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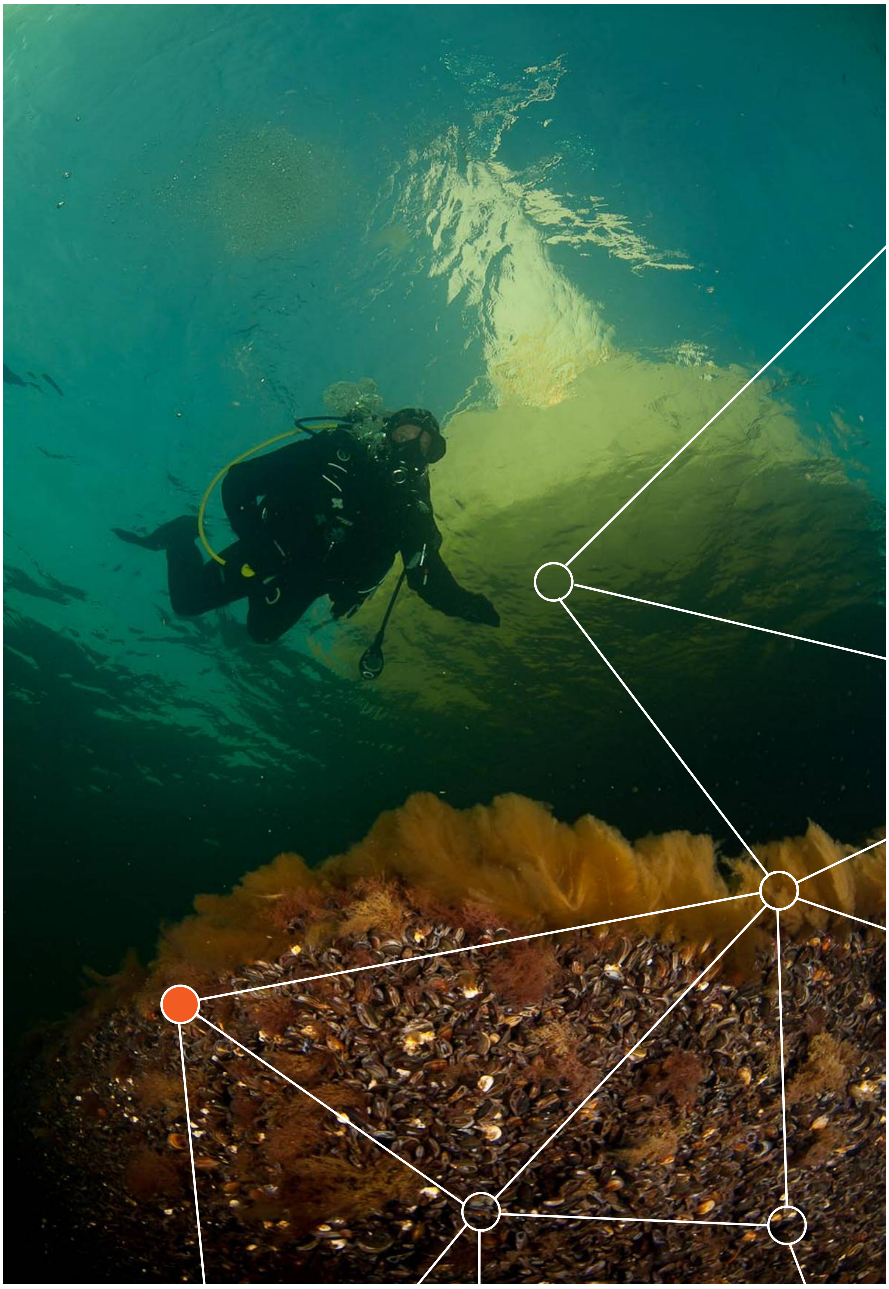
Moving towards integrated ecosystem monitoring

ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES



ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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Editor

I. J. de Boois

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International Council for the Exploration of the Sea

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Contents

1 Introduction

Monitoring at sea has taken place for a long time. Over time, management requirements have changed, and focus has shifted from "studying one specific topic", such as hydrography, chlorophyll, or fish species, to a wider ecosystem scope. Technological developments and improved insights on ecosystem functioning provide the opportunity to re-evaluate current marine monitoring strategies.

This report provides guidance on the development of ecosystem monitoring, defined here as "the monitoring of one or more components of the ecosystem". The guidance is developed under the umbrella of the ICES Working Group on Integrating Surveys for the Ecosystem Approach (WGISUR). This report is focused around platform-based approaches, usually research vessels. It is influenced by the framework for ICES coordinated surveys, which use national efforts to collect information on fish abundance, diversity, and distribution. However, it is set up in such a manner that the general concepts can be useful for integrating other marine monitoring. The report describes how moving towards ecosystem monitoring can take place through three different approaches:

a) starting ecosystem monitoring from the very beginning;

b) redesigning existing monitoring by combining new objectives with existing objectives; or

c) adding data collection to existing monitoring without changing the design.

The approaches are not mutually exclusive but should be considered as the starting point for the change towards ecosystem monitoring. The choice for either of the approaches depends on multiple factors such as end-user requirements, available resources and available data acquisition techniques.

The guidance aims to help decision-making on the choice of approach when moving towards ecosystem monitoring, and is designed to be adaptable and flexible. All input on experiences, and suggestions for improvement, can be directed to the WGISUR chair (via WGISUR). Only by sharing knowledge and feedback on the document can we move forward.

1.1 Definitions

This report uses the definitions listed in Box 1. The current literature on integrated ecosystem monitoring uses the same or similar terms for different activities or designs.

