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Environmental Quality Standards for Mediterranean marine finfish farming based on the response of experts to a Delphi questionnaire *(draft version 1)*

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Introduction

Regulators, farmers and environmental organizations and international bodies have often asked for a calculation of the carrying capacity of a site or area in terms of aquaculture production. The concept of carrying capacity is fundamental for Ecology and it means "the maximum population size of the species that the environment can sustain indefinitely" i.e. it is the K parameter in the logistic equation of population growth (Cohen 1995). In the case of some types of farming or ranching on land or in the sea (e.g. mussel farming) the issue of carrying capacity is applicable since the farmed organisms highly depend on natural food resources (grass or phytoplankton). But even in this case there are more issues that need to be taken into consideration. McKindsey at al (2006) have identified four types of carrying capacity that are relevant to mussel farming i.e. (i) *physical carrying capacity*: the total area of marine farms that can be accommodated in the available physical space, (ii) *production carrying capacity*: the stocking density of bivalves at which harvests are maximized, (iii) *ecological carrying capacity*: the stocking or farm density which causes unacceptable ecological impacts, and (iv) *social carrying capacity*: the level of farm development that causes unacceptable social impacts. Some of the above (i-iii) are determined by the availability of plankton food to the farmed mussels and therefore the system itself imposes an upper limit to the production.
In the case of finfish farming, however, the calculation carrying capacity is not straightforward. The farmed stock does not depend on natural food produced in situ but on allochthonous fish feed which could practically be unlimited, whereas site selection and farm management play a very important role determining the levels of stress on the farmed fish. The levels of oxygen could perhaps be seen as a natural resource that could be locally depleted in cases of excessive and unconscious levels of aquaculture production but one would probably agree that we need limits preventing the system from reaching at this level of environmental crisis.

Why do we need EQSs: As was shown above, for the definition of carrying capacity for aquaculture in a particular area, it is needed to define beyond which point the environmental impacts become "unacceptable" and starting from this point we could delineate the excessive levels of aquaculture production i.e. those exceeding the acceptable levels of impact. By doing this we end up with environmental quality standards (EQSs) which should be respected by the fish farming industry but also by the other stakeholders.

The overall principle for site selection in the coastal zone is that **(a)** site selection would define a certain area that could be used for aquaculture in the AZA context, **(b)** the regulatory authorities recognize that in the zone of the immediate vicinity to the fish farm there will be an Allowable Zone of Effects (AZE) where some deviation from natural variability is expected but this deviation is not unlimited; it has to conform with specific environmental objectives and associated environmental quality standards. In this case the objective is to maintain at least a minimum level of ecosystem services such as the assimilation and remineralisation of wastes.

The literature review showed that there are different EQSs in different parts of the world which invariably distinguish the situation beneath or close to fish farms to that of the general environmental quality standards which apply to large water bodies or allegedly pristine areas. The EQSs in Scotland (Henderson & Davies 2000) comprise different criteria for the mixing zone or Allowable zone of Effects (AZE) requiring information on a large number of variables on the water column and sediments such as oxygen, pH, chlorophyll *a*, N, P, macrofauna, organic material, redox, various types of pharmaceuticals and chemotherapeutics. The regulation scheme used in Norway (Maroni 2000, Hansen et al. 2001) involves different monitoring requirements (and associated EQSs) depending on the scale of the farm and the sensitivity of the receiving environment. On the other end the regulation in Japan (Yokoyama 2003, Yokoyama et al. 2004) uses a much shorter list of variables, mainly Oxygen, sulphide, C,N,P and presence of macrofauna.

Given the environmental peculiarities of the Mediterranean, the distinct characteristics of the fish farming industry in the Mediterranean countries and the need to achieve agreement by a multinational set of stakeholders, a new set of EQSs was derived based on the consensus of scientists involved in research and monitoring of aquaculture – environment interactions. This set of EQSs may be seen as a starting point for the harmonization of monitoring and environmental regulation among Mediterranean countries.

Methodology

A series of experts with working experience on environmental interactions of fish farming and the Mediterranean marine ecosystems were asked to provide their judgement on the suitability of a set of environmental variables as descriptors of the environmental quality as well as on the “safe” and “critical” levels of these variables. The overall process uses the Delphi method. The Delphi method was developed in the late 1950’s (Dalkey & Helmer 1963) in order to obtain the most reliable consensus of opinion of a group of experts by a series of intensive questionnaires and soon was applied to a vast range of situations (Linestone et al. 2002). Among others, the Delphi method has been used widely during the past decades in the management and EIA of the aquatic environment (e.g. Zuboy 1981, Crance 1987, Dinius 1987, Green et al. 1989, Mohorjy & Aburizaiza 1997, Clark & Richards 2002, Taylor & Ryder 2003). Delphi exercise was named by the Delphic oracle and its motto is that “two heads are better than one”, meaning that experts are most likely right in issues of their own field and especially if they agree with each other. There are three major points of the Delphi exercise that underline the objectivity of this method (Dalkey 1969): (1) the scientific views of the team members are given by filling official questionnaires (anonymity of the participants), (2) the questions for the experts are posed during one or more rounds, during which the experts are informed for the general results of the previous round (feedback control) and (3) the statistical analyses determine the general response of the specialists team, in this way it is ensured that the aspect of the group is an aggregation of individual opinions and that each of them is represented in the final result.

