microbiological indicator, detection of algae bloom, rate of water interchange with open ocean, percentage of used space or volume of water occupation per kg of product. One worry in the determination of what level of impact is acceptable at a determine AZE is the possibilities of recovery. Assessment of the rate of ecosystem recovery following the removal of marine fish farm cages or the cessation of farming must be considering in monitoring programs. Estimation of potential removal and burial of wastes by seabed currents, bio-geochemical processes, and consumption of waste nutrients by epibenthic grazers should be achieved. The use of AZE concept accepts that aquaculture will have an impact restricted to a defined area, but this area should not be degraded to a point beyond which the services provided by the ecosystem will be severely or irreversibly compromised, and impact can be reversed by a year or two.

### 5.2 Recovery of benthic communities and sensitive habitats,

Recovery of marine communities in relation to aquaculture effects is poorly studied. Angel et al. (1998) describe several extreme bioturbation events that occurred during the recovery of a farm site, involving invasions by organisms not normally found on the site and suggest that the recovery process might be bi-phasic, i.e., since there are many different processes going on, some geochemical, some bacteriological, and some involving higher levels in the ecosystem (Tlusty et al., 2001). Impact on the seabed is the most persistent pollution effect from fish farms and measures of this effect are the main method of regulating and controlling the size of fish farms such that the environment in AZE is not totally degraded. Several studies have analysed the rate at which sedimentary ecosystems recover following the removal of cages or the cessation of farming, aspect hat it is of considerable interest regarding the philosophy of AZE. Mazolla et all (2000) showed that environmental conditions after cage removal changed very rapidly, which further strengthens the importance of the organic loads coming from the cage. Farm sediments showed an immediate increase in the oxidized layer from 0 to about 2 cm, thus becoming indistinguishable from the control after a few weeks. Another example is give by Karakassis et al. (1999), with a recovery experiment carried out at a silty sediment site. After the removal of fish cages at an intensive aquaculture site, the sedimentary environment was seasonally monitored over 23 months for geochemical variables and macrofauna. At the stations near the farming site, the sediment was initially found to be anoxic and overlain by a highly organic black layer. Although initially (during the first 6-10 months) there was a rapid improvement in benthic conditions, subsequently the system showed large fluctuations in the values of most variables over the 23 months, indicating that the environment had not fully recovered until the end of the observations. This regression was attributed to a secondary disturbance due to a benthic algal bloom, caused by the seasonal release of nutrients from the farm sediment. It is concluded that the recovery process of heavily enriched benthos in a dynamic coastal environment is subject to the influence of different factors resulting in progress and regression. In shallower coastal areas particulate organic wastes from cage farms have a profound effect on the benthic environment and recovery, on cessation of farming, may work at temporal scale of ten of years, especially if it is considered sensitive habitats such as seagrass meadows. If spatial planning has not been considered properly before development of aquaculture, and coexist fish farming and *Posidonia oceanica* seagrass beds in a determine region, cessation of the activity or reallocation of AZE can be necessary for potential recovery of *P. oceanica* meadows. However the recovery of these meadows will be characterized by importance of the vegetative growth and successful sexual reproduction is infrequent (Gonzalez-Correa et al, 2005). Compared to all other seagrass species, *P. oceanica* has the lowest growth rate (Marba and Duarte, 1998). Delgado *et al*. (1999) studied the recovery process of a *Posidonia* meadow after the cessation of a fish farm in the Western Mediterranean. Although the water quality had recovered early, the *Posidonia oceanica* meadow was still declining three years after the cessation of the fish farming. The authors attributed this decline to mineralization of settled organic material and increased nutrient fluxes. Those nutrients in turn favoured the growth of epiphytes and phytoplankton which both reduced light availability for *Posidonia* photosynthesis.Other important Mediterranean habitat, because of its high biodiversity and fragility, is the maerl communities. Maerl habitats consist of coralline red algae that is not tied up to the bottom and can need hundreds of year to create biogenic carbonate-rich gravel, and usually occurs in areas with clear water and strong current, at depth from 30 up to 60 m depth. As aquaculture is far from the coast to avoid negative interactions with other users and protected habitats as seagrass meadows, offshore fish farming can be located near of maerl habitats. It has been demonstrated that, despite of the action of strong currents, salmon farms could lead to a build-up of organic water in the vicinity of cages and significant alter benthic assemblages (Barbera et al., 2003). Hall-Spencer et al., (2006) indicate that should be recommended a moratorium, based on the precautionary principle, on fish farm licences above unexploited maerl beds, as maerl was thought to be easily damaged by fine particulate matter. Maerl habitats are highly susceptible to the effects of fish farm deposition, with significant effects recorded to at least 100 m from farmed sites. The fallowing system whereby cage positions are rotated to allow the deposit-feeders of muddy fjord habitats time to process organic waste, recovering to the original condition (Fernandes et al. 2001) is not suited to maerl habitats because of the likely longevity of the damage caused.