1.2 Report structure

- Section 2 forms the basis for the rest of the document. It describes how moving towards ecosystem monitoring can take place based on three different approaches:
  - a) starting ecosystem monitoring from the very beginning;
  - b) redesigning existing monitoring; or
  - c) adding data collection to existing monitoring without changing the design.
- Section 3 describes the essential elements to consider when developing an ecosystem monitoring programme, including a framework with concrete steps.

- Section 4 contains more details on how to move towards ecosystem monitoring for the three different approaches listed above.
- Section 5 provides examples of practical applications for all approaches.

Box 1: Definitions used in this report

Coordinated ecosystem monitoring: ecosystem monitoring with improved efficiency through sharing platforms and/or conducting complementary survey elements to collect the necessary ecosystem information.

Ecosystem component: part of the ecosystem that can be monitored, such as fish, seabirds, water quality, or habitat features.

Ecosystem monitoring: marine or aquatic monitoring of multiple components of the ecosystem.

Index: relative measure for a parameter, often used to create consistent time-series

Indicator: quantitatively defined metric representative of the state of an ecosystem component with respect to a specified objective.

Integrated data collection: collection of data that can be meaningfully combined, mostly leading to added value from the full data set when compared to data from the separate elements.

Integrated ecosystem monitoring survey: data collection on more than one ecosystem component, which explicitly considers in the sampling design the processes that link the sampled components.

Integrated ecosystem monitoring programme: the combination of multiplatform and multi-scales integrated data collection to evaluate ecosystem status and to establish management objectives.

Integrated ecosystem assessment: quantitative evaluations, and synthesis of information on physical, chemical, ecological, and human processes, which provide the scientific understanding to deliver advice on societal trade-offs among different policy options

Objective: monitoring goal.

Task: concrete actions to be carried out during a survey.

Time-series: comparably collected set of monitoring data with defined periodicity used to calculate a specific index or indices.

2 Moving towards ecosystem monitoring

2.1 Reasons to move towards ecosystem monitoring

Two main drivers currently form the basis for a more ecosystem-based focus: management requirements and available budgets. Examples of new management drivers are e.g. the requirements of the EU Marine Strategy Framework Directive (MSFD), ecosystem status assessments (e.g. Arctic, NOAA), or habitat assessments (MSFD, IUCN). For the EU Common Fisheries Policy (CFP), increased understanding of ecosystem processes is needed for fish stock assessments. All monitoring managers seek ways to increase the cost-efficiency of their programmes.

There is also a scientific interest to integrate marine monitoring, as ecosystem understanding can only develop by combining information from different aspects of the system in an integrated manner (integrated data collection).

2.2 Approaches towards ecosystem monitoring

There are different approaches towards ecosystem monitoring: (a) develop a new ecosystem monitoring programme, (b) change the existing monitoring by adding new objectives while maintaining existing objectives, and (c) add data collection to the existing monitoring (Figure 2.1). The most suitable approach depends on a number of factors, e.g. the future monitoring objectives; or the scope for adapting existing monitoring programmes with tasks, without incurring major change in the objectives and resourcing. In addition, the multiple levels of management (international, national, local) play a role with overlapping/variable scales of requirements and interests (e.g. fisheries and biodiversity). This means that, in general, there is no "good" or "bad", or even "better" or "worse", approach. The main selection criteria is whether the chosen approach fits the purpose and is efficient and effective given the circumstances. It should be noted that these are not polar approaches. At times an approach that combines aspects of different approaches may be the ideal solution.

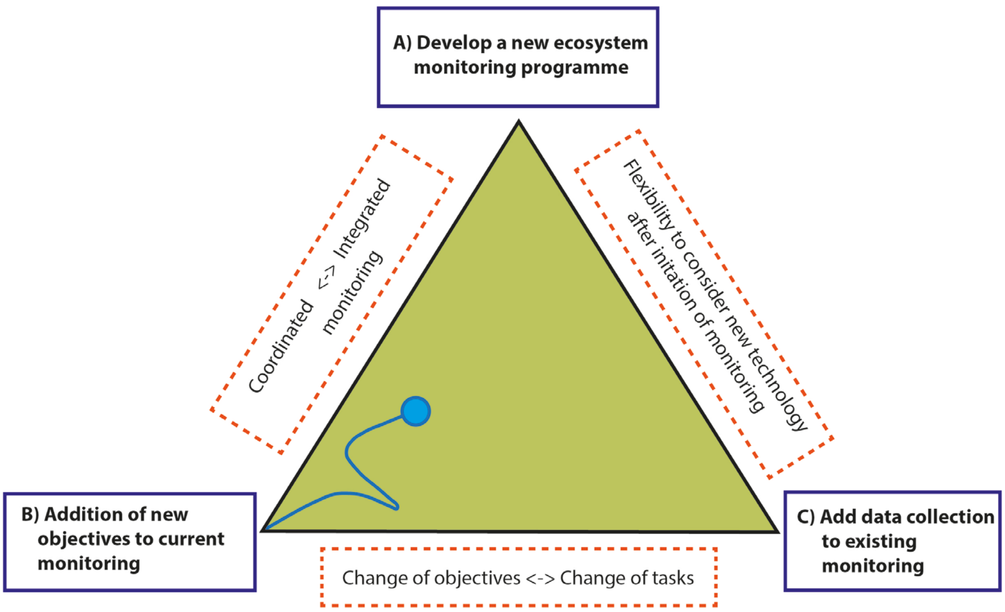

Figure 2.1. The continuum of ecosystem monitoring planning developments. The blue boxes (A, B, C) are entry points. Example path (blue line and dot) shows the iterative development of the optimal solution through the considerations of the framework flexibility constraints and technical analytical considerations.