It has been shown that numerous geochemical and biological variables (no less than 120) have been used by scientists to monitor or investigate environmental impacts of aquaculture (Kalantzi & Karakassis 2006) and most of them are significantly intercorrelated. In the SHoCMed workshop involving scientists and stakeholders which was held in Malta in 2010, a list of variables was compiled after removing redundant variables and a list of experts that were asked to fill in an online questionnaire developed by the GFCM staff.

The experts were asked to provide (a) their opinion on the usefulness of the indicator and (b) thresholds for the *safe* conditions (i.e. close to normal) and *critical* conditions (i.e. the values beyond which the ecosystem services are severely compromised) as well as other comments on each variable.

The responses were analysed according (a) to the percentage of approval regarding the usefulness of the indicator as a descriptor of the ecological quality at the impacted sites and (b) to the number of thresholds provided by the experts for the critical values. Thresholds for safe and critical levels were derived as the median of the values provided by the experts in order to avoid dominance of extreme values or outliers.

A total of 28 experts from 15 countries (Table 1) have answered the questionnaire. All but 3 came from Mediterranean countries, spanning also a wide range of fields of expertise and they provided input regarding the suitability of variables and/or thresholds for safe and critical status for some of them.

Table 1. Affiliation of experts who participated in the Delphi exercise

Country	experts
Croatia	1
Egypt	1
France	1
Germany	1
Greece	3
Israel	1
Italy	4
Malta	1
Montenegro	1
Morocco	1
Slovenia	1
Spain	5
Tunisia	2
Turkey	3
UK	2
Total	28

Results

Total organic matter in sediments (%). This variable provides an estimate of the organic content in the sediments. The Organic Material (or loss on ignition, LOI) is determined as the weight loss of the dried sample after combustion for 6 h at 500°C (Kristensen & Andersen 1987), regarding the units, 1% is equal to 10 mg/g sediment. This variable was considered as highly relevant by 22 experts (79% of all responses).

Comments - Critique: Useful as general characteristic of site and cheap to do, it is considered clearly important because it correlates well with benthic results. There are no generally established safe limits and these will be context dependent. The interpretation of the data depends on the natural background levels. In a depository environment, the %OM will naturally be higher than in an area with strong currents. Measure should be taken at multiple distances from the farm and comparison should be made between several reference and farm sites.

Thresholds: Seven experts provided values for thresholds in this variable. The median for safe values is 4% and for the critical is 10%.

Table 2 Responses for safe and critical values thresholds for total Organic Mater

Safe	**Critical**
2%	2%
3%	3%
3%	4%
5%	10%
5%	10%
5%	10%
	10%
Median:	
4%	**10%**

Total Phosphorous (%): as in the case of organic Carbon or organic material in total, P is released in particulate form (fish faeces and unused feed) and precipitates beneath and close to fish farms. High sedimentation rates of P have been measured around fish farms (Holmer et al. 2008) and discernible distribution patterns have been found in profiles and transects around fish farms (Karakassis et al. 1998, 2000). P has been suggested as a useful indicator of fish farm waste loading (Holmer et al. 2008) and it has also been proposed as an indicator of fish farm impact on *P. oceanica* habitats (Pergent-Martini et al. 2006, Apostolaki et al. 2007). Total phosphorus is determined in the dried sediment samples, which were homogenized by grinding and digested with a mixture of perchloric and nitric acid (Burton & Riley 1956, Sturgeon et al. 1982). The concentration of P is determined colorirnetrically as molybdate reactive phosphorus (Strickland & Parsons 1972).
This variable was considered as highly relevant by 17 experts (61% of all responses).

Comments - Critique: It has some use as an indicator where feed is fishmeal rich as it is present in fish bones. There is some variability in the background levels. Samples for P, as well as for other sediment variables should be carried out during the high production period (i.e. summer). The method depends on SCUBA diving to get sediment cores, thus increasing the cost, but besides this the cost for determination is rather low.

Thresholds: Six experts provided values for thresholds in this variable. The median for safe values is 0.05% and for the critical is 0.18%.