### 5.2. Recovery of pelagic communities.

Coastal zones around the world are subjected to increasingly nutrient inputs as related to human activities including direct discharges and via rivers, ground water and atmospheric deposition. These inputs not only originate from land but also increase in aquaculture activities can result in increased nutrient loading in certain areas (Masó and Garcés, 2006). One of the problems associated with intensive cage farming in coastal and, especially, in close sea locations is the discharge of phosphorus and nitrogen. The release of large fluxes of nutrients from fish farms may alter the ratios of essential nutrients, which could lead to eutrophication and algal blooms at the local scale. The environmental effects of aquaculture are strongly linked to the hydrodynamic regime; in areas with low flushing rates there is a greater chance of algal blooms and associated oxygen stress (Dalsgaard and Krause-Jensen, 2006). For these reasons AZE should be generally located in areas with high current velocities (and flushing rates), and when inputs of dissolved nutrients from farming activities bring to an end. Anyway, the pelagic system will show a very quick recovery to primary conditions because in the euphotic zone, inorganic nutrients released from the cages (ammonia, phosphorous) are immediately taken up by phytoplankton, macrophytes and bacteria. In addition to this rapid assimilation, the nutrients are dispersed downstream of the cages by currents. Therefore nutrient uptake, and its subsequent transition within the planktonic food web, and dispersal are the fundamental processes determining the assimilative capacity of the relevant water body (Olsen et al., 2006) and will define the possibilities of recovery after activity cessation.However, algal bloom events of toxic phytoplankton, harmful algal bloom events (HABs; Masó and Garcés, 2006), has been related with over-enrichment due to aquaculture (Spatharis et al, 2007), and HAB may persist after aquaculture cessation because the production of germinating resting cyst. For example, the dynoflagelates *Alexandrium* and *Gonyaulax* are responsible of HABs in the Mediterranean, and can produce resting cysts. A persistent outbreaks of *Alexandrium taylori* episodes in NW Mediterranean, along the Catalan coast, have been described as originated from widely distributed germinating resting cysts, with emergence controlled by an endogenous clock that restricts germination to a seasonal window irrespective of the external environment (Garcés et al., 1999). Therefore these blooms will be originate from isolated and autochthonous cyst seedbeds, with no input of cells from coastal waters, and can persist along time, with recurrent HABs.