Each of the three approaches (A, B, and C in Figure 2.1) can serve as an entry point for the planning and execution of ecosystem monitoring. The identification of the most appropriate approach will guide the (re)design process, and the advance towards finding the optimal solution (the blue dot).

The first step in ecosystem monitoring design is to determine the lowest common denominator with regard to options for change. The different entry points all contain their specific flexibility. In relation to current and anticipated management objectives (fisheries and ecosystem), the most suitable entry point can be chosen based on the potential for adaption/change, and on assumptions about the degree of flexibility around current fisheries survey objectives.

The challenges for the three approaches differ and are described in more detail in the following paragraphs.

2.3 Approach A: Develop a new ecosystem monitoring programme

The development of a completely new ecosystem monitoring programme allows the ecosystem component to be the central focus, as opposed to species (or groups) that are often the main focus in existing monitoring programmes.

The basis of this approach is the belief that ecosystems are highly connected through ecosystem processes, and this needs to be understood in order to provide effective management advice. Compared to most existing programmes and surveys, integrated ecosystem monitoring programmes focus more on studying the processes rather than the state of the ecosystem.

To cover ecosystem components which are difficult to monitor by ship-based surveys only, data from additional platforms are needed. In consequence, a fully integrated ecosystem monitoring programme includes a range of different platforms, e.g. surveys, gliders, and satellites.

A fully integrated ecosystem monitoring programme:

i) uses the understanding of the relationship among ecosystem processes to minimize the uncertainty in sampling design and, therefore, becomes efficient for complex systems;

ii) gives the chance to revisit current and future aims and objectives in relation to the ecosystem under consideration;

iii) provides the opportunity to examine and seamlessly incorporate new methodologies and technologies into monitoring;

iv) allows the evaluation of the survey/monitoring programme in the context of other available data sources, maximizing the effectiveness of the use of costly surveys; and

v) creates flexibility in the development of a long-term monitoring programme. Process-oriented monitoring merely represents some node points in the web of ecosystem interactions, because increasing understanding on how the nodes relate to each other is more important than which nodes exactly are monitored. In consequence, as long as interactions change slowly, the monitoring can be adapted without losing the value of the time-series.

2.3.1 Reasons to choose (or not) this approach

Approach A is very effective when: (i) there are different responses to a single pressure under different conditions; (ii) the effect of multiple pressures on a single process is not merely the addition of their individual effects; or (iii) highly standardized time-series of ecosystem states do not fulfil management needs.

Approach A is recommended in situations where: (i) there is little ecosystem monitoring or monitoring of any kind in place; (ii) the advisory requirements have evolved rapidly; and (iii) new or specifically allocated resources are available.

Transitioning to integrated ecosystem monitoring allows a more rapid development of the monitoring programme, so that new methodologies/sensors can be incorporated without the "standardization" constraints generally found in existing surveys. In addition, full integration of monitoring means the programme possesses flexibility, allowing it to be continually up to date with technological advances.

Approach A is not recommended when: (i) the monitoring is only needed to fulfil the minimum requirements for a specific purpose (e.g. MSFD); (ii) other approaches are as cost-effective and less complex for reaching the goal (e.g. adding an objective to existing monitoring - approach B in Section 2.4); or (iii) the continuity of (data from) existing monitoring programmes has a high priority in the short term.

2.3.2 Advantages

A newly developed ecosystem monitoring programme will be both fit for current purposes and flexible to adapt future needs and technological developments. As the main purpose is to collect information about the ecosystem component, as opposed to specific species or species groups, the monitoring furthermore provides maximal gains in process understanding.

2.3.3 Risks

The risks of creating a completely new ecosystem monitoring programme are mainly related to either (i) any existing monitoring programmes that will be replaced, or (ii) limited knowledge of the dominant ecosystem processes:

i) When existing monitoring programmes are replaced:
    - substantial changes to existing time-series are almost inevitable. In the short term, this will result in a loss of precision, and potentially accuracy, of stock assessments;
    - there is a risk of trying to fix things that were not broken, i.e. changing things that we are already doing well; and
    - priorities/objectives need to change, otherwise this approach is likely to be less efficient than approaches B or C.

ii) When there is little understanding of the dominant ecosystem processes, and no current monitoring exists in the short term, there will be substantial increases in costs, which will only decline if ecosystem connections are demonstrable.

2.3.4 Specific points requiring attention

The following aspects should be specifically considered when a new ecosystem monitoring programme is being developed:

i) Thorough analyses on how the ecosystem components interact are a vital part of the process. The likelihood of benefiting from this approach is directly proportional to the available knowledge of the specific ecosystem.

ii) A centralized overview of monitoring data is essential and, therefore, requires buy-in from end-users at all levels (ranging from modellers to managers using the advice, or policy-makers) in order to avoid undermining the benefits. Data collections are interdependent in their use, and changes to specific collections will have wide-ranging impacts.

iii) It is essential that an integrated ecosystem assessment be developed alongside the monitoring. This will provide an important connection among survey scientists, policy customers, and legislative entities across the advisory process. The value of data depends on being correctly framed within the context of the ecosystem understanding as a whole. In a fully integrated ecosystem monitoring programme, survey data can only be evaluated in relation to all other available data sources.

2.4 Approach B: Addition of new objectives to current monitoring

Existing monitoring can become more valuable for assessing ecosystem components by adding objectives that will lead to an increase in the understanding of the ecosystem. This approach takes the continuation of existing time-series into account. The addition of objectives may lead to a slightly re-designed survey, and may result in the move towards an integrated ecosystem monitoring programme. However, changing existing surveys into ecosystem monitoring can only take place after consulting the current end-users about their needs. The change may also be beneficial for the end-users, because there may be a desire to obtain different or additional data from the monitoring programme.

