<u>ECASA Indicator assessment</u>

Summary of the proposed water column indicators with in the project.

Helén Andersson, Carina P. Erlandsson and Anders Stigebrandt, Gothenburg University, October 2005.

Within ECASA we strive to suggest a number of parameters where trends, in relation to background values, indicate

A) change in water quality in the vicinity of a farm due to increased environmental pressure associated with the farm (WP2)
B) change in water quality within the farm due to increased pressure from sources in the environment (WP3).

Some of the proposed indicators can be used for assessment of both A) and B) while others specifically indicate if pressure is on farm or on environment.

Several stakeholders may have interest in water quality in a certain area and their definitions of water quality may differ. Tourists may be interested in swimming which requires hygienic water (low concentration of coli bacteria) of relatively high transparency. Here we discuss indicators of water quality that have particular relevance for the aquaculture industry and environmental authorities. Several of the proposed indicators relates to eutrophciation effects due to increased plankton growth. This is relevant at many sites in e.g. Norway and Scotland but perhaps not a primary indicator to use in some of the Mediterranean sites or highly turbulent sites. Further discussion (and perhaps proposals) of indicators of water quality for different purposes is needed.

The usage of indicators is included both as part of monitoring programs/surveys for site selection, where the indicator is directly measured (e.g. O_2 in cages), and in models of the site where typical values of e.g. salinity, temperature and minimum current speed together with details of the culture can predict e.g. levels of O_2 within cages.

Models are able to predict the impact of the farm on the environment. The monitoring frequency should be proportional both to the predicted and actual impact (Proposed Norwegian Standard NS 9410 (E), 2002).

Monitoring programs and the use of indicators can be conducted at different levels. Simple and inexpensive surveys can be performed by farmers/authorities at short intervals. One example is the use of Secchi depth as an indicator of eutrophication due to farm outlets. Should changes in water clarity relative reference values be detected a more thorough investigation can be performed by trained personnel (of e.g. chlorophyll_a) to further establish and evaluate the detected trend (c.f. Proposed Norwegian Standard NS 9410 (E), 2002).

It is of clear advantage if there is a long history of measurements of the proposed indicator. It is of further advantage if it is used in national standards as it then is likely to be regularly measured in many places. The reliability of evaluation of change is directly linked to the knowledge of the variability at a site before the establishment of a farm.

The following Indicators have been proposed:

Indicator Name	**Proposer**
1. Min O_2 in bottom water	Gothenburg University
2. Secchi depth	Gothenburg University
3. Maximum production with respect to wq. in farm	Gothenburg University
4. Fish growth	Gothenburg University
5. Chl_a	Napier/Haifa and Venice Universities
6. Winter Nutrient concentrations (DIN & DIP)	Napier University
7. Particular Organic Carbon (POC)	Venice University

In order to evaluate the different proposal we have scored (with short motivation) the different advantages and disadvantages of the proposed indicators. The criteria used are the following:

Evaluation criteria:

- Obvious significance– clear meaning to authorities, farmers as well as scientists.
- Realistic collection or development costs – must be simple and cost effective.
- Clarity in design – must be simple to set reliable reference points that can asses the risk of current status of the indicator relative reference points so that the indicator does not fail to inform about events that have occurred in the real world, or provide false alarms about events that did not happen. Reference points depend on local conditions.
- High quality and reliability – related to its accuracy/precision/sensitivity of both measurements and modelling results. Could depend on the local conditions.
- Availability of historical data. Historical data helps to clearly establish reliable reference points/sensitivity of indicator at a specific site.
- Theoretical basis. How established is the indicator in science/management.
- Appropriate spatial and temporal scale. Spatial scale: is the impact on local, intermediate or regional scale. Temporal scale: will the value of the indicator change due to monthly, seasonal, annual variability. Must be related to local conditions.
- Relevance to objectives. Hundreds of indicators have been proposed in various papers/programs and they are sometimes established with just one site in mind. As ECASA will propose a tool-box of indicators/models for farms in Europe it is of advantage if the suggested indicators could be used at several of ECASA sites. Trends should however be evaluated against local background conditions. The tool-box will benefit from having a set of indicators that can be used both for site-selection and environmental impact assessment. In the management program the indicators have to be cost-effective to be useful, in site selection a prognosis of the indicator value under suggested farming in a specific area should be possible to attain from the models of the tool-box.

