EU FP7 Project CREAM

Coordinating research in support to application of EAF (Ecosystem Approach to Fisheries) and management advice in the Mediterranean and Black Seas

Deliverable 3.3

Report on proposed indicators, models, methodologies and reference points for the EAF in Mediterranean and Black Sea

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1. Background and objectives

The objectives of the CREAM project Task 3 was to develop on indicators, models, methodologies and reference points for the EAF, within the specific context of the Mediterranean and Black Sea basin, and taking into account the availability and quality of the supporting data and information.

Indicators are deemed to be essential tools for policy making and public communication, by synthesizing the complexity of our environment into an understandable amount of meaningful information. They have been increasingly used in the late twentieth century to advise on fish and shelfish stock management, especially since the precautionary approach to fisheries management was developed (Garcia, 1996; Garcia and Staples, 2000). Scientific stock assessment and management advice became increasingly based on considering one or two indicators measuring fishing pressure and/or stock abundance, and their reference points. The role of reference points is to provide an interpretation scale, primarily related to overexploitation. Moving to an ecosystem approach to fisheries management implied a broadened view of the ecosystem components to be considered beyond single stocks, which strengthened the demand for indicators. The indicator concept was initially borrowed from environmental management, which has relied on pollution indicators, bio-indicators, and indicator species for a long time. In this field, which is now joining forces with fishery management towards an integrated approach, indicators “are designed to inform us quickly and easily about something of interest” because “it is not possible to measure everything” (National Research Council, 2000). The multidimensionality and complexity of natural ecosystems and human impacts implies that all environmental variables cannot be monitored and assimilated, and that indicators have to be used to summarize the information of interest; cost-effectiveness concerns were included in the concept as well (National Research Council, 2000). In terrestrial ecology or pollution monitoring, indicator species were expected to fulfill this need, although additional indicators at the ecosystem level were thought to be needed as well (Landres, 1992).

Although proposing a list of potential indicators is an exercise which cannot be complete and comprehensive, the deliverable 3.1 proposed a list of the main indicators available. In the recent development, the 11 descriptors of the EU MSFD ‘good environmental status’ and IndiSeas indicators seem to reach consensus as those indicators needed to be implemented. In Istanbul (December 2013) Ministers and Heads of Delegations from 21 Mediterranean Countries Contracting Parties to the Barcelona Convention, and the European Commission committed to take all the necessary measures to make the Mediterranean a clean, healthy and productive sea with conserved ecosystem. Among the most important decisions adopted were the Development of an Action Plan on Sustainable Consumption and Production in the Mediterranean and the Application of the Ecosystem Approach towards achieving Good Environmental Status in the Mediterranean for 11 ecological objectives.

This deliverable will develop on the proposed indicators for the Mediterranean and Black Sea and on methodologies to construct and follow-up these indicators in a practical context.

2. Recall of the data mining exercise

At the start of the project a questionnaire was sent to all CREAM partners to inform on the availability and quality of the historical data. The subsequent recepton of 114 files of information from the questionnaire proved that all CREAM partners were committed to extract the information demanded from their archives and routine monitoring programmes.

There is a large amount of data available for EAF in the Mediterranean and Black Sea. The time series may be discontinued at some locations and the format range from paper sheet to structured databases. There is probably hardly any location gathering all the data needed for ecosystem based fisheries management (EBFM).

The subsections on families of parameters (sections 3.1 to 3.9 of deliverable 3.2) are given to be the core information needed for an EAF. The possibilities to use SeaDataNet for abiotic parameters should be investigated further. Fleet and fisheries statistics are compiled through GFCM Task 1 and, although still incomplete, are available on the GFCM public website. Status of marine resources and level of fishing pressures are provided by FAO sub-regional projects, agreed and validated in GFCM and EU/STECF relevant working groups. Fishermen awareness should be undertaken on the ongoing initiatives for a better quantification of by-catches of vulnerable species.

Scientific surveys are an important means to collect biological information and habitat description, but the addition of all surveys in a given year never encompasses the whole Mediterranean and Black Sea area. Biological information and habitat description are predominantly in published documents. Whether the original samples are available for computing or not will have to be investigated if this information is required, or an area-based overview will need to be compiled. The occurrence and spatial distribution of non-indigenous species is also available through published documents.

Economics information is often seen as confidential and difficult to gather and share for analysis. The Mediterranean and Black Sea is no exception to this rule, and very few partners reported economic data, and when available, it was only on an aggregated form. Similarly, pollution and contaminants were scarcely reported, but some EU projects are on their way and may lead to progress in this field of knowledge.

Spatial planning is an essential tool for management in an EAF, and a comprehensive overview of existing marine protected areas in the Mediterranean is available within the MedPAN network. The EU project MESMA (2009-2013) will support integrated management plans for designated or proposed sites with assessment methods based on European collaboration. Their approach will make it possible to compare pressures on an inter-regional level (e.g. Offshore wind farms in the North Sea, Black Sea and Baltic), or a multi-pressure level for a specific region (e.g. Spatially Managed Areas in Fishing, Wind-energy, Geo-hazards and Tourism in the Black Sea).

Considering quality issues, there should be no doubt that the data collected by all CREAM partners are the best available, and that they are predominantly validated and reliable. They are often incomplete or discontinued, they are scattered in terms of geographical dimension and scientific surveys all together do not cover the whole Mediterranean and Black Sea.

Standard outputs and aggregated information are generally available to the public, whereas original datasets have a restricted access. Data is often stored in Excel format which may lead to difficulties for sharing the information. Data collection protocols are difficult to find or not existing. Only national protocols are referred to, and agreements on regional data collection protocols would be welcome.

When formulating an EAF management plan, lack of data or uncertainty about the impact of the fishery should not be used as an argument for delaying the plan (FAO guidelines for an EAF). Given the uncertainties associated with the lack of knowledge, data, and understanding about the ocean and living marine resources, the precautionary approach is a fundamental and inextricable feature of implementing EAF (Meltzer, 2009).

3. Selection of indicators

3.1. Definition

The indicator definition remains vague, because the concept is overburdened with too many roles, from a decision tool used to trigger management measures through reporting on management performance to communication with a wide audience (Rochet and Trenkel, 2009).

Here we focus on indicators as variables which are either monitored directly or derived from collected data and used to provide scientific advice for managing human activities in complex natural systems such as marine ecosystems, in a context of uncertainty and limited knowledge. Some well-developed indicator examples are the fishing mortality rate of an exploited stock, the abundance of an exploited or protected species, or the fraction of a region closed to fishing.