2.4.1 Reasons to choose (or not) this approach

Approach B is the best available pathway when (i) a long-term shift is desired in monitoring objectives (e.g. monitoring different ecosystem components, or monitoring ecosystem processes), while maintaining existing, more topical, objectives; or (ii) the evaluation of an existing survey suggests that the monitoring effort can be used in a more efficient way to achieve target objectives, freeing resources for other data collection (e.g. money, personnel, and/or ship time).

Approach B is not recommended when (i) existing objectives are no longer relevant (in which case approach A should be considered, see Section 2.3); or (ii) existing objectives will always have priority and no discussion on prioritizing the new objectives can take place (in which case approach C should be considered, see Section 2.5).

2.4.2 Advantages

The benefits of adding new objectives to an existing monitoring programme and clearly prioritizing the new suite of objectives include:

Data and knowledge benefits:

i) Data collected for the new objectives may increase the understanding of the ecosystem, which, in turn, may lead to improved management advice.

ii) Increased data quality/precision with respect to existing objectives could occur as a result of added information from the new objectives.

iii) Data time-series for existing objectives, e.g. assessment of a certain fish stock, can still be used in relation to the new time-series.

Organizational benefits:

i) Opportunity to optimize monitoring, such as modernizing existing sampling methodology by e.g. automation, continuous sampling, and/or use of new sampling equipment.

ii) Existing processes for coordination and delivery of data and advice are maintained, e.g. ship planning, personnel training, and on-board organization.

2.4.3 Risks

The risks of adding, and clearly prioritizing, new objectives to an existing monitoring programme include:

Data and knowledge risks:

i) Survey design might not be optimal/suitable for certain objectives, which may lead to loss in data quality/precision/quantity compared to data collection specifically designed for that one particular objective.

ii) Sampling methodology might be compromised for some objectives compared to sampling methodology specifically used for the one particular objective.

Organizational risks:

i) Flexibility to fulfil the sampling programme may decrease due to the existence of multiple objectives, e.g. in case of bad weather.

2.4.4 Specific points requiring attention

i) Adding new key objectives to the existing monitoring, while keeping existing objectives, requires discussion on their relative priority with existing and new end-users.

ii) For the new setup to be accepted, it is important to define at an early stage who is responsible for the implementation of the changes, and who makes the final decision on whether the design and objectives can be changed.

iii) If the change in survey objectives leads to a modified survey design, standardization with previous datasets or methods of calculation is required. This will enable analyses of temporal changes across the point in time when the survey design was altered.

2.5 Approach C: Add data collection to existing monitoring

Existing monitoring may provide room for additional data collection on specific topics without or with limited additional resources. In this manner, more information on the ecosystem component can be collected. The main difference with approach B is that in approach C the existing objectives will always be most important.

2.5.1 Reasons to choose (or not) this approach

Approach C may be the most cost-effective choice if the added data collection is compatible with the existing survey programme, and a review of the additional time, costs, and expertise required to include the new objectives indicates it is feasible.

This approach is especially valuable when (i) the main aspects of the survey design cannot be modified; (ii) optimal data collection for the new objectives can be achieved through the existing survey design; (iii) new objectives for the survey are only relevant during a limited period; or (iv) when no resources, in terms of e.g. time, money or people, are available to thoroughly evaluate the effect of a changed survey design on the current time-series (see Appendix table).

It is always valuable to improve the degree of ecosystem monitoring in the objectives of a survey, because it increases the scope of its relevance to ecosystem studies, and, thereby, the value of the survey as a monitoring tool.

Approach C is not recommended when the new objectives are long-term objectives that should be prioritized together with the original objectives.

2.5.2 Advantages

Approach C:

i) maintains the existing time-series. Since the additional data collection does not change the original survey, data use and analyses can be carried out as before;

ii) provides a good way to evaluate the benefits of collecting the additional data, and may facilitate transitioning the survey towards ecosystem monitoring in the longer term;

iii) improves the cost/benefit balance for the survey, because more data is collected during the survey; and

iv) can be implemented on short notice, especially when the new data collection can be achieved through extracting additional information from the original samples.

2.5.3 Risks

i) The priority level of the newly added data collection may be lower than meeting the original objectives. This can lead to lacking or incomplete data collection in case of delays, e.g. as a consequence of bad weather.

ii) The existing survey design may be suboptimal for the additional data collection, affecting the data analysis and/or the interpretation of results.

2.5.4 Specific points requiring attention

i) The added value of the additionally collected data must be defined. This is especially important when the sampling scheme is suboptimal or unsuited for the new parameters measured. When the added value is relatively low, it may be worthwhile to search for other solutions (e.g. external data sources, other monitoring activities) to collect information for the new objective.

ii) An evaluation should be carried out on whether the additional objectives result in an unacceptable risk to the likelihood of achieving the primary objectives.

iii) An assessment must be carried out on whether resources (e.g. time, money, and/or people) are already available to collect the additional information during the survey, or whether additional resources – and which type of resources – must be made available. Examples:

- If no additional financial resources are available for additional data collection, and it does not require additional sampling (such as stomach contents or finclips from fish caught in a survey), ensuring that sufficient time and personnel (e.g. volunteers, students) are available for additional data collection between sampling events may facilitate the data collection.
- When the newly added data collection requires additional sampling, a review of existing protocols may indicate potential opportunities to provide time without negatively affecting the existing objectives of the programme.

iv) It is important to review the constraints placed upon the survey, because the original objectives will be first priority, unless resources (e.g. money, ship time, personnel) become available for additional tasks.