Criteria	1	2	3	4	5	6	7
Obvious significance	5	5	5	5	5	2	5
Realistic collection or development costs	4	5	4	4	4	4	4
Clarity in design	5	4	5	5	5	2	5
High quality and reliability	5	4	5	5	5	5	5
Availability of historical data	4	4	4	3	4	4	3
Theoretical basis	5	5	5	5	5	3	4
Appropriate scale	5	4	5	5	4	4	4
Relevance to Objectives	5	5	5	5	5	2	5

Score: 5 perfectly adequate – 1 not relevant

1. **Min O_2 in bottom water**

Obvious significance: Increased organic load to the bottom may lead to decreased oxygen levels in the bottom water. Low oxygen concentration in the bottom water affects the survival of benthic fauna and thus its diversity. This indicator has clear meaning to farmers, authorities and scientists. Appropriate in areas where restricted water exchange can lead to periods with low oxygen concentrations in the bottom water.
Score: 5

Realistic collection or development costs: The oxygen level is easy and not too expensive to measure in a monitoring program. It is also easy to establish an appropriate depth of measurement in areas with stagnant conditions. Minimum oxygen concentrations occur at the end of a stagnant period while maximum O_2 occurs at the beginning. Periods of low/high O_2 can probably be defined in most areas.
Score: 4

Clarity in design: The parameter is easy and reliable to evaluate if one has information on minimum oxygen levels before the establishment of the farm(s). It is then fairly simple to relate trends in oxygen concentrations to increased pressure from the farm or to changes in water circulation.
Score: 5

High quality and reliability: Can be measured and modelled before the establishment of the farm and monitored by measurements of O_2 to detect trends.
Score: 5

Availability of historical data: The parameter is well established and often included in historical data sets.
Score: 4

Theoretical basis: Oxygen concentrations in bottom water and the relation to physical and biological factors is the focus of a number of papers. The parameter is both modelled and monitored within the MOM-system (Ervik et al., 1997, Hansen et al., 2001, Stigebrandt et al., 2004)

Score: 5

Appropriate scale of indicator: Seasonal and interannual variations due to physical as well as biological processes can be expected (Erlandsson et al., 2006). There is therefore a need of long and regular time-series to establish the necessary background information. Spatial scale is local or regional depending on stratification and topology at the site and its surroundings.
Score: 5

Relevance to objectives: Oxygen level in the bottom water is relevant for all objectives included in ECASA. It is suitable in both monitoring programs and for site selection as it is included in models and is easy to measure. It can primarily be used in WP2 to asses how increased loading of organic matter impacts the deepwater and bottom conditions and is thereby a highly appropriate indicator for the ecosystem approach of sustainable usage of coastal areas. The parameter is used by e.g. the Swedish Environmental Protection Agency Standards in the Water Framework to assess the environmental objective of no eutrophication. Standards for evaluation are set for Swedish coastal waters.
Score: 5

2. Secchi depth

Obvious significance The Secchi depth has significance in deep stratified waters, where the amount of matter resuspended from the bottom sediment is insignificant. 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.
Score: 5

Realistic collection or development costs: Secchi depth is a very simple and inexpensive device to measure changes in chl a concentrations as 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.
Score: 5

Clarity in design: Evaluation of trends is easy and reliable if one has information on Secchi depth levels before the establishment of the farm(s). Standards ranging from insignificant change to high change have been set by Swedish National Environmental Protection Agency.
Score: 4

High quality and reliability: Megard and Bergman (1989) found that the information obtained at sea with Secchi disk observations was as accurate and precise as that obtained with a photoelectronic sensor. The Secchi depth is however not a reliable measure of changes in chl a concentrations in areas where light is limiting for growth i.e. in

resuspension areas, or areas with a lid of strongly coloured freshwater. Thereby, it should only be used in areas where phytoplankton growth is nutrient limited. Further, in areas where the Secchi depth is less than 1 m water clarity is not relevant. Trends can be a signal of eutrophicational effects due to farm but also of changes in temperature, light, current systems or other nutrient sources.
Score: 4

Availability of historical data: Secchi depth observations have been conducted since the 1850s, but may not be available in all areas.
Score: 4

Theoretical basis: A number of scientific papers address this indicator (Bjorkman and Smayda, 1998, Portielje and Van det Molen, 1999, Preisendorfer, 1986, Sandén and Hakansson, 1996). It is a well established indicator in Norway where it is used monitoring and modelling programs within the MOM-system. Secchi depth can be modelled quite accurately and further development of the calibration of Secchi depth to local conditions is ongoing work within ECASA (Erlandsson and Stigebrandt, 2006).
Score: 5

Appropriate scale of indicator: Secchi depth indicates trends in water clarity due to local, intermediate or regional changes depending on the source of the outlet. Secchi depth values often vary a great deal over the year.
Score: 4

Relevance to objectives: It is simple to measure changes in Secchi depth and so it is useful for both management (at sites where light availability is a forcing function of the farmed species) and monitoring of the on-growing farm (to track impact of farm on the environment). Thereby it can be related both to WP2 and WP3. The parameter is used by The Swedish Environmental Protection Agency Standards in the Water Framework for environmental objective of no eutrophication. Standards for evaluation are set for Swedish coastal waters.
Score:5