3.2. Matching indicators with objectives

Ecosystem management objectives are generally broadly defined, leaving much room for their translation into operational objectives and the selection of suitable indicators. As a consequence lists of indicators have proliferated over the last decades (Rochet and Trenkel, 2009). This is not surprising given marine ecosystems have many properties and components of concern and few established, recognized general state measures. Therefore numerous driver, state and impact indicators have long been available. A wider range of pressure indicators has been more recently developed, for example as they became explicitly requested for the implementation of the EU MSFD. Response indicators are the only category which does not seem overpopulated. For example, only two indicators have been proposed for measuring the response to fishing pressure impacts: the degree of translation of scientific quota advice into political quota decisions and the implementation of those decisions into actual landings (Piet et al. 2010).

For practical implementation of an indicator approach to ecosystem assessment management, the need to reduce indicator lists has led to a bloom of criteria and frameworks to evaluate and select indicators, in particular in the area of fisheries management (FAO, 1999; Rice and Rochet, 2005). Below we briefly summarize those selection criteria, and refer to published indicator lists.

3.3. Selection criteria

It is generally recommended that pressure, state and impact indicators used for communication should be concrete, easy to understand, and the target audience should be aware of the issue they are informing about.

Criterion	Applies to individual candidate indicators	Applies to suites of indicators
Concreteness	X	
Public awareness	X	
Sensitivity	X	
Specificity	X	
Responsiveness	X	
Consistency		X
Theoretical basis	X	X
Measurability	X	
Cost-effectiveness		X
Availability of historic data	X	

Table 1 = list of criteria.

Many other selection criteria relate to indicators used in support of decision making. It is recommended that in this case state and impact indicators should be sensitive, specific, and responsive (Table 1). Sensitivity means that indicators should measure changes in ecosystem components and properties that are actually caused by the human activities to be managed, and that these changes are detectable. Specificity has a clear advantage – it means the indicator measures changes which are primarily caused by the activities to be managed rather than by other factors, for example environmental variability. Responsiveness implies that the indicator responds to the changes in pressures, or to the management measures, within a short time frame. Moreover, the suite of indicators should be consistent and structured. Obviously all these qualities are desirable for any use of a given indicator or indicator suite – but some user groups would give more importance to some criteria than others (Rice and Rochet, 2005). For instance, responsiveness is important to the managers who need feedback on the effectiveness of their decisions.

Indicator qualities important to all users include: measurability, cost-effectiveness, and availability of historic data (Table 1). Since indicators are numbers, they need to be quantities that can be measured or estimated with a reasonable degree of precision and accuracy – and uncertainties, that is, variance and bias, ought to be estimable as well, and possibly achievable at minor cost and not relying on sophisticated measurement tools. If historic data are available then they will help evaluating some of the above criteria – sensitivity, specificity, responsiveness, measurability; and also, interpreting the indicator value, for example by providing the means to calculate reference points for a historical, possibly unimpacted, or at least satisfactory situation.

3.4. Pressures and indirect impacts

Consistency and theoretical basis are the central criteria for selecting matching suites of pressure and impact indicators. It means that pressure and impact indicators have causal links. In practice selecting consistent indicators is however not always easy as certain pressures can not only lead to direct impacts, for example bottom trawling will remove structural benthos such as corals or sponges, but also have repercussions elsewhere in the ecosystem as the result of indirect effects. In the bottom trawl example this could be a lack of shelter for species hiding from predators, which in turn might increase their natural mortality and hence decrease population abundance. Another example might be fisheries discards feeding marine birds and thus fueling larger bird populations than could be sustained without fisheries, which means taking biomass from the sea floor and making it available at the sea surface. These are just some hypothetical examples intended to illustrate the issue of indirect impacts of human pressures on marine ecosystems.

The only way to ensure consistency between indicators is to understand, at least to some degree, ecosystem functioning. Many more or less formal approaches have been used. One way to start is to draw a conceptual model for example of fishing in a simplified food web. The mathematical analysis of some model describing the conceptual model will provide insights into the expected direct and indirect effects of pressure changes, e.g. the impact of a decrease in fishing effort by the pelagic fleet on demersal piscivores. The type of mathematical analysis will depend on the degree to which the model is formalized and parameterized.

4. Proposed Indicators

4.1. The agreed approach : 11 objectives of the good environmental status

In support to the Barcelona Convention for the implementation of the ecosystem approach, UNEP-MAP (UNEP-MAP, 2012) agreed that, as a starting point, the 11 EU MSFD descriptors will be used as a basis for defining the Mediterranean ecological objectives taking into account the regional specificities. This approach was confirmed in December 2013 (Istanbul, COP 18) by the 21 Mediterranean Countries Contracting Parties to the Barcelona Convention and the European Commission.

The EU Marine Strategy Framework Directive (MSFD) adopted in July 2008 aims at achieving or maintaining a good environmental status by 2020 at the latest. It is the first legislative instrument in relation to the marine biodiversity policy in the European Union, as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving good environmental status. It enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. In order to achieve the objective the Member States have to develop Marine Strategies which serve as Action Plans and which apply an ecosystem-based approach to the management of human activities.

The Commission Decision on criteria and methodological standards on good environmental status (GES) of marine waters in the framework of Article 9 (3) of the MSFD contains a number of criteria and associated indicators for assessing good environmental status, in relation to the 11 descriptors of good environmental status laid down in Annex I of the Directive.

Qualitative descriptors for determining GES (Annex I)

Descriptor 1: Biological diversity

Descriptor 2: Non-indigenous species

Descriptor 3: Population of commercial fish / shell fish

Descriptor 4: Elements of marine food webs

Descriptor 5: Eutrophication

Descriptor 6: Sea floor integrity

Descriptor 7: Alteration of hydrographical conditions

Descriptor 8: Contaminants

Descriptor 9: Contaminants in fish and seafood for human consumption

Descriptor 10: Marine litter

Descriptor 11: Introduction of energy, including underwater noise

The European Commission has issued a guidance aiming to frame monitoring for MSFD[1] before the establishment of the first monitoring programmes. An expert group was brought together and agreed on some minimum standards to be followed and concepts to be considered and, in particular, applying the already agreed recommendations in specific monitoring issues. The guidance is limited to marine monitoring for the MSFD and does not include other data collections for the purposes of the MSFD. The future research needs on monitoring listed in the guidance is presented in Annex A.

4.2. The comparative approach across world marine ecosystems : IndiSeas

The status of an ecosystem is the result of multiple factors and needs to be assessed in this light. One way to help facilitate ecosystem assessments and the implementation of an EAF is through comparative ecosystem studies (Shin *et al.* 2010). Such comparative analyses provide an opportunity for taking a broader ecosystem perspective.