Table 3 Responses for safe and critical values thresholds for total P in sediments

Safe	Critical
0.01%	0.02%
0.03%	0.10%
0.05%	0.15%
0.10%	0.20%
0.30%	1.20%
	1.50%
Median:	
0.05%	**0.18%**

Total Nitrogen in sediments (%).Total Nitrogen concentrations are expressed as % of N in sediment. The concentration can be referred to the whole 6 to 10 cm core or to the surface sediment (1 to 1.5 cm). 1972). It is measured in sediment samples using a CHN Elemental Analyzer according to the procedure described by Hedges & Stern (1984). This variable was considered as highly relevant by 19 experts (68% of all responses).

Comments - Critique: Useful especially when used to compute C:N ratio an indicator of carbon quality, is used in Law 14 Feb 1997 for the Andalusian water quality regulation. It is considered pH and salinity dependent and some experts feel that no definite value can be stated for either cautionary or critical condition since baseline values differ between different sites in the same locality and between different localities.

Thresholds: Seven experts provided values for thresholds in this variable. The median for safe values is 0.10% and for the critical is 0.25%.

Table 4 Responses for safe and critical values thresholds for total N in sediments

Safe	Critical
0.07%	0.10%
0.10%	0.20%
0.10%	0.20%
0.10%	0.25%
0.12%	0.25%
0.12%	0.25%
0.15%	0.30%
Median:	
0.10%	**0.25%**

Total Organic Carbon or TOC (%): as in the case of organic mater it is related to the sedimentation of fish faeces and unused fish feed in the vicinity of the farms but also to natural sedimentation of organic material e.g. from primary production in the water column. It is determined in sediment samples using a CHN Elemental Analyzer according to the procedure described by Hedges & Stern (1984). This variable was considered as highly relevant by 22 experts (79% of all responses).

Comments - Critique: Useful in itself and in computing C:N ratio, it may give a good idea of natural sedimentation which may be a guide to site selection. It is used in Turkish regulation. Some experts feel that no definite value can be stated for either cautionary or critical condition since baseline values differ between different sites in the same locality and between different localities, and that it does not seem to correlate reliably with benthic impact. On the other hand Hyland et al. (2005) have shown that TOC concentration in sediments is a very good indicator of stress in marine benthos.

Thresholds: Nine experts provided values for thresholds in this variable. The median for safe values is 1.5% and for the critical is 2.5%.

Table 5 Responses for safe and critical values thresholds for TOC in sediments

Safe	Critical
1.0%	2.0%
1.0%	2.3%
1.2%	2.5%
1.5%	2.5 %
1.5%	2.5 %
1.5%	3.0%
1.5%	3.5%
2.0%	5.0%
	6.0%
Median:	
1.5%	**2.5%**

Sulphide: The pathways of sulphide oxidation in marine sediments involve complex interactions of chemical reaction and microbial metabolism where Sulphide becomes partly oxidized and bound by Fe(III), and the resulting iron-sulphur minerals are transported toward the oxic sediment-water interface by bioturbating and irrigating fauna (Jørgensen & Nelson 2004). Established relationship between organic enrichment processes and concentration of sulphide within the sediment pore water are given in Wildish et al. (2004). The sedimentary sulphide is measured by means of combined electrodes (Blackburn and Kleiber, 1975; Heijs et al., 1999). Brooks and Mahnken (2003) give examples in the literature of this technology being used in assessment of aquaculture impacts. This variable was considered as highly relevant by 16 experts (57% of all responses).

Comments - Critique: According to the ECASA toolbox (www.ecasatoolbox.org.uk), this method is *useful in that it can be used in-situ and instant measurements are obtained. This technology could be used in the field in monitoring surveys to give information on the zone of impact of the aquaculture operation. By obtaining this information quickly, sampling stations for macrofauna could then be appropriately placed on a site specific basis, rather than using a non-site specific spacing between wwwwwwstations. This is particularly relevant in determining the boundary of the zone of impact which may not be known until some preliminary samples are taken*". Some experts expressed doubts whether the data/limits provided by Brooks and Mahnken (2003) can be used also for the Mediterranean, and also suggested that no definite value can be stated for either cautionary or critical condition since baseline values differ between different sites in the same locality and between different localities. Scepticism was also expressed regarding its cost-effectiveness and the interference with metals.

Thresholds: seven experts provided values for thresholds in this variable. The median for safe values is 1000-2000 micromoles and for the critical 3000 micromoles.

Total sulphur and **Total carbon** received very low scores (43% and 32% respectively) on the question on the relevance of the variable for the monitoring and <2 participants provided thresholds, so these were excluded from the analysis.

Redox Potential or Eh (mV): The oxidation-reduction (redox) conditions in the surficial sediment depend on the degree of organic enrichment and therefore the measurement of Eh can be used as a proxy for the calculation of organic loading with the method described by Zobell (1946). The Eh decreases with the depth and with decreasing O2 concentration in the interstitial water. Negative redox-potential values are associated with anoxic conditions, i.e. degradation of the organic matter by anaerobic bacteria, which, in marine sediment, use mainly sulphate as electron acceptor and release hydrogen sulphide. Redox potential is measured by profiling an electrode down a sediment core to as deep as is necessary to detect the redox discontinuity layer (RPD).