3 Designing an ecosystem monitoring programme

Independently from which approach is chosen, some general topics should be considered when moving towards integrated ecosystem monitoring. First of all, communication with all parties involved is crucial throughout the process of development of or change to the ecosystem monitoring, including aspects such as setup, objectives and design. It is important that everyone involved, from scientists on-board until data end-users, understand the survey and/or monitoring programme, the reasoning behind the design, and the limitations for data use. Furthermore, clarity should be created on decision-making (Section 3.1), and integration and use of data (Section 3.2). All important features to consider are provided in the stepwise approach for integrated ecosystem monitoring (Section 3.3).

3.1 Decision-making

It should be clear to everyone involved in the process who has the responsibility to make the final decision, and in which form will the monitoring take place. Furthermore, the following responsibilities should be defined:

a) Who (authority, institute, or person) sets the priorities in the ecosystem monitoring?

b) Who decides in which form the ecosystem monitoring will take place, i.e. who decides which entry point is taken as the starting point in Figure 2.1?

c) Who should provide advice on the new or adapted integrated ecosystem monitoring programme, or the modified integrated ecosystem survey? Data users need to be involved in the agreement on the final plan. This is especially important if existing objectives should still be met when the suite of monitoring objectives and the survey design changes.

d) Who has the authority nationally, and, if relevant, internationally, to implement the changes to existing monitoring programmes or surveys with existing resource providers and end users?

3.2 Data integration and data use

A principal ambition of integrated ecosystem monitoring should always be that collected data can be integrated and easily combined. This requires arrangements for data storage and accessibility (e.g. do all parties involved have access to all monitoring data?), as well as consistency among data types (e.g. when different data types will be collected at one station, this should be easily retraceable).

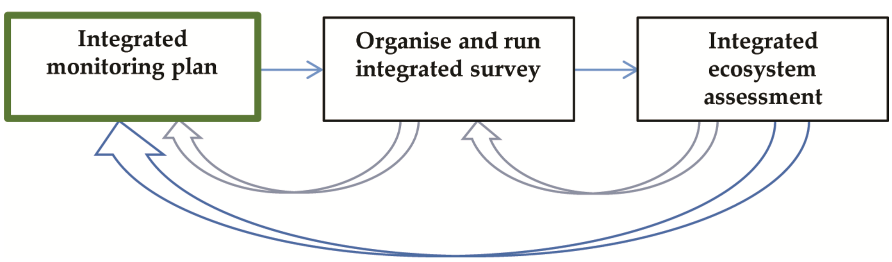

Figure 3.1. Process from monitoring plan to integrated ecosystem assessment (ICES. 2015). The squares represent the different steps in the process. The arrows indicate the feedback that is needed to align end-user needs and data collection.

To ensure ecosystem monitoring is fit for purpose, a link between data end-user and data providers should be established before the monitoring starts (Figure 3.1). Feedback on the usability of the data collected has to take place, as well as feedback on the operational aspects of the integrated surveys. Based on the feedback, the plan can be altered when needed.

3.3 Framework

Marine integrated ecosystem monitoring is in general carried out across a range of platforms. This includes surveys on-board vessels, stand-alone instruments (e.g. buoys, ROVs) and remote data collection (e.g. satellite data). Designing an integrated ecosystem monitoring survey or programme is complex, so it is important to follow a clear procedure when designing it. Figure 3.2 provides a stepwise approach that may serve as a starting point and can be adapted to specific needs. Each step in Figure 3.2 consists of three sections: the first (arrows) lists the steps to be conducted, the second (rectangles) lists the topics belonging to each step, and the third (clouds) contains aspects to consider when going through each step. It is recommended to follow the steps in order to achieve a logical order. The topics suggested in the steps can, however, be extended or decreased based on the specific situation. The suggestions in the clouds are not comprehensive, but mainly intended as a starting point for reflection. In Section 4, the framework has been elaborated for each of the three approaches.

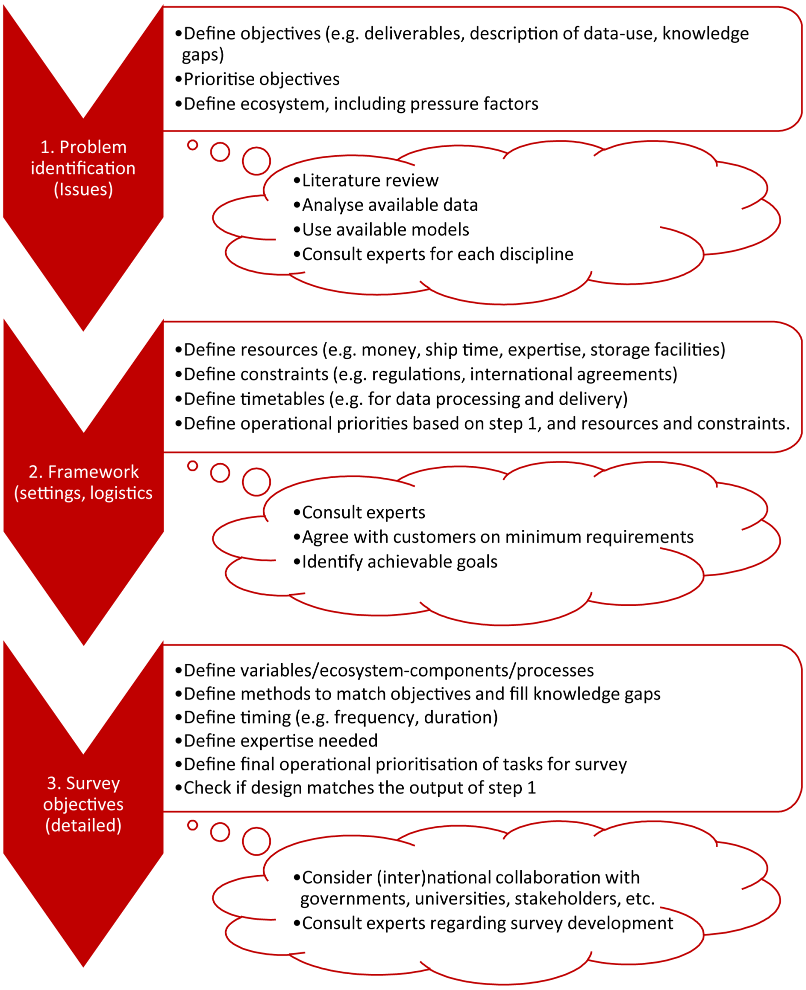

Figure 3.2 (part 1 of 2). Stepwise approach for the development of ecosystem monitoring (ICES, 2012a). Blue: at sea; red: desk.