The selection of the final set of indicators by the IndiSeas WG followed three simple rules: the selected indicators had to fulfill the four main criteria listed (ecological significance, sensitivity, measurability, and general public awareness), there had to be at least one indicator per category (size-based, species-based, trophodynamic, pressure, biomass-related), and at least one indicator per management objective. To facilitate communication, each indicator selected was given a headline label (Table 3), and indicators were all formulated positively, so that a low value of an indicator reflected strong impacts of fishing, and a higher value suggested weaker fishing impacts. Similarly, an increase in an indicator meant an improving state, whereas a decrease was assumed to reflect deterioration of an ecosystem as a result of fishing.

[1] http://meeting.helcom.fi/c/document_library/get_file?p_l_id=16324&folderId=2434394&name=DLFE-54651.pdf

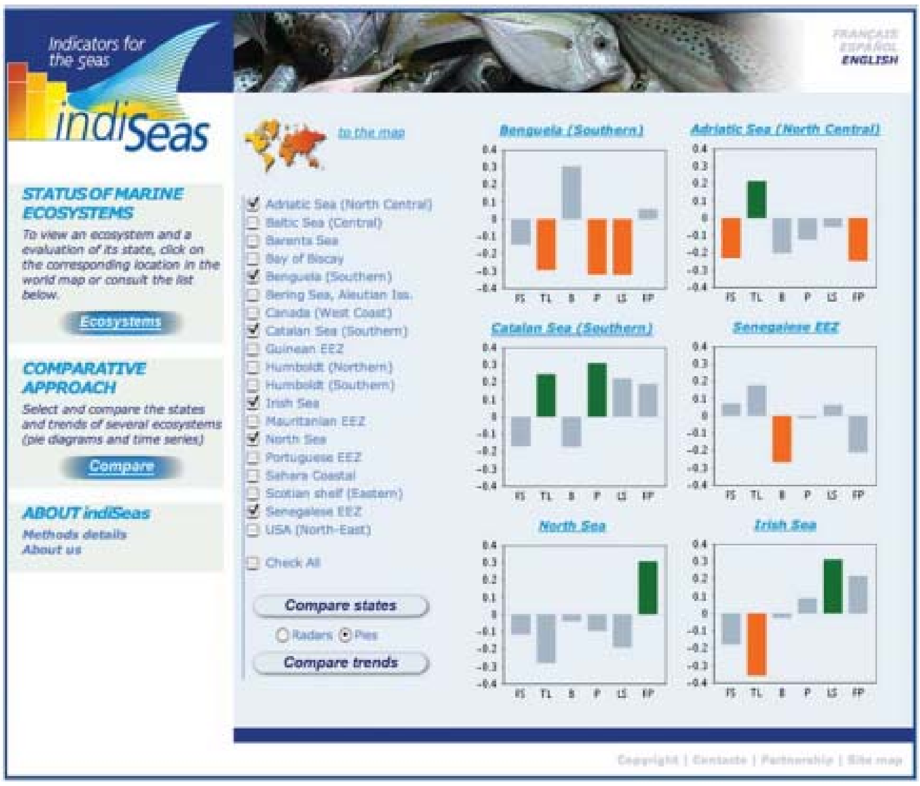

Figure 1 : An example of bar plots comparing the short- to medium-term trends (1996–2005) of 6 of the 19 ecosystems of the IndiSeas project. Bars represent the slopes of the fitted linear trends. Green indicates a significant increase, red a significant decrease. Grey bars indicate non-significant trends. FS, fish size; TL, trophic level; B, biomass; C, catch; P, % predators; LS, lifespan; FP, inverse fishing pressure. (in Shin and Shannon, 2009).

.Indicators	Headline label	Used for State of Trend	Management Objective*
Mean length	Fish size	S, T	EF
TL of landings	TL	S, T	EF
Precaution of under and moderately exploited stocks	% healthy stocks	S	CB
Proportion of predatory fish	% predators	S, T	CB
Mean lifespan	Lifespan	S, T	SR
1/CV of total biomass	Biomass stability	S	SR
Total biomass of surveyed species	Biomass	T	RP
1/(Landings/Biomass)	Inverse fishing pressure	T	RP

*CB, Conservation of biodiversity; SR maintaining ecosystem stability and resistance to perturbation; EF, maintaining ecosystem structure and functioning; RP, maintaining resource potential

Table 3 : Summary of ecological indicators selected by the IndiSeas WG and the corresponding management objectives (*In* Shin et al. 2010)

The eight indicators listed in Table 3 were selected based on the above criteria and are proposed from now on for diagnosing the status of a fished marine ecosystem. Six of them were used to measure the state (S) of the ecosystem, and six (of which two differ from state indicators) were used to measure trends (T) over time (Table 3). Data for the indicators were derived primarily from fisheries-independent (survey) and fisheries-dependent (commercial catch) data, with auxiliary information used where indicated (such as ecosystem models).

Governance and management need to be linked to the status of the exploited ecosystem; at the same time, external drivers of change, such as environmental variation, climate change and anthropogenic forcing, or the contribution of fisheries to society, cannot be ignored. IndiSeas has recognized this need and is currently incorporating multi-disciplinary indicators, including indicators of climate, biodiversity, ecological and human dimensions that represent different facets of the EAF, to produce a multi-disciplinary assessment of ecosystem status and provide scientifically sound inputs for policy and decision makers (Bundy *et al*., 2012)

5. Reference points and management objectives

In most of the fisheries and marine ecology literature, reference points are an integral part of the indicator concept. Reference points are values of a given indicator that help interpreting its level and trend. They can be either a target – a desirable level of the indicator, or a limit – a level that should not be exceeded for fear of unwanted consequences, such as serious or irreversible harm to some ecosystem component of interest (Caddy and Mahon, 1995). For management purposes, precautionary reference points have been added, which take into account uncertainty in the indicator assessment. When there is a limit that should absolutely be avoided, but the actual value of the indicator or of the reference point, or the efficiency of management actions, are not accurately known, the precautionary level defines a buffer zone in which action is recommended to reduce the risk of overstepping the limit unintentionally.

Reference points are not only used for management purposes. As increasing dimensions of ecosystems receive attention, the need to integrate information and diagnostic across indicators develops. Reference points are thought by some as a cornerstone of integrated assessment and advice because they enable to standardize non-commensurate indicators and bring them on a common scale in a way that is deemed consistent (Borja et al., 2012; Samhouri et al., 2012).