This variable was considered as highly relevant by 20 experts (74% of all responses).

Comments - Critique: Experts considered is as an important variable which is very widely used and there is potential for comparative studies. The main critique is that the Eh measurement is very variable due to sediment heterogeneity and the repeatability is rather low. Simpson et al (2005) consider acceptable Eh error ranges of 20-40 mV.

Thresholds: Ten experts provided values for thresholds in this variable. The median for safe values is 0mV and for the critical is -100 mV.

Table 6 Responses for safe and critical values thresholds for Redox potential (Eh) in sediments (in mV)

Safe	Critical
-100	-200
-100	-150
-50	-150
-50	-100
0	-100
0	-100
50	-100
50	-50
100	0
	50
Median:	
0 mV	**-100 mV**

Macrofaunal Biomass (g m^{-2}): Both abundance and biomass of macrofaunal species are significantly modified along organic enrichment gradients (Pearson & Rosenberg 1978). Azoic conditions close to heavily polluted sites result in zero abundance and biomass, which gradually increase with spatial distance from the site or temporal distance from a pollution event. The determination of biomass requires quantitative sampling of macrofauna, sorting of samples to separate benthic animals from the sediment, and weighting of the wet or dried mass of the specimens.

This variable was considered as highly relevant by 20 experts (71% of all responses).

Comments - Critique: Biomass is very useful but can be very expensive to measure. many indices do not use biomass but mean animal size gives an idea of bioturbation potential. Care should be taken with the interpretation of the data because total biomass could be driven by one large individual. Time consuming, generally low additional information. Too onerous to apply for rapid assessment. Biomass changes along an organic gradient are typically quite complex, with peaks in biomass associated with peaks in opportunistic species and a larger peak in biomass at unimpacted locations, therefore there are some implications regarding the use of biomass as an indicator of environmental quality.

Thresholds: Three only experts provided values for thresholds in this variable. The median for safe values is **10 g m^{-2}** and for the critical is **5 g m^{-2}**.

Table 7 Responses for safe and critical values thresholds for benthic biomass (in g m^{-2})

Safe	Critical
10	0
10	5
100	10
Median:	
10 g m^{-2}	**5 g m^{-2}**

Number of (macrofaunal) species: The number of macrofaunal species indicates the level of degradation of the seabed since it is one of the variables which are significantly linked with the macrofaunal succession along gradients of organic enrichment (Pearson & Rosenberg 1978). On the other hand, the number of macrobenthic species provides a measure of the potential of the benthic communities to provide ecological services such as the mineralization of the settling organic material. The technical requirements are similar to those for abundance and biomass, plus the identification of the specimens at the species level which normally entails substantial taxonomic expertise.

This variable was considered as highly relevant by 20 experts (71% of all responses).

Comments - Critique: some experts consider it as a key-variable to measure. It is already used in Scotland and Turkey. Typically it is very low beneath the cages, composed of opportunistic species but it increases rapidly with distance from the cages. Criticism involves the dependence of the values on the ecotope (i.e. mainly sediment type) and the high cost required for the identification of the specimens to species level. The sample size regarding the number of individuals or area sampled affects significantly the number of species found.

Thresholds: Six experts provided values for thresholds in this variable. The median for safe values is **10** and for the critical is **3**.

Table 8 Responses for safe and critical values thresholds for number of species

Safe	Critical
8	2
9	2
9	3
10	3
40	25
75	30
Median:	
10	**3**

Shannon diversity index: the Shannon index (Shannon & Weaver 1949) is derived from a data set of macrobenthos identified to species level (as described in the number of species above). This index is sensitive to two diversity components i.e. the number of species and the equitability i.e. the equal/unequal distribution of specimens among the species found in the sample. Despite its' widely acknowledged limitations it is probably the most commonly used diversity metric in the history of Benthic Ecology. It has been shown to change with distance from fish farms (Karakassis et al. 2000) but also it varies considerably among different sediment types.

This variable was considered as relevant by 20 experts (71% of all responses).

Comments - Critique: Very dependent of the environmental conditions and ecotope-type, mainly granulometry. Is important to consider if there are indicator species (or families) or not. Shannon index is influenced by sampling effort and sampling size. More than using limits, it would advisable to assess the variation from initial conditions. The cost is quite high as in the case of the number of species above.

Thresholds: Only four experts provided values for thresholds in this variable. The median for safe values is **10** and for the critical is **3**.