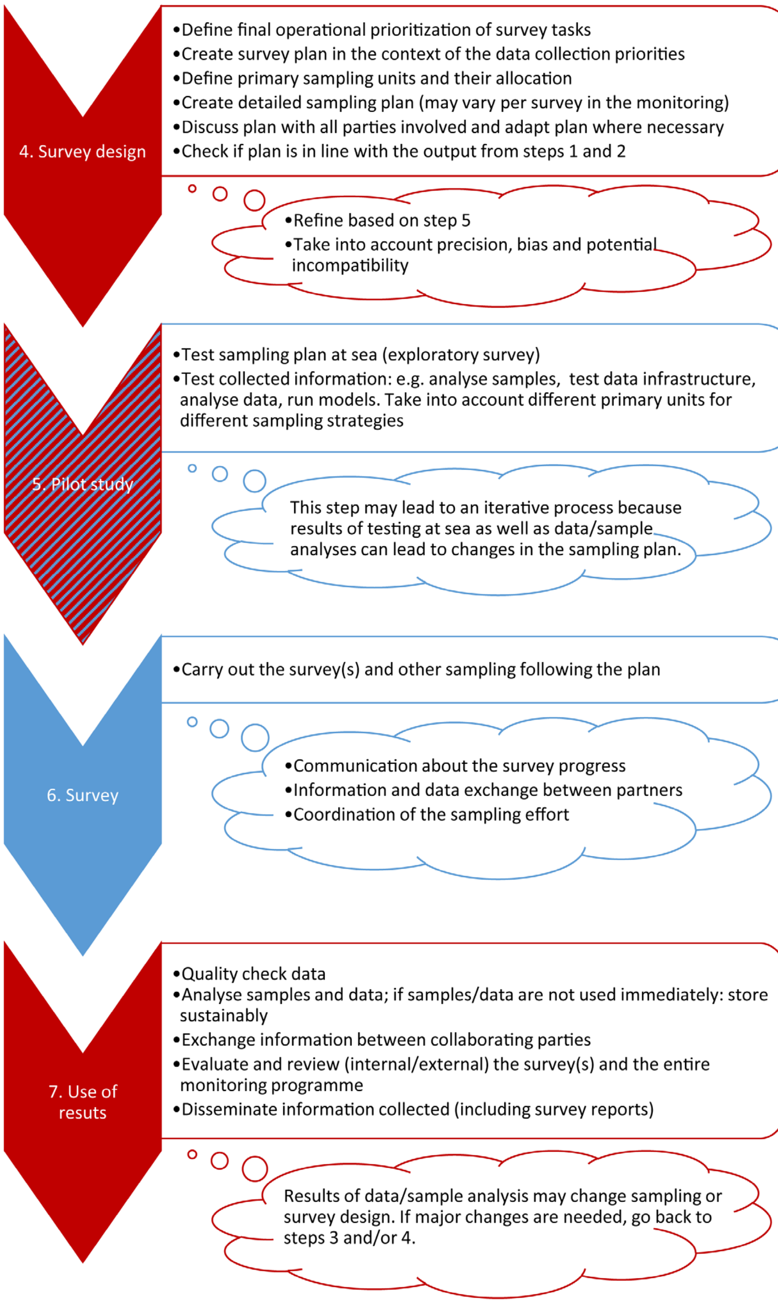

Figure 3.2 (part 2 of 2). Stepwise approach for the development of ecosystem monitoring (ICES, 2012a). Blue: at sea; red: desk.

4 Applying the framework

4.1 Approach A: Develop a new ecosystem monitoring programme

The following subsections cover each of the steps presented in Figure 3.2, considered specifically for the application of approach A.

4.1.1 Problem identification

This step is the most complicated in the preparation phase, and probably the most time-consuming. Creating a new ecosystem monitoring programme from the beginning requires input from various experts and buy-in from customers. The improved cooperation of ecosystem experts is beneficial later in the development of the programme.

The overall objective is to monitor the predefined ecosystem components and the important processes therein to supply information for marine management purposes. Although this high-level objective sounds simple, the detailed understanding of how this translates into an actual monitoring plan is considerably more complicated. Taking what is important in an ecosystem as a starting point presupposes that there is sufficient knowledge available on the ecosystem. Analyses, or even studies, have to take place on how the ecosystem components interact, in order to define the components to be monitored and the data collection needs.

Determining appropriate prioritizations for monitoring and detailed objectives is not possible at this step, at the level of the data end-user. High-level (advice customer) buy-in on the principles of the approach, and acceptance of the associated risks, are essential to the successful development of integrated monitoring programmes. A detailed and convincing analysis of available data, despite its current weaknesses in integration, is vital.

4.1.2 Monitoring infrastructures

The most restrictive infrastructure may be resources (e.g. financial resources or ship time). Furthermore, it is likely that appropriate data storage structures and facilities will need to be developed to ease the integrated data use and get the most out of the approach.