5.1. Definition of reference points

Three broad categories of approaches are used to define reference points for all categories of indicators and translate management objectives into operational, quantitative targets or limits – spatial, historical, and mechanistic (functional) approaches. Spatial comparisons across pressure or impact gradients have been well developed for freshwater bodies, estuaries and coastal areas. Issues related to this approach include the non-interchangeability between areas, implying that a given level of pressure that is safe in one place might be harmful in another place with different conditions; and definition of the boundaries of areas in the case of open seas. Historical approaches consist in evaluating current state with respect to past conditions, based on time series data. This case carries in itself an issue of comparability – some drivers and pressures other than those of interest have changed over time, and limit the comparability between time periods. This is of particular concern when regime shifts or large changes in system productivity have occurred. Another issue is that the historical approach does not allow the setting of reference limits for systems that have not already been overexploited at some point during the past. For both the spatial and historical approaches, the main conceptual shortcoming concerns the definition of "reference". Pristine conditions may not be a useful reference since some degree of impact must be accepted if an ecosystem is aimed to be exploited; besides, there is generally a lack of data from unexploited places or times. "Baseline" conditions or "minimum acceptable impact" are other options for target reference points; the issue there is that they may be determined more by data availability than by management considerations. The recent developments of integrated data collection systems may imply that we gauge ecosystem status with a myopic perspective on a narrow range of potential system states.

The mechanistic approach relies on the establishment of a relationship between the state or impact indicator and some measure of the pressure or human activity to be managed (Rice, 2009; Samhouri et al., 2012). This relationship can be empirical, but it is more likely to be useful if the statistical link is supported by knowledge of a causal link between pressure and impact. The preferred relationships are those with some non-linearity, as this will facilitate the selection of a threshold or limit pressure reference value. For determining reference points for pressures, the relationship to consider is that with the quantity of pressure on the x-axis and the state indicator on the y-axis. For example, a mode in the pressure-state relationship might be an "optimum", such as maximum sustainable yield as a function of fishing mortality. Alternatively, the point of a curve where the change in state is the steepest for a given change in pressure may be the limit reference point to trigger management action. This approach is conceptually appealing but may be difficult to operationalize, because the availability of knowledge and data might limit the ability to quantify the pressure-state relationship with accuracy sufficient to estimate the reference points. Also non-linearities in the pressure-state relationships do not necessarily reflect management priorities or have any meaning with respect to sustainable exploitation.

Finally, let us consider the ideal situation where causal relationships could be parameterized between each pair of pressure and ecosystem component of interest, and the corresponding reference points set up. The number of such relationships increases exponentially with the number of pressures and components of interest. There is no reason to expect that reference points determined on the basis of separate independent relationships would be consistent, be it across pressures for a given component, or across components linked by ecosystem structure and dynamics – they may even be incompatible. In the case of multiple ecosystem components, incompatibility would mean that for a given pressure, say the physical removal by gravel dredging, a certain dredged surface area might be detrimental to some fish species for which the essential spawning or nursery habitats are critically reduced, while for benthic invertebrates the same amount of dredging creates negligible impacts. Another example would be the permissible level of targeted fishing mortality for small pelagic fish which could leave their predators starving; in this case the prey fishing mortality would be suitable from a single stock management point of view but not for the wider food web. In the case of multiple pressures, incompatibility between reference points of different pressures could occur. To set consistent reference points across multiple pressures and components, a fully parameterized quantitative mechanistic ecosystem model would be necessary. In practical applications however, limited knowledge might mean that we have to fall back to historical or spatial approaches, and in the case of limited data, even to expert judgement. Neither of these other approaches are however likely to lead to more consistent reference points, since they all are treating each indicator separately.

5.2. Reference states and reference directions

Given the difficulties in setting reference points outlined above, the use of reference directions or reference states as alternative or complementary approaches have been proposed. Reference directions are desirable or undesirable trends in indicators (Jennings, 2005; Jennings and Dulvy, 2005). Determining which trends are desirable or not still requires assessing the state of the system at the beginning of the time series: was it consistent with the management objectives? If not, the desirable trends are those which point towards the objectives; at any rate, the undesirable trends are those that depart from the objectives. (Rochet et al., 2005). Reference states are regions in the multivariate indicator space, which can be labeled as “sustainable” or “desirable” based on the analysis of indicator time series. (Link et al., 2002). Basically one still has to set a reference by either of the processes described above, but instead of doing that indicator by indicator, this is examined in a more holistic perspective on the system. Once this is done, conceptual models can be used to interpret the observed combinations of indicators trends.

5.3. Diagnostic and management advice

Once a suite of indicators is available they need to be combined to provide management advice, which consists of two steps: assessment and advice *stricto sensu*. First the diagnostic or ecosystem assessment considers the indicator values and trends to establish how far away the system is from the management objectives – the vision or desired state. At this stage the ecosystem components which are seriously harmed or threatened and the human pressures which generate more impact than deemed acceptable need to be identified. For example, in a multi-fleet fishery if fishing mortality has increased partial mortality rates or trends in fleet sizes can be used to try and identify which fleet(s) caused the increase. Based on this assessment the advice consists in suggesting management measures that could be taken to (i) steer the system towards the desired state or away from the undesirable state, and (ii) address the most pressing issues.

5.4. Combination of indicators

Fundamentally there are two ways for combining indicators: creation of one or several composite indices, or combination of a set of diagnostics based on an indicator suite. As the issues raised and methods available in each case differ, these are discussed separately.

5.4.1 Composite indices

Simple and comprehensive indices are required for integrated assessments, management and most importantly for communication purposes. In response composite indices are increasingly being developed. For example, the global ocean index strives at assessing the health and benefits of the world ocean in relation to 10 “public goals” from food provision through carbon storage to sense of place (Halpern et al., 2012). The Nature Index synthesizes the state of biodiversity in Norway by averaging 308 biodiversity indicators (density, diversity, or other natural metrics) across trophic groups, major ecosystems, and spatial units (Certain et al., 2011). At any rate averaging across non-commensurate indicators, i.e. indicators on different scales and units, requires to standardize them, which is generally done by the means of reference points. For example, the relative position of each indicator with respect to its reference point is calculated by subtracting the reference point value from the indicator and then dividing by the reference point value. Although this transformation may seem consistent at first sight, the more composite the index, the less likely it is that reference points for all indicators can be estimated based on consistent approaches, such that for example indicators that are half-way from the worst observed point in the time-series are compared with other indicators half-way to the best known value. In the standardization process, there seems to be some confusion about how to score uncertainty – sometimes it will pull scores towards intermediate or neutral values, sometimes components lacking information or knowledge will receive low scores pulling the evaluation towards “poor state”.