Table 9 Responses for safe and critical values thresholds for Shannon index

Safe	Critical
1.5	1.0
1.5	1.0
3.0	2.0
4.0	2.5
Median:	
>2.25	**<1.5**

AMBI Biotic index: The AMBI, was defined by Borja et al. (2000, 2003a), and is a biotic index which provides a 'pollution classification' of a particular site, representing the benthic community 'health'. It uses scores for an extensive number of species which may be found in the database of AZTI (www.azti.es) and calculates a total score i.e. a number in a range of 0-6 (7 for azoic sediments) that can be simplified into five classes from undisturbed communities to extremely disturbed communities or from High to Bad Status (sensu European Water Framework Directive (WFD), in the assessment of the Ecological Status.

This variable was considered as relevant by 20 experts (71% of all responses).

Comments - Critique: Borja et al (2009) found that AMBI and ITI correlated well. AMBI is probably preferable on theoretical grounds but ITI does seem to work better in some circumstances. Other experts expressed doubts whether AMBI is better than BENTIX or M-AMBI and particularly in the Mediterranean , whereas others thought that perhaps it is not cost-effective and therefore not very suitable for rapid assessment. As alternative it was suggested to identify only polychaetes at the family level and then use multivariate data analysis techniques. It was also mentioned that no limits should be used but rather focus on the variation from initial conditions.

Thresholds: Six experts provided values for thresholds in this variable. The median for safe values is **3.35** and for the critical is **5.0**.

Table 10. Responses for safe and critical values thresholds for AMBI

Safe	Critical
1.5	3.0
2.0	4.0
3.3	5.0
3.3	5.0
4.0	5.5
4.0	5.5
Median:	
<3.35	**>5.0**

Percentage of capitellid polycaetes over macrofaunal biomass: *Capitella capitata* or (more correctly) the *Capitella* sp. complex is the most well known opportunistic organism found in heavily polluted (organically enriched) marine sediments (Pearson & Rosenberg 1978). Although not all the species of the Capitellidae family are opportunistic, the high percentage of capitellids in a sample is almost certainly due to proliferation of the opportunistic species of this taxon. Capitellids are fairly easy to identify provided of course, that the samples have been collected and the specimens have been extracted from the sediment. Therefore the cost for this indicator is higher than weighting the total biomass but considerably lower than that required for Shannon, number of species or AMBI.

This variable was considered as relevant by 20 experts (71% of all responses).

Comments - Critique: Most experts thought it as a relevant bioindicator, easy to calculate (for abundance as well). Some experts considered more relevant the situations with dominance of Capitellids or other indicators species (or families) such as the ITI group 4, than the % of Capitellids. Capitellids are usually indicators of high pollution levels that are well past a 'cautionary' stage. It was also suggested to be considered with reference to initial number.

Thresholds: Seven experts provided values for thresholds in this variable. The median for safe values is **28%** and for the critical is **50%**.

Table 11. Responses for safe and critical values thresholds for % of captellids

Safe	Critical
3%	2%
5%	40%
25%	50%
30%	50%
70%	60%
70%	90%
	90%
Median:	
<28%	**>50%**

Gas bubbles (outgassing): Outgassing i.e. the release of gas (H_2S or even CH_4) from the bottom sediments is a clear sign of anaerobic processes in the benthic environment, occasionally found beneath the cages mainly during the warm seasons of the year (Karakassis et al. 2002). It is an easy to observe environmental characteristic. The release of H_2S is considered as a risk for the farmed stock due to the toxicity of H_2S to most marine fish. However, it is worth noting that H_2S is rapidly oxidized in the seawater (ca 90% of it is removed from the bubbles after ascending 20m from the sediment surface).

This variable was considered as relevant by 22 experts (79% of all responses).

Comments - Critique: Some experts wrote that: This would be a limit and critical situation that should be prevented in advance. If gas bubbles present, the critical conditions are reached. It is therefore too late. A good Environmental Monitoring Program should prevent this type of situations. If the sediment is outgassing this is a clear indication that it is grossly overloaded with organic material. It can be helpful in some areas but gas bubbles should not be given a high priority in monitoring programmes. Monitoring programmes must exist in any case but the appearance of bubbles is a bad signal.

Thresholds: No experts provided values for thresholds in this variable. It is considered as a qualitative indicator that should be recorded in the framework of EMP.

Beggiatoa-type mats: These are formed by chemotrophic bacteria living on the interface between oxic and anoxic conditions. Beggiatoa-type mats may be seen beneath fish cages during the warm season, in shallow sites with high organic content and often with silty sediments. Their presence indicates that the sediment is fully reduced i.e. anoxic with not even a few mm of surface mixed oxic sediment. Occasionally, depending on the seabed morphology, the sediment and the direction of local water currents there are patches of Beggiatoa-type mats in parts of the seabed whereas other parts of the site are colonized by macrofauna. The presence/absence of Beggiatoa type mats is relatively easy to measure by means of divers, ROVs or even SPI devices (Karakassis et al 2002).