3. Water quality in cages (O_2, NH_4^+)

Obvious significance: The water in cages must not be poisonous to the species living in it; bad quality of the water in the cages will reduce the production and even kill its inhabitants. The indicator is therefore relevant to scientists, farmers and authorities alike. It relates to farming of fish but also to farms of bivalvia. The indicator can be used both at inshore and offshore sites.
Score: 5

Realistic collection or development costs: It is a robust parameter to optimize the living conditions within the cages. Automatic probes for oxygen measurements can be used by farmers while ammonia measurements and calibration has to be done by trained personnel on a regular basis. Frequent observations of ammonia and oxygen might be important in areas under heavy pressure from fish and mussel farms and industrial and municipal outlets of waste water.
Score: 4

Clarity in design: Easy to evaluate as it is often known what levels different species can tolerate.
Score: 5

High quality and reliability: Measurements are reliable and parameters are modelled in MOM system (with a ‘worst case scenario’).
Score: 5

Availability of historical data: Probably not so good. Model predictions of changed water quality in cages due to changes in farming or environment must be calibrated, especially at time of highest pressure (low currents, high biomass in cages.) and thereby rely on the availability of measurements. If available, modelled results can easily be checked against measurements of O_2 and NH_4.
Score: 4

Theoretical basis: Good.
Score: 5

Appropriate scale of indicator: The spatial scale concerns the actual farm. Seasonal variations in absolute concentrations can be expected but they must never go below critical threshold values at any time.
Score: 5

Relevance to objectives: Suitable for site selection as well as monitoring. The indicator is highly relevant to farmers of fish in cages as it is directly linked to productivity of the farm. The indicator can be used for inshore, offshore and for pond cultures of fish and crustaceans. Within ECASA it relates to the objectives of WP3; changes in water quality within the farm due to changes in the environment.
Score: 5

4. Fish growth

Obvious significance: This is a very meaningful indicator for farmers as it is directly linked to the profit of the farm. The growth is a function of local conditions such as light, temperature, oxygen/ammonium concentrations and deviations from normal growth rates indicate changes in the environment of the farm (or disease) if no changes in food availability for the intensive farm has been done. For the extensive farm it can also indicate change of food availability due to environmental changes.
Score: 5

Realistic collection or development costs: Simple and inexpensive to measure for the farmers.
Score: 4

Clarity in design: Farmers probably have a pretty good idea of ideal weight at different stages of the fish life and are probably already aware that deviation is a signal of “something is wrong”. Values of deviations from normal that signals warning can be worked out during ECASA project for farms/species of the European farms (WP5).
Score: 5

High quality and reliability: Growth functions under normal conditions are well established for most farmed species. Measurements are robust and reliable. When a deviation from normal is detected, the scientific challenge is to establish the nature of the change. The MOM-system models growth rates for salmon but could be extended to include other species (WP4) and thereby be used to assess the relative impact of different environmental variables.
Score: 5

Availability of historical data: Measurements probably done regularly at every farm by the farmers (but the availability of the data might be a concern).
Score: 3

Theoretical basis: Models of growth rate exists for a number of species. MOM-system models the growth rate of salmon due to weight of fish, feed composition and water temperature.
Score: 5

Appropriate scale of indicator: Indicates local (feed, diseases, water circulation), intermediate (water circulation) and regional (water circulation, nutrient loading) changes. The life cycle of species is well established and changes from standards should be quickly discovered (monthly, seasonal basis).
Score: 5

Relevance to objectives: Directly relevant as a monitoring indicator at the on-growing farm. Where reliable growth rate models exist the indicator is a useful tool for prediction of changes due to changes in both environment and farm management. When correctly modelled and linked to a local water circulation model it is a useful tool for site (and species) selection. The indicator relates to changes in farm due to changes in the environment (WP3).
Score: 5

5. Chl_a

Obvious significance: An increase of nutrients from the farm can result in increased chl_a concentrations. At some sites it has a higher relevance than Secchi depth as an indicator of eutropicational impact as the Secchi depth also is affected by other particles in the water mass. Chl_a can also be used in shallow and homogenous water bodies.
Score: 5

Realistic collection or development costs: It is a rather simple procedure to measure Chl_a with the fluorescence technique. As chl_a fluctuates during the season, the time of measurement of this indicator can not be optimized: continuous observation over several production seasons is needed in order to establish mean and maximum background concentrations, which makes it a bit less cost efficient.
Score: 4