For indices based on commensurate metrics, such as the Living Planet Index which uses population time series to track trends in biodiversity (Loh et al., 2005), there are still technical complications and incommensurability due to differences in catchability between taxa, places, and periods (Powers and Monk, 2010). Another issue relates to the representativeness and relevance of the available data. The index summarizes trends in species for which there are time series available – this means that some taxa such as mammals, some regions such as western countries with a lot of data, some threatened species on which science has focused might be over-represented in the index. This obviously also applies to composite indices combining incommensurate indicators.

The alternative to treating all indicators the same consists in introducing weights. The appropriate weighting system pertains to management objectives and trade-offs, and the final index value will obviously be sensitive to the choice (Dobby and Dail, 2013). Because of differences in scales of different indicators, to keep the preference ordering across multiple dimensions independent of data transformations, the arithmetic mean is generally inappropriate, and using a geometric mean makes more sense as it is more robust to large values driving the result (Ebert and Welsch, 2004).

5.4.2 Combining indicator or diagnoses

When using indicator suites the state or impact diagnostics of several indicators can either be combined into a composite index, or use the suite directly for creating a single diagnostic. The two approaches can also be combined, for example by using a suite of indicators for given ecosystem components and then combining the diagnostics on the ecosystem level.

From a statistical point of view combining state or impact diagnostics can be done in a hypothesis testing framework. For example, a fish stock might be considered overexploited if its biomass is below a certain reference level Bref or fishing mortality (the anthropogenic pressure) is above a threshold (reference) level Fref. The combined diagnostic would consist in calculating the joint probability that stock biomass is below Bref or F is above Fref.

Jointly interpreting temporal or spatial trends of a suite of indicators is the other approach which has the advantage that it has the potential to point at the underlying process changes and thus at possible responsible pressures for the monitored ecosystem. Effective management responses crucially rely on identifying responsible pressures, whether they are anthropogenic or not. This means that the suite of indicators has to be carefully composed to include complementary indicators, that is indicators which taken together allow to deduce the underlying process changes. Trenkel and Rochet (2010) proposed a statistical method based on the likelihood principle for using the unique combinations of change of two or three indicators to identify the underlying processes changes and identify possible pressures.

5.5. Giving advice

Using indicators for providing scientific management advice requires collaborations between scientists and managers, such as national and international administrations. Starting from ecosystem objectives a certain number of choices are societal which are translated into policy. Scientists propose indicators with corresponding reference points or directions as well as methods for carrying out a diagnosis. On the basis of this diagnosis they make recommendations for suitable management measures. Deciding on these measures, that is selecting the management response and implementing it is the role of managers. It has to be noted that while indicators can be used to diagnose the current or past state of the ecosystem and identify impacts of pressures, they can only provide information on the type of management measure that might help to mitigate impacts or improve states. Determining the amount of each management measure needed to reach the ecosystem objectives within the desired time frame requires methods for projecting the current state into the future. For example, to determine the reduction in anthropogenic activities needed to ensure species of interest recover their normal geographic range will require some kind of quantitative or semi-quantitative modelling.

6. Monitoring program

6.1. Setting a sampling design

To design an ecosystem monitoring program five essential questions need to be answered: what to measure, how, where, when and how often?

What to measure will depend on the set of selected indicators.

How to monitor relates to the observation method. In the marine environment observing consists generally of taking biological, physical or chemical samples using trawls, grabs, nets, bottles, collecting images using videos or acoustics, or other *in situ* measurement methods. A monitoring program will typically use a range of observation methods.

Where to monitor is a question of the statistical sampling design and of the area or region for which the indicators should provide information. If monitoring stations are selected because they are easy to get to or are in a location of particular interest, it is statistically invalid to draw inference for a larger area. If the monitoring results need to inform on a wider area, suitable statistical sampling designs are simple random sampling or stratified random sampling. Fixed station designs are also possible if their locations were selected randomly in the first place or the sampling grid was positioned randomly. The idea underlying stratified sampling is that spatially close areas are similar, because of similar environmental conditions, bottom habitat, etc. So by dividing the area of interest into approximately homogenous strata (sub-areas), higher statistical precision of indicator estimates can be achieved. This works of course only if the spatial homogeneity is similar for all indicators to be estimated from data collected with the same sampling design. This is by no means guaranteed for large scale monitoring programs collecting simultaneously data for a list of ecological state and impact indicators. To handle this case a sampling design with nested strata might be suitable. The nested design has the advantage that it allows drawing inference on a larger spatial scale while the nested strata can be chosen in a way to suit the different processes to be monitored.

When to monitor is as much a question of feasibility as of seasonal biological and ecological dynamics. For example, it is difficult to trawl or collect fisheries acoustics information during heavy storms. So the stormy months might be better avoided unless there are other good reasons for sampling during those months. Seasonal dynamics of for example fish communities can impact species richness or other diversity measures if some of the species carry out migrations outside the area at certain times of the year and the sampling happens during that period. The converse is also true. Large pelagic fish such as bluefin tuna carry out large scale migrations and will be present in certain ecosystems at certain times of the year only.

How often to monitor is both depending on the expected time frames of ecological changes and the frequency of management actions. For example, many fish populations only reproduce once a year, hence stock abundance will increase at an annual level. In contrast, natural mortality or removal by harvesting is continuous. So if the objective is to rebuild a stock, there is no need to monitor population abundance every month. Management decision might be taken on an annual level, such as the setting of catch quota, or at a lower frequency in the case of wider ecosystem objectives. Since the spatio-temporal dynamics of biological processes differ, it might be necessary to design a monitoring program with distinct spatial coverage (using nested strata if appropriate), sampling frequency and timing for different ecosystem components and indicators.

In certain cases data time series might already exist which could be combined into an ecosystem monitoring program. The objectives for which these data were collected most likely differed from those of the monitoring program. Hence it is necessary to carefully evaluate the appropriateness of each existing time series. For the case where data for indicators informing on the status of populations need to be evaluated, table 2 provides a list of pitfalls and analysis methods which can be used (Trenkel and Cotter, 2009). The important questions to ask are which factors could make indicator value, time trend or spatial trend misleading. This is of course related to the questions of what, when and where the data were collected.