This variable was considered as relevant by 17 experts (63% of all responses).

Comments - Critique: Indicates bad management (accumulation of uneaten food and/or casualties). Beggiatoa presence means that the sediment is sulphidic up to the surface and this is an obvious indicator that all is not well. Beggiatoa is a matter of good production practices. The presence of Beggiatoa could be recorded by divers or by video camera. It is more a qualitative indicator than a quantitative indicator. A visual estimate of % cover would be more relevant and cost-effective.

Thresholds: No experts provided values for thresholds in this variable. It is considered as a qualitative indicator that should be recorded in the framework of EMP.

Dissolved oxygen (DO): The DO concentration in the cages or, preferably, at the benthic boundary layer, beneath the farm provides a serious indication of the ambient conditions in the farming environment but also an alarm for risks that might endanger the production and/or the health of the farmed stock. According to the ECASA toolbox (www.ecasatoolbox.org.uk), eutrophication effects in an inshore area could result in increased DO consumption in the basin water. This could be caused by increase in organic matter from fish farms. Low DO levels often result in basins with long residence times, and the lowest concentration of oxygen will occur at the end of a stagnation period. The level at that time will therefore also strongly rely on the rate of water exchange and hypsography of the area and climatic variations of the water exchange may be important as well. The minimum oxygen concentration that could occur in the bottom water might change due to changes in the vertical flux of organic matter from the surface water and/or fish farms. The measurement of DO could be straightforward by using a water sampling bottle and a portable oxygen meter, although it would be advisable to calibrate it regularly using the Winkler titration method.

This variable was considered as relevant by 23 experts (82% of all responses).

Comments - Critique: The maintenance of high DO levels is a matter of good production practices- it should be obligatory daily evidence registered in the logbook of the farm - participation of the farmer in the monitoring program is also necessary. A large decrease in the oxygen level would be detrimental to the farmed fish themselves and it is therefore very unlikely that values of this variable will be allowed to lower as a result of fish farming activities. Water column needs to be intensively sampled in order to have representative data.

Thresholds: 14 experts provided values for thresholds in this variable. The median for safe values is **28%** and for the critical is **50%**.

Table 12. Responses for safe and critical values thresholds for dissolved oxygen (mg l^{-1})

Safe	Critical
3	1.5
4	2
5	2
5	3
5	3
6	3
6	4
7	5
8	5
	5
	5
	5
	5
	5
Median:	
>5 mg l^{-1}	**<4 mg l^{-1}**

Chlorophyll *a*: The concentration of Chl-*a* in the water column provides a measure of the phytoplankton biomass which is likely to be affected by various factors such as nutrient input from the fish farms but also from other uses of the coastal environment, discharges from rivers, agricultural runoff etc. Several papers (Pitta et al. 1999, Sotto & Norambuena 2004) have shown that fish farming does not induce high Chl*a* concentrations, probably due to grazing by zooplankton (Pitta et al 2009). However, the monitoring of this variable could provide some information regarding the trophic status of the farming site and the risk for diel oxygen fluctuations. The method used for the analysis of Chl*a* content in marine water samples (Yentsch & Menzel 1963) is of relatively low cost and the results may be obtained rather quickly.
This variable was considered as relevant by 16 experts (57% of all responses).

Comments - Critique: No definite value can be stated for either cautionary or critical condition since baseline values differ between different sites in the same locality and between different localities. It could be of importance when monitoring a huge aquaculture area. It depends on the site. One off the measurements which are probably not worth doing.

Thresholds: Only 3experts provided values for thresholds in this variable. The median for safe values is **2.4** for the critical is **5.0**

Table 13. Responses for safe and critical values thresholds for dissolved Chlorophyll a (μg l^{-1})

Safe	Critical
1	3.6
2.4	5
6	25
Median:	
<.4 μg l^{-1}	**>5** μg l^{-1}

Turbidity: This variable may be easily measured by means of a Secchi disk. The Secchi depth (i.e. the maximum depth at which the Secchi disk is visible from the surface) has significance in deep stratified waters, where the amount of matter resuspended from the bottom sediment is insignificant (see ECASA toolbox at the site: www.ecasatoolbox.org.uk). The significance is less in shallow homogeneous waters where the amount of resuspended matter might be quite large. The Secchi depth can be calibrated to estimate the concentration of particulate organic matter (POM) or equivalently Chl*a* in the surface layers. After local calibration, it can also account for coloured matter supplied by freshwater runoff in coastal and inshore waters if synoptic vertical profiles of salinity are measured. Secchi depth is obviously of great significance to farmers of filter feeders and to authorities interested in environmental effects of fish farming. If widely used, it might also be of significance to scientists. It does not require any special training. Thereby Secchi depth observations often can replace Chl*a* measurements at sites where Chl*a* is used as an indicator of eutrophication. As Chl*a* fluctuates during the season so does the Secchi depth and measurements needs to be done regularly.