Clarity in design: Easy and reliable if one has information on chl_a levels before the establishment of the farm(s). A relative increase/decrease should be established instead of using actual concentrations for evaluations of monitoring measurements. The chl_a is not

a good water quality indicator in areas where light is limiting growth, i.e. resuspension areas (Secchi depth of < 1m).
Score: 5

High quality and reliability: Probably good but also chlorophyll measurements are influenced by freshwater runoff. Data from fluorescence technique may be burdened with an error from fluorescence of CDOM, which perhaps is a problem in areas with large freshwater input (comments wanted, please!!)
Score: 5

Availability of historical data: Frequently measured in many places, but the frequency needs to be rather high for accurate determination.
Score: 4

Theoretical basis: Good. Many models describing eutrophication and eutrophication indicators utilize chl_a concentration (e.g. Carlson 1977, Giovanardi and Tromellini 1992, Vollenweider et al. 1998). (Please add comments and references!)
Score: 5

Appropriate scale of indicator: Indicator relates to local, intermediate or regional scale depending on stratification, water circulation and topology. Values are highly time variable.
Score: 4

Relevance to objectives: Chl_a is relevant indicator of eutrofication for nutrient limited areas but can in many cases be exchanged for Secchi depth observations which are cheaper and uses a simpler technique. Within ECASA the indicator relates primarily to WP2, however the indicator also useful for site selection of extensive farms (e.g. mussels) as it indicates the amount of accessible food. The parameter is used by the Swedish Environmental Protection Agency Standards in the Water Framework for the environmental objective of no eutrophication. Standards for evaluation are set for Swedish coastal waters.
Score: 5

6. Winter DIN/DIP

Obvious significance: The meaning of this parameter of water quality is perhaps not so obvious as the connection between winter nutrient concentrations and summer concentrations of chlorophyll not is well established. If there exists time-series of winter concentrations of DIN/DIP before the establishment of the farm this indicator assess if there is an increase in concentrations due to the farm but not of the actual impact of the increase.
Score: 2

Realistic collection or development costs: Measurements should be pretty robust and accurate within a monitoring program. As the indicator relates to winter values the frequency of the surveys can be optimized which makes it cost efficient.
Score: 4

Clarity in design: Easy and reliable when the leakage from the farm is reflected in the winter values. Probably difficult to establish acceptable impact levels at a specific site as prediction of the effect of the higher concentrations is not straightforward.
Score: 2

High quality and reliability: The relation winter concentration/spring blooms is not reliable. Maximum winter concentrations are also dependant on water circulation and climate – winter could be a blooming season at some sites. If changes are detected the source function must be established (farm, loading from land, changed water circulation.)
Score: 5

Availability of historical data: Data probably available at many coastal sites. It is necessary to have time-series that stretches over several years as one would need to know the variability between different winters.
Score: 4

Theoretical basis: Rather good.
Score: 3

Appropriate scale of indicator: The indicator relates to intermediate and regional scales. The timescale is seasonal.
Score: 4

Relevance to objectives:
Changes in DIN/DIP concentrations are relevant for all areas, also light limited as excess nutrients can be exported. The indicator is related to environmental impact of the farm as well as to the farm-impact on the environment (WP2 and WP3).
Score: 2

7. Particulate Organic Carbon, (POC)

Obvious significance:
The significance of this indicator is obvious for both farmers and scientists. POC includes both living and dead organic matter in the water column, and can be used as a measure of food availability for bivalvia.
Score: 5

Realistic collection or development costs:
This is a well defined parameter with a well developed analysing method. It is rather expensive though, about twice the cost of nutrient analyses.
Score: 4

Clarity in design:
The parameter is easy to evaluate, and can be used for establishment of trends. Analyses of the quality of the background POC (off-season) might be important, if POC is used as an indicator for food availability.
Score: 5

High quality and reliability:

Can be measured and modelled before the establishment of a farm and monitored to detect trends.
Score: 5

Availability of historical data:
Analyses of POC have been performed since the beginning of the 1980s, POC is included in monitoring programs. But as the analysis is somewhat costly, it might not be available in some areas.
Score: 3

Theoretical basis:
Numerous papers address this parameter and it is well established. Rather high background (winter) values have been found e.g. in the Gullmar Fjord (Erlandsson et al. 2006). The lack of knowledge of the quality of off-season POC might be a problem?
Score: 4

Appropriate scale of indicator:
The amount of POC varies with the growth season with lower values off season and higher values during the productive part of the year. Higher amounts of POC may occur e.g. in the vicinity of freshwater discharge carrying organic matter to the sea. Enclosed areas with no freshwater input may on the other hand work as a sink of POC. The choice of sampling area of this parameter is therefore important.
Score: 4

Relevance to objectives:
This Parameter is highly relevant both for investigations before the establishment of a farm (WP3) and also as an indicator of the effect of the farm on the surroundings (WP2).
Score: 5

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