### 5.3. Changes on fish assemblage after cessation.

In addition to other environmental impacts, fish cages affect the presence, abundance, diet and residence times of wild fish on surrounding areas. Fish farms attract a huge variety of wild fish by providing structure, refuge from predators and food resources. Additionally, farm-aggregated wild fish consume large quantities of pellets lost from cages (Sanchez-Jerez et al., 2011a). Cessations of farming activities can affect to the fish assemblage around fish farms, because bring to an end the income of particulate organic matter and the reduction of spatial complexity. There are scarce studies on this subject. Tuya et al. (2006) studied the changes in the composition and abundance of wild fish assemblages associated with a sea-cage fish farm ‘before’ and ‘after’ the cessation of farming, by establishing the temporal and spatial persistence of the differences between the ‘impacted’ location (the fish farm) and the two nearby sandy locations as controls, following the appropriate criteria of a beyond-BACI design (Underwood, 1991, 1992, 1993). The cessation of farming produced qualitative and quantitative changes in the composition and structure wild fish assemblages beneath the sea-cage fish farm compared with nearby control locations under the influence of natural variability. Abundances of particulate organic matter as mugilids, chondrichthyes, *Pagellus* spp. and the escapes of *Sparus aurata* declined significantly, whereas other fishes were not significantly affected by the cessation of farming. In terms of overall abundance of wild fishes, the aggregative effect due to the existence of the farm decreased from c. 50 times compared to nearby controls when the farm was in full operation to less than two times when only the farm structures remained.

In addition, the persistence of escapes is one aspect to be considered. Escapes of sea bream and sea bass form sea cages in the Mediterranean have been sporadically recorded, due to storms, resulting in mass escapes or because holes or manual harvesting techniques, producing minor losses (Dempster et al., 2007). Escapes of other species, such as meagre (*Argyrosomus regius*) has been also recorded (Sanchez-Jerez et al., 2011b). These escapes can produce a permanent population in the wild, even after cessation of farming activities, with potential deleterious effects on wild fish assemblages or local fisheries. Mitigation actions may be necessary for eliminating the escapes around farms and at regional scale (Chittenden et al., 2011).

### 5.3 Biodegradation of antibacterial agents in sediments.

Antibiotics are dispensed to fish through medicated food pellets. Antibiotics enter the marine environment when some of the feed is not eaten and sinks to the seabed or is eliminated in fish excretion. One of the effects of the spread of antibiotics to the marine environment to be highlighted is the antibiotic resistance an accumulation on sediments. The biodegradation of antibiotics in the sediments goes relatively slowly (a half-life of up to 150 days in the topmost sediment layer, 0-1 cm), but varies substantially among the various agents and among types of sediment (Hektoen et al., 1995). Antibiotic sensitivity tests have showed a high percentage of resistant strains in both control and impacted sediments, which indicates a widespread antibiotic resistance within bacterial populations in areas surrounding fish farms (Chelossi et al. 2003). A high frequency of antibiotic resistance was observed for ampicillin in sediment under the cages, displaying the Gram-negative bacteria the highest resistance to ampicillin, and streptomycin. Therefore the incidence of multiple resistance patterns in bacterial isolates can be an important aspect to manage impacted sediments on AZE.

### 5.4. Heavy metal accumulation.

The high amount of particulate matter sediment from fish farming facilities, uneaten food and faeces have a very low concentration of heavy metals, but the total amount along the activity period of several years may become an important problem for AZE recovery. Mendiguchía et al. (2006) demonstrated the accumulation of selected heavy metals (Zn, Cu and Pb) in marine sediments as a consequence of intensive marine aquaculture, with an average enrichments were: 140%, 362%, and 97%, respectively. The authors suggested that trace metals' enrichment in the sediments may be attributed to the fish farm effluents, although metal concentrations are not likely to cause harmful effects in the marine ecosystem.

## 6. Final recommendations for management of AZE.

Management of AZE and the regional area of influence should address environmental goals following a precautionary management, and trying to conserve and maintain the biological diversity and ecosystem health as much as possible. Decisions about the mitigation and modification of production level or reallocation of fish farm should be based on statistical decision criteria after the detection of unacceptable changes on environmental indicators. In all cases, the precautionary approach should be adopted, and management action should be considered for any significant trend away from an EQS on the area of influence, or once the EQS has been dramatically affected on the AZE. Estimation of carrying/holding capacity of AZE would be important, in spite of the technical problems for a correct definition of these environmental descriptors. The management objective should be to ensure no accumulation of chemicals, as therapeutans or anti-fouling substances, because the potential bioaccumulation and the persistence on sediment after farming cessation. If data for a reference/control site have only been collected for a limited period or baseline data are scarce, it should be used a more number of indicators, and broad spatial sampling effort along the disturbance gradient.

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