Organizational infrastructures can often be based on current monitoring coordination infrastructures. Existing technical expertise can be used to implement ecosystem monitoring programmes.

4.1.3 Monitoring objectives

This step encompasses setting the objectives for the entire monitoring programme. It mainly involves decisions on the practical implementation, such as defining data collection on stand-alone platforms (e.g. buoys, ROVs), choosing specific gears, or defining spatial and temporal units. Furthermore, this step includes the identification of processes that cannot be effectively monitored by stand-alone platforms and have to be monitored from a vessel.

Special consideration should be given to ensuring that manned surveys using vessels provide the link among the various data collections on less flexible platforms. The main considerations while planning are logistic constraints (ICES. 2012b), and selecting the appropriate methodologies and platforms for providing data for the ecosystem monitoring programme.

4.1.4 Survey design

The ecologically relevant areas and periods determined in Section 4.1.1 provide a good starting point for the survey design. Resource constraints and survey objectives provide rough estimates of the sampling levels that can be achieved. Based on this, a decision is made on the most appropriate monitoring programme design and the design of each survey considering variances and biases.

4.1.5 Pilot study

Operational implementations should be tested on a smaller scale as a pilot study, including the use of multiple devices next to each other on the same platform. Furthermore, the feasibility of integrating data from different sources should be tested, as it is a crucial aspect for the success of the monitoring programme. The pilot study step can be approached as an iterative process, with testing phases at sea, onshore evaluation and data use. It is recommended to only commence with the real fieldwork once the pilot phase has reached satisfactory outcomes.

Specific attention should be given to dealing with unforeseen circumstances. As a result of the monitoring complexity, the consequences of decisions made at sea at the monitoring task level are difficult to interpret at the assessment level. In the pilot phase, those circumstances can be simulated to investigate if the scientist in charge at sea has sufficient insight into the consequences of any decisions taken.

4.1.6 Conducting the surveys

Conducting the surveys according to the plan is relatively straightforward under ideal circumstances. However, the multidisciplinary nature of an integrated monitoring programme increases logistic complexity during surveys, particularly with regard to potential weather impacts. In order to optimize data delivery when the survey cannot be carried out according to plan, it is important that the scientist in charge has insight into, or direct access to, information on the presumed data use. Furthermore, onshore "sparring partners" for the scientist in charge are recommended.

4.1.7 Use of results

Along with the problem identification (Section 4.1.1), this is the most effort-intensive part of the development of approach A. First of all, the data have to be used in the integrated assessment that is developed alongside the monitoring plan. Furthermore both the monitoring programme and the assessment need to be evaluated with respect to their contribution to the understanding of the ecosystem. If no additional value can be discovered, then the monitoring programme should be modified. This may also be the case after a number of years monitoring, when sufficient information is available about specific processes. In this concrete case, new objectives may be set that will increase the added value of the monitoring programme.

The integrated monitoring approach reaches its performance pinnacle when everything about the ecosystem is known. As long as only some information is available, the monitoring will change in the future when current knowledge gaps have been filled and other knowledge gaps become more prominent.

4.2 Approach B: Addition of new objectives to current monitoring

The following subsections cover each of the steps presented in Figure 3.2, considered specifically for the application of approach B.

4.2.1 Problem identification

As an existing monitoring programme is used as a starting point, it is recommended that it is thoroughly evaluated. First of all, this gives insight into the extent to which the programme still fulfils its purpose, and second, it becomes clear where room for adaptation lies. During the evaluation, consider the following aspects: (i) is there still a need to fulfil existing objectives? (ii) does the existing monitoring cover the needs of the existing objectives? (e.g. which time-series are used for management purposes), (iii) has existing data use reached its full potential? (iv) can data collection be changed without losing information for the existing end-users? (e.g. based on knowledge of ecosystem processes), and (v) are there any data gaps for meeting the existing objectives?

Following this analysis, the overall objective for the adapted monitoring programme should be defined, based on the predefined ecosystem, the management purposes it will deliver information to, and the end-users. This may be done extensively, in line with the process for the development of a new ecosystem monitoring programme (see Section 4.1.1), or through a more pragmatic approach, e.g. based on data needs for new marine management purposes. Independently of the route chosen, every effort should be made to ensure the combination of objectives adds value to the investigation of the ecosystem.

The need for specific new objectives will arise from combining existing objectives with the overall objective. It may well be that parts of the existing programme already meet these new objectives at least partly, e.g. through reanalysis of existing data. Data end-users can be asked to provide information on the required data quality for existing and new objectives. In many cases, no clear targets will exist yet for the required quality or precision of the survey estimates.

Communication on, and insight into the changes carried out to the setup of the monitoring programme are important aspects in this phase. Clearly defining priorities is a joint responsibility for both users employing the data in existing models, and users responsible for marine management, e.g. ministries may be involved in this phase. End-users and survey scientists should agree together on the prioritization of the objectives to ensure useful data delivery under all circumstances. As marine monitoring programmes are vulnerable to adverse weather conditions and technical issues, research priorities should be clear beforehand.

It is recommended that the changes in the monitoring programme are also explained to third parties that indirectly depend on the results at this or a later stage, e.g. fishers or NGOs.

4.2.2 Monitoring infrastructures

Since some or all of the existing objectives will be kept, fixed elements must first be listed, i.e. those that are defined by the primary objectives. These generally include the timing, frequency, spatial coverage of the sampling, and the sampling equipment. Next, the elements that may be modified should be specified, such as survey duration, spatial coverage, and monitoring platform (research vessel, satellite, etc.).

Further, it may be worth investigating whether any ongoing data collection exists by national or international parties not involved in the monitoring, and, if so, whether collaborations can be set up or improved. This may lead to additional resources and/or shifts in tasks by the different parties, depending on available facilities and capacities.