Issue	Methods
Survey area ≠ stock area	• year class curves • ratio of abundance estimates of succeeding ages of a cohort • density maps
Variable catchability across length/age classes	• comparison of abundance estimates or length/age frequency distributions for different data series
Variable catchability in space or time	• checking consistency of survey protocol
Sampling effort not sufficient	• occurrence limit • density limit

Table 2. Methods for identifying problems with existing time series for using them for deriving population indicators. Adapted from Trenkel and Cotter (2009).

6.2. Indicator calculation

Once a data collection program has been implemented or appropriate historic data have been identified the next step is to calculate each indicator. There might be several ways (formulas) to estimate any given indicator. The first important point is that the estimation procedure must take into account the sampling design. If this is not done, the resulting indicator estimates can be biased with respect to the underlying true situation for which they should provide insights into changes in space and time. The second important point is to estimate the uncertainty of indicator estimates. The appropriate method will depend on the sampling design but also on the estimator used. Uncertainty is generally expressed as variance, confidence interval or coefficient of variation (CV). It can be estimated parametrically or non-parametrically using a resampling procedure such as a bootstrap or a Jackknife.

The utility of uncertainty estimates is twofold. First, they allow the validation of the sampling program as for sample size and sampling effort allocation. If the CV is high, this could indicate that not enough samples were taken or not enough stations visited. Second, they are needed to determine significant changes in indicator values. If the uncertainty is large only large changes can be detected. If smaller changes are of interest, the sampling program needs to be revised, e.g. by adding more sampling stations.

Time trends in indicator time series can be extracted in several ways. For short time series the simplest is to fit a linear regression model. For longer time series a power model can be fitted or simply a smoother. In all cases the objective is remove the noise in the time series to bring out the dominant time trends. Alternatively, nonparametric statistical methods can be used. A range of nonparametric methods exist which allow to test for the existence of a monotonic time trend, estimate the trend or compare trends or their existence between indicators. Cotter (2009) provides an overview with worked examples for indicators derived from bottom trawl survey data. These nonparametric methods often use the rank instead of absolute values and are therefore more robust to distributional assumptions and uncertainty in indicator estimates.

7. Conclusions

The context of the Mediterranean and Black Sea may be seen as difficult for the implementation of the Ecosystem Based Fisheries Management (EBFM) but Hilborn (2011) expressed that there are “core” and “extended” aspects of EBFM. The “core” consists of three primary features:

(a) doing single species management right, i.e., keeping fishing mortality at or below FMSY, and keeping fleet capacity in line with the potential of the resources,

(b) preventing by-catch of non-target species, which can be achieved by gear modification, providing incentives for by-catch avoidance, or by area and seasonal closures, and

(c) the avoidance of habitat modifying fishing practices primarily by closing areas or banning of specific fishing methods or gears in sensitive areas.

Consideration of trophic interactions and area-based management characterize “extended” EBFM.

Hilborn concludes that we will have great difficulty in moving EBFM beyond the core components of eliminating overfishing of the main species, reducing by-catch and habitat impact, and protecting endangered or charismatic species without firmer policy guidance regarding the social objectives of fisheries and their impact on marine ecosystems and human communities. This policy guidance was given recently since UNEP-MAP (UNEP-MAP, 2012) agreed that, as a starting point, the 11 EU MSFD descriptors will be used as a basis for defining the Mediterranean ecological objectives taking into account the regional specificities. This approach was confirmed in December 2013 (Istanbul, COP 18) by the 21 Mediterranean Countries Contracting Parties to the Barcelona Convention and the European Commission

In terms of scientific developments, IndiSeas gives us the way forward and the steps that the scientific community as a whole need to take to make EAF a reality (Shin *et al*, 2012):

1. Combining and integrating multi-disciplinary indicators. These include indicators of climate, ecological and human dimensions that represent different facets of the EAF. Integration should be quantitative to compare, classify and rank the status of exploited marine ecosystems. It should also be graphical so that we can communicate ecosystem status to a broad spectrum of stakeholders including managers, decision-makers and the public.

2. Developing a synergy between model- and data-based approaches. This will allow the testing of the sensitivity and specificity of ecological indicators to fishing versus climate, the performance of indicators for decision support, and the identification of reference levels and tipping points of ecosystems submitted to different drivers. This important step allows models to handle explicitly multiple drivers, their impacts, and expected feedbacks in marine ecosystems. It will therefore enable ecosystem indicators to be tested in a fully integrated way under various scenarios of global change and fisheries management.

3. Using research survey data. Global comparisons of states of marine exploited ecosystems have previously relied almost exclusively on commercial catch data. Catch data have advantages of easy access through FAO and Sea Around Us Project

(http://www.seaaroundus.org) databases, extensive geographical coverage, and existence of long time series, but have biases associated with sampling by commercial vessels.

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ANNEX A – MSFD MONITORING GUIDANCE

Based on the annex of the JRC guidance document for EU MSFD, the future research needs on monitoring mer MSFD descriptor are as follows :

D1: Biodiversity

Possible research to implement at short-term

- Identification of habitats/biotopes present in different marine environments (from shallow to deep sea, soft to hard bottom).
- Define GES for the identified habitats/biotopes based on densities, biomass and morphological attributes to some representative organisms or an index that mirrors the health status.
- Develop analytical methods and assessment tools.
- Develop cost-efficient monitoring methods for communities.
- Research programs on the status of populations, and monitoring programs of pressures with reliable and accepted internationally methodologies.
- Development of projects and studies on benthic habitats, identification, mapping, and analysis of its structure and functioning.

Possible research to implement at medium-term or requiring moderate investments

- Understand natural variation in biodiversity in order to design optimal monitoring programs.
- Integrative methods enabling valorisation of incomplete and heterogeneous monitoring data.
- Implement automatic analysis methods of analysis for plankton samples, to carry out an objective analysis (not influenced by expertise in taxonomic identification) of certain plankton attributes, such as size structure and taxonomic composition.
- Development of innovative monitoring tools to provide real-time information: e.g. remote sensing for plankton composition, use of ferry boxes, ROV, acoustic, molecular approaches, etc.

Long term research or important investments

- ‘Business models’ for upscaling and operationalization of biodiversity monitoring, realizing economies of scale on a shorter timescale.
- Population genetics studies: DNA barcoding/Metagenetics, Short Nucleotide, Polymorphisms.

D2: Non indigenous species

Possible research to implement at short-term

- Harmonisation criteria.
- Design of specific and standardized monitoring programs for alien species.
- Develop, using international cooperation, criteria for determining which species are invasive, or potentially invasive.
- Identify the major vectors facilitating the spread of alien species.
- Involvement of 'public science' or/and fishermen to be part of the monitoring system.