This variable was considered as relevant by 17 experts (61% of all responses).

Comments - Critique: No definite value can be stated for either cautionary or critical condition since baseline values differ between different sites in the same locality and between different localities. Water column needs to be intensively sampled in order to have representative data. It is easily accessible for general public. .

Thresholds: Four experts provided values for thresholds in this variable. The median for safe values is **5 m** for the critical is **2.25 m.**

Table 14. Responses for safe and critical values thresholds for turbidity as Secchi depth (m)

Safe	Critical
3	1
5	2
5	2,5
6	3
Median:	
> 5 m	**<2.25m**

Percentage of silt/clay in sediments: The silt and clay content of the sediment is an important variable for the characterization of the seabed since it describes in a way rather easy to understand one of the most determining characteristics of the benthic environment. The sediment contains silt and clay from natural sources but also there is an increase due to sedimentation of suspended solids in the vicinity of the sea cages. The technique used is rather straightforward and inexpensive. It involves drying the sediment, weighting, wed sieving over a 63microns sieve, drying the aliquot with the fine particles and weighting again.

This variable was considered as relevant by 24 experts (86% of all responses).

Comments - Critique: The structure of sediment should be known for Site Selection. Variations on this structure should be monitored. This variable is useful for interpretation of other variables, it should be measured but it is not suitable as EQS.

Thresholds: Six experts provided values for thresholds in this variable. The median for safe values is**70%** for the critical is **85%.**

Table 14. Responses for safe and critical values thresholds for silt content (%)

Safe	Critical
15	40
60	50
70	85
70	85
80	90
	95
Median:	
< 70%	**> 85%m**

Grain size sediment structure (MD in mm): As in the case of silt and clay content, other sediment variables such as the Median diameter of particles of the sediment are important for the characterization of the seabed. The protocols for the analysis for all different fractions of the sediment are provided in Buchanan (1984).

This variable was considered as relevant by 20 experts (71% of all responses).

Comments - Critique: More useful it is not sure it is really cost effective. More cost effective might be a visual description of the sediment type. Small particule (5-25 micron) blocks egg incubation, big size (>25 micron) damages gill filaments. It depends on the zone. This variable is useful for interpretation of other variables. It is very dependent of the granulometry of the original sediment. No critical conditions, depends on the ecotope. It provides indication on the current speed on the bottom. This parameter is important, but ""site dependent"".

Thresholds: No experts provided values for thresholds in this variable. It is considered as a qualitative indicator that should be recorded in the framework of EMP.

Litter in the surrounding area: the presence of litter in the vicinity of the fish farms is probably among the environmental effects the one which is most visible to the public. Although the presence of litter normally would not have any toxic effect on the farmed stock and/or the consumers, it is likely to attract negative publicity and to result in local conflicts with other users of the coastal zone.

This variable was considered as relevant by 24 experts (89% of all responses).

Comments - Critique: Litter is a telling indicator of the quality of farm management. If a site is dirty smelly or has lots of litter then you can bet that its staff are demotivated, management is poor and environmental impacts are greater than they need be. It could be a quick component of a video or diver survey. Important for the evaluation of the environmental management. A useful qualitative indicator. If we monitor the area around the farm, perhaps we need to do the same at reference stations far way

Thresholds: No experts provided values for thresholds in this variable. It is considered as a qualitative indicator that should be recorded in the framework of EMP.

Discussion

The overall exercise gave a number of variables that could be used as a basis for discussion among stakeholders for the adoption of a common set of environmental quality standards. In the Table 15 the indicators were ranked depending on a combination of cost and confidence on the information provided by each indicator and on the EQS that have been provided. In this case the confidence is inferred from the percentage of experts that considered it useful and from the number of those that provided thresholds.

In this context dissolved oxygen is considered as the best indicator for the water quality, whereas redox potential and total organic mater and TON are selected for the benthic effects. Three more characteristics (Litter, % silt and gas bubbles) are believed to convey very useful qualitative information that should become part of standard monitoring although there are no reliable threshold variables to be used as EQSs.

Table 15. Summary of the Delphi exercise results. Additionally cost levels (L: low, M: medium, H: high), confidence on EQS and on information provided by the indicator.