If no additional resources become available, existing resources will dictate the newly designed monitoring programme or survey. On the one hand, this restriction may feel like a burden; but, on the other hand, a clear financial framework may facilitate the prioritization process.

The resources needed to fulfil the data collection for the objectives include, at least, ship time, on-board capacity, financial costs, and the personnel needed for the work at sea, as well as prior to and after the survey (sample and data processing). The at-sea and onshore available sample and data storage should also be taken into account. Table 4.1 provides an example format to obtain insights into the different required resources.

Table 4.1 Template for checking requirements for data collection for new objectives or for new sampling types

Sampling type/objective:			
	Before survey (preparation)	**During survey**	**After survey**
Sampling equipment			
Analytical instruments			
Analysis software			
Preservatives			
Data storage facilities			
Sample storage facilities			
Laboratory facilities			
Personnel			
Expertise			
Skills			
Ship time			
Permit/s for sampling activity			

Overall, to develop a realistic monitoring plan operational priorities must be defined based on the objectives and available resources, and in collaboration with data end-users and sea-going experts.

4.2.3 Monitoring objectives

More detailed plans can be developed once the monitoring objectives and the resources are established. An important step is identification of the appropriate sampling methods and/or instruments to achieve the objectives. This should include an evaluation on whether the selected instruments or sampling methods can be combined in practice. For example, if two fishing gears require the same winches for operation, it should be checked whether shifting between gears is possible at sea, and what amount of time the change requires. Planning may also include decisions on the time of day when certain types of sampling should or could take place, or whether sampling can take place through e.g. a continuous sampler or on a remote platform. Possible synergies between currently unlinked monitoring efforts should also be identified by checking the coherence of operational objectives throughout the monitoring programme (e.g. surveys and other observation platforms).

An inventory should be carried out of the expertise, and if possible, the specific experts, needed to: collect the data at sea; process samples and data, especially with respect to the newly added objectives; provide insights into the finances needed to run the monitoring; and ensure that the monitoring data will be collected and processed in time.

As marine monitoring is vulnerable to adverse weather conditions and technical issues, defining the minimum requirements for survey deliverables will help decision-making while at sea. Furthermore, a method to prioritize activities under a range of conditions will be helpful to support decision-making (e.g. what can be dropped).

Finally, discussions at an early stage on data exchange (standard formats, timing, quantity, aggregation level, etc.) is important in order to optimize combining the results, especially when multiple parties are involved. This also includes appointments regarding maintenance, accessibility, data security, quality assurance, and quality checks. It is advised that the institution responsible for the data acquisition is primarily responsible for safe and durable storage, and quality checking.

4.2.4 Survey design

Concrete survey plans must be created that accommodate the new objectives into all surveys in the monitoring programme. Together, the survey plans form the monitoring plan. Communication on the full monitoring plan with all parties involved is crucial, especially the data collectors and end-users. In addition, the decision-making tool in case of unforeseen circumstances can be discussed. If necessary, adapt the plans until an agreement is reached.

4.2.5 Pilot study

A pilot study is a relatively inexpensive and effective method to investigate if the final monitoring plan can be carried out and leads to the required deliverables.

The pilot should, at least, include the processing of the samples and/or the data collected for the new objectives by means of the changed methodology (i.e. sample analysis, data analysis, and running the models). If multiple parties are involved, data exchange should also be tested during this phase.

The pilot may further consist of operational tests, such as running two gears simultaneously or after each other, or simulations of situations that could lead to potential constraints in carrying out the monitoring in order to test the decision-making on priorities.

As an alternative for the pilot study, the original survey design could be kept and put on trial to test its validity for the new design. This allows for comparison of the existing and the new designs and, where needed, intercalibration.

4.2.6 Conducting the survey/s

When the pilot has been successful, carrying out the redesigned surveys according to plan should be possible.

4.2.7 Use of results

In approach B, it is expected that the use of results for the existing objectives does not change. For the data supporting the new objectives the data calculation procedures have to be put into practice based on experiences from the pilot study.

For data related to the original objectives that have been collected in a different manner than before, an evaluation should be carried out on whether the redesigned programme meets all objectives. Results should be compared to those from the previous programme or time-series (precision, etc.), and revisions should be carried out if appropriate.

Continuous evaluation of the adapted monitoring programme is always recommended in order to improve monitoring. This should involve all parties and key persons, and assess factors such as practical feasibility, organization of on-board operations, further training needs, and available resources.

4.3 Approach C: Add data collection to existing monitoring

The following subsections cover each of the steps presented in Figure 3.2, considered specifically for the application of approach C. In contrast to approaches A and B, for approach C data collection is added to specific surveys and not to a wider monitoring programme (see Box 1 for definitions).

4.3.1 Problem Identification

Adding new objectives can improve the degree to which surveys contribute to ecosystem monitoring. In this scenario, the original survey objectives are defined and accepted, and should be treated as first priority. Increasing the scope of the survey towards ecosystem studies may however add value as a monitoring tool.

When a concrete request for additional data collection exists, it should be investigated whether the objective can be met without affecting existing objectives. If an additional objective requires additional vessel time or alterations to the cruise track, these additions should be reviewed as outlined for the redesign of sampling programmes (see approaches A and B in sections 4.1 and 4.2). If the added task can be carried out during the existing survey, the review simply needs to assess the time required in relation to available vessel time.

When no concrete request for additional data collection is made, but there is a strong wish to increase the degree of ecosystem monitoring, knowledge gaps that could be addressed during the survey should be identified. The additional objectives should be assessed in relation to the ecosystem monitoring goals.

4.3.2 Monitoring infrastructures

The existing survey setup will