Possible research to implement at medium-term or requiring moderate investments

- Study the changes to the functioning of marine ecosystems subjected to an impact of invasive alien species.
- Conduct studies to assess how invasive species affect marine ecosystem services and socio-economic benefits.
- Develop a bioinvasion impact assessment methodology enabling quantification and comparative analysis of the consequences of NIS introductions.
- A managed web-based image database should be developed.

Long term research or important investments

- Molecular genetic methods to trace the origin of NIS: Fast and accurate identification of species (this would be partially solved by metagenomics, DNA barcoding / Metabarcoding).
- Studies on the natural dispersion mechanisms of each invasive species. Development and application of relevant hydrodynamic models for understanding the processes of natural dispersion.
- Development of innovative monitoring tools to provide early warning information on invasive species.
- These priorities are concerned with “early warning” about NIS.

D3: Commercially exploited fish and seafood

Possible research to implement at short-term

- Determine a method to select the scale to monitor and to respond to dynamics of fish populations:
    - All exploited populations
    - Dominant populations

    - Dominant fisheries

- Determination of targets.
- Establish consistent reference points, as well as to develop additional indicators (e.g. related to mixed fisheries characteristics) is highlighted.
- Conduct studies with fish populations for which there is little information, such as deep-sea fish, to obtain information on their fishing mortality rates and biomass indices. Shellfish are another group with scarce data.
- Collate information on by-catch.
- Study the impact of discard ban on the monitoring.
- Interactions between D1, 3, 4 and 6.

Possible research to implement at medium-term or requiring moderate investments

- Integration of the criteria and indicators of biological disturbance by fishing, which are related to the level of fishing pressure, particularly ensuring a fishing mortality (F) at or below the maximum sustainable yield (MSY), in complex situations, such as mixed fisheries and cases of important ecosystem interactions
- Analyze that SSB_{MSY} probably cannot be achieved simultaneously for all stocks due to interactions between them.
- Study impacts of selectivity on stocks.

Long term research or important investments

- Develop new methods: new genomic methods e.g. short nucleotide polymorphism (SNP's).
- Develop and adapt the productivity and susceptibility" PSA approach: this could be one way to identify which populations should be surveyed and resources prioritized.

D4: Marine food web

Possible research to implement at short-term

- Study energy flows between benthic invertebrates and waterbirds.
- Study of organisms for which there is scarce or incomplete information:
    - meso-bathypelagic fish, gelatinous zooplankton, suprabenthos
    - top predators
- Monitoring of jellyfish would be needed (proper methods lacking).
- Adapt existing programs to food webs characteristics.
- Development of monitoring programs including different compartments of coastal communities, with different methodologies (visual census by diving, ROV video), completed with feeding studies.

Possible research to implement at medium-term or requiring moderate investments

- Cost efficient methods for monitoring and sample analysis for microplankton.
- Understand resilience to develop global approach.
- Study cumulative effects.
- Further extensive data collection to fill gaps in knowledge of food web structure and connectivity.
- Develop indicators:
    - Of population status: total mortality index, exploitation rate, or average length.
    - To describe communities from a functional point of view: the size spectrum, or the proportion of piscivores in the community.
    - Integrative for trophic connections and energy fluxes.
- Isotopic based research is needed to understand trophic position and relationships and assess group-specific and community-specific indicators.

Long term research or important investments

- Identify new relevant indicators especially based on data from genomic methods: DNA barcoding/metagenetics for species level identification including gut contents/highly digested prey.
- Technological development and miniaturization of sensors are needed to increase the automatic data collection.

D5: Eutrophication

Possible research to implement at short-term

- Other characteristics should be included in addition to Chl-a, such as changes in community composition, occurrence of nuisance and toxic species that result from changes in nutrient ratios, and increased duration and frequency of blooms which result from increases in nutrient loads.
- New development of phytoplankton assessment tools that account for shifts in species composition and frequency of blooms in the status assessment scoring.
- Support to evolving monitoring strategies aimed at optimal integration of various monitoring tools.
- Needs for interregional harmonization.

Possible research to implement at medium-term or requiring moderate investments

- Adapt research strategies to offshore issues.
- Research on Harmful Algal Blooms: Identification of the role of mechanisms such as upwelling relaxation events, cyst formation etc in HAB formation, and the extent to which these events are manageable;
- Development of a regional algorithm that allows reducing the uncertainty in the calculation of satellite chlorophyll from global algorithms;
- Continuous monitoring of the incidence of green tides and of the overall ecological status of macroalgal communities
- Implications on the social costs of load reduction compared to benefits received.

Long term research or important investments

- Research on value, resilience and recovery of marine ecosystems: This includes research exploring potential recovery pathways from eutrophic to non-eutrophic states.
- Develop algorithms for phytoplankton composition identification using remote sensing and satellites modelling.
- Develop metagenomics in identification of species microarrays.
- Develop biological trait analysis for phytoplankton.

D6: Sea floor integrity

Possible research to implement at short-term

- Agreement on habitats description (EUNIS?)
- List of habitats containing the main habitats found must be agreed following a hierarchical classification;

- Development of projects and studies on benthic habitats: identification, mapping, functioning and structure
- Develop methodological standards
- Study of pressures: studying gradient of pressures and comparing it with state scale:
    - Mapping
    - Intensity
    - Impacts
- Study relations between pressures and microbiology

Possible research to implement at medium-term or requiring moderate investments

- Studies on the responses of species to pressures, to clarify the identification of opportunistic species and develop sensitive indices
- Habitat suitability modeling
- Development of new devices and data transmission for the observation and study of deep sea habitats

Long term research or important investments

- Metagenomics for a faster, accurate and harmonized identification of species across Europe: DNA barcoding / Metagenetics / Metagenomics
- Integration of information from different sources and surveys

<u>D7: Alteration of hydrographical conditions</u>

Possible research to implement at short-term

- Define permanent vs. temporary and permanent vs. natural variability.
- When and where pressures are significant and permanent alteration to ecosystem functioning.
- Develop monitoring methods:
    - remote sensing
    - oceanographic cruises
    - uplooking Acoustic Doppler current profiler (ADCP)
    - satellite data
- Ship availability is crucial in order to maintain the monitoring program (both cruises and mooring maintenance).

Possible research to implement at medium-term or requiring moderate investments

- Adapt available methodologies to offshore conditions.
- Determine targets and limits.
- Issues related to scale/area assessments which at present are quite impresice are highlighted.
- Determine the relationship between hydrographical data and human pressures: studying the human impact need to know the natural level/situation.
- Develop 'risk-based' approach.