Environmental Variable	% consi-dering useful	thres-holds given	Safe	Critical	Cost	EQS	info-	over-all
Dissolved oxygen (mg l^{-1})	82%	13	5	4	L	High	High	
Redox potential (mV)	74%	10	0	-100	L	High	High	
Litter in surrounding area	89%				L	IR	High	Y
% of silt – clay in sediment	86%	6	70%	85%	L	Mod	High	Y
Total organic matter (%):	79%	7	4.0%	10.0%	L	High	High	
Gas bubbles	79%				L	IR	High	Y
Total nitrogen (%)	68%	7	0.10%	0.25%	L	High	Mod	M
Total organic carbon (%)	79%	9	1.5%	2.5%	M	High	High	
Total phosphorus (%)	61%	6	0.05%	0.18%	L	Mod	Mod	
Capitellids biomass(%)	71%	7	28%	50%	M	High	Mod	Y?
Turbidity (m)	61%	4	5	2.25	L	Mod	Mod	L
Litter Far from the area	54%				L	IR	Mod	
Grain size sedim. structure	71%				L	None	Mod	
Chlorophyll a (μg l^{-1})	57%	3	2.4	5	L	Mod	Mod	
Beggiatoa	63%	diverse			L	IR	Mod	
Macrofaunal biomass (g m^{-2})	71%	3	10	5	M	Mod	Mod	
Sulphide (%)	57%				L	None	Mod	
Number of species	71%	6	9.5	3	H	Mod	Mod	
AMBI (Marine Biotic Index)	71%	6	3.3	5	H	Mod	Mod	
Shannon Diversity (bits)	71%	4	2.25	1.5	H	Mod	Mod	
Total sulphur (mg g^{-1})	43%				L	None	L	
Total carbon (%)	32%				L	None	L	

Further down the list there are also the benthic macrofaunal indicators which are of fairly high cost but are considered as useful/important by ca 71% of the experts. The percentage of capitellids in the total biomass, the total macrofaunal biomass are ranked higher because of the low cost of the analyses although the indicators involving taxonomy and diversity are likely to supply more information even if they are analysed at higher taxonomic levels.

In the Table 16 some details for the sampling frequency and the requirements for each method are presented. Most of the methods are straightforward and may be used by personnel with a reasonable amount of training. The exception is the CHN analyzer which needs specially trained and normally dedicated staff as well as in the case of macrofaunal variables including taxonomy (species number, AMBI, Shannon diversity etc).

Table 16. Suggested sampling frequency or sampling season, indicative time required to obtain the results, major equipment required and indicative cost (sampling /diving expenses not included)

Environmental Variable	sampling frequency	time to get results	Equipment required	Cost / sample (Euros)
Dissolved oxygen (mg l^{-1})	**daily**	**minutes**	**oxygen meter, Niskin bottle**	**0**
Redox potential (mV)	**seasonally**	**minutes**	**electrode, corers**	**0**
Litter in surrounding area	**seasonally**	**minutes**	**none**	**0**
% of silt – clay in sediment	**annually/ summer**	**10 hours**	**drying oven, sieves, balance**	**10**
Total organic matter (%):	**annually/ summer**	**10 hours**	**drying oven, sieves, balance**	**10**
Gas bubbles	**seasonally**	**minutes**	**none**	**0**
Total nitrogen (%)	**summer**	**1 day**	**CHN analyzer – Oven – balance**	**20**
Total organic carbon (%)	**summer**	**1 day**	**CHN analyzer – Oven – balance**	**20**
Total phosphorus (%)	**summer**	**1 day**	**Drying oven, chemistry lab**	**10**
Capitellids biomass(%)	**summer %**	**8 hours**	**sampling gear, sieves, balance, microscopes**	**70**
Turbidity (m)	**seasonally**	**minutes**	**Secchi disk, rope**	**0**
Litter Far from the area	**seasonally**	**minutes**	**None**	**0**
Grain size sedim. structure	**summer**	**2 days**	**drying oven, sieves, balance, water bath**	**20**
Chlorophyll a (μg l^{-1})	**seasonally**	**12 hours**	**filtering system, fluorometer**	**20**
Beggiatoa type mats	**summer**	**minutes**	**SCUBA diving**	**0**
Macrofaunal biomass (g m^{-2})	**summer %**	**6 hours**	**sampling gear, sieves, balance, microscopes**	**70**
Sulphide (%)	**summer**	**minutes**	**corers, electrodes**	**0**
Number of species	**summer**	**2 days**	**sampling gear, microscopes, taxonomic keys**	**140**
AMBI (Marine Biotic Index)	**summer**	**2 days**	**>>**	**140**
Shannon Diversity (bits)	**summer**	**2 days**	**>>**	**140**

The above set of EQSs may be seen as a starting point but also as a yardstick. A starting point because it helps to coordinate monitoring among different countries, institutes and companies, to bring together data and to assess how these EQSs match the real picture of the environmental interactions in the Mediterranean. But also as a yardstick because it provides values against which producers but also other stakeholders may evaluate the results of monitoring. This set of EQSs should by no means be seen as the end of the discussion on environmental interactions of fish farming in the Mediterranean. A period of application with a pilot set of farms in different regions covering different depths, background environmental conditions, farming practices and farmed species and or the meta-analysis of existing data sets are likely to provide a better understanding of the interactions under all these sources of variability.

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