Long term research or important investments

- Development of operating models to characterize the hydrographic conditions on short scales and infer if these can be affected by infrastructure development
- Develop cumulative effects assessment methodologies for geomorphological complex situations.
- Regional scale modelling study- model possible anthropogenic activities.
- Creating an integrated global earth observation system.

D8: Contaminants

Possible research to implement at short-term

- Quantification of contaminants fluxes and inputs.
- Development of monitoring methodologies: passive sampling, new biological effects techniques, analytical methodologies.
- Develop a cost-effective deep sea sampling.
- Marine ecotoxicology data, including for emerging contaminants.
- Bioavailability and effects of emerging contaminants.
- Integrated surveillance programs should include, at least, different compartments of the ecosystem for the study of pollutant concentrations and associated biological responses.
- Include in the pollution monitoring programs, new groups of contaminants such as TBT and alkylated PAHs, and tissue level biomarkers (histolopatology and gametogenesis), as well as embryo-larval bioassays in sediment pollution monitoring
- Determination of adequate standards for marine waters.
- Increase knowledge on new substances.

Possible research to implement at medium-term or requiring moderate investments

- Pre-concentration of samples at sea: development of new passive samplers.
- Understanding causal relationship and mechanistic processes between contaminants and their effects.
- Development of biological effect techniques particularly for new and immuonotoxic substances and the development of validated biological effects assessment methods.
- Responsible adaptation of marine monitoring strategies for 'ubiquitous' contaminants.
- Affection of substances to organisms.
- Ecological relevance and relationship between early warning signal at cellular level and the alteration of physiological function as reproduction, immunotoxicity and fitness.
- Understand better how contaminants are transferred across trophic levels.

Long term research or important investments

- Screening for risk assessment of relevant mixtures of emerging pollutants and existing contaminants.
- Understanding of the transfer and fate of contaminants through the marine food webs and their biological effects at different trophic level with different species including top predators.
- To generalize the use of integrative organisms (like mussels) and matrixes (sediments), to harmonize the statistical processing of the data, and to define for biota and sediments regional quality standards taking into account the natural variability of contamination rates.
- New genomic methods development: Transcriptomics/Ecotoxicology.
- Study the complimentarily between assessment of chemical and biological effects.

<u>D9: Contaminants in fish and seafood</u>

Possible research to implement at short-term

- Further development of regulatory thresholds was proposed.
- Need for specific and ongoing monitoring of the concentrations of contaminants in fishery products traceable to its source.
- Analysis of additional contaminants, sampling in a wider range, and including more marine commercial species, and development of new criteria regarding microbiological indicators.
- Synergy between D8 and D9: Use the same data but thresholds are different between seafood and environment: data from D8 can be used for D9.
- It is noted that no single 'species' can be used across European waters, as a global indicator for all Member states. One part of the system is not 'manageable' considering the species

mobility: the mussel watch approach might be a way to address both the issue of (1) side effects resulting from finfish mobility limiting global explanation and further management,(2) a single species used across European waters.

- Adequate spatial and temporal coverage of monitoring program that are now based on individual monitoring of contaminant.

Possible research to implement at medium-term or requiring moderate investments

- Analysis of additional contaminants, sampling in a wider range, and including more marine commercial species, and development of new criteria regarding microbiological indicators.
- Better understanding of the life cycle of contaminants between water and fish is needed.
- Determination of harmonized quality standards across Europe.
- Outside coastal areas monitoring of seafood contamination.

Long term research or important investments

- Cumulative effects of different pollutants.
- Effects of world wide pollution and long range transport.
- One of a main difficulty is to know where is the contaminants are from.

<u>D10: Marine litter</u>

Possible research to implement at short-term

- Conversion factors number/weight/volume to be developed.
- Determination of litter degradation rates.
- Increase knowledge in microplastics:
  - Size to be specified and harmonised, protocols inter-calibration and harmonization needed.
  - Quantifying microparticles in the environment (including sediments from submerged substrates and beaches, as well as surface water).
  - Effects: Regarding the impact indicators, the scientific and technical basis exist, but information collection network still needs to be optimized.

Possible research to implement at medium-term or requiring moderate investments

- Development of indicators:
  - GES definition is based on trends and decrease. There is to define thresholds to verify the achievement of GES.
  - Intercalibrations are needed for most indicators (floating litter and microplastics especially)

  - Fish indicators are still under development.

- Development of monitoring plans using video or photo images, which will assess the litter on rocky and deep bottoms.
- Assessing the landscape and / or cognitive effect of litter on society, mainly affecting tourism and the development of water activities, in order to assess the economic and social damage to the affected areas.

Long term research or important investments

- Opportunistic data acquisition for deep areas/canyon (cost of data acquisition important), allowing a long term monitoring.
- Identify /quantify sources, importance of rivers and fate of litter: Determine the possible origin of the litter and dispersion vectors by studying their distribution and the coupling with particle drift models or identifying characteristics of the waste.

<u>D11: Introduction of energy, including underwater noise</u>

Possible research to implement at short-term

- Impulsive noise: it is not essential to develop new technology and techniques, but the required systems/registers to collect and assess these data still needs to be developed.
- Ambient noise: Much fundamental knowledge about measuring, processing and storing the data is available but with presently available technology collecting field data about ambient noise will be very costly.
- Organisation of efficient data gathering (register) for impulsive noise and ambient noise, preferably at EU or regional scale.
- Development of a registry of activities and an inventory of the sound sources that generate impulse noise of medium and low frequency.

Possible research to implement at medium-term or requiring moderate investments

- Development of sound maps, integrating acoustic models, source information and environmental parameters to describe actual sound levels and trends.
- Technology to store and transfer measurement data in a cost effective way
- Establish a system for monitoring underwater noise, by mixed techniques of *in situ* measurements (hydrophones) and models, in order to have a "noise map".
- Establish a system for monitoring underwater noise, by mixed techniques of *in situ* measurements (hydrophones) and models, in order to have a "noise map".

Long term research or important investments

- Analysis of the relationship between acoustic trauma animals stranding record (cetaceans, cephalopods, etc.) and authorizations of activities that generate such sounds.

- Sound repellers (for mammals) are used in fishery without any true assessment. Similarly light use in fisheries is not under controlled.
- Gliders and specific moorings are suggested as development technology for developing a monitoring network focusing on noise...
- Develop models from time series using hydrophones direct measurements with sufficient spatial coverage.
- Investigate aspects of the introduction of energy in the marine environment that has not yet been considered, for example the high frequency masking, the effects of light, thermal pollution, electromagnetic fields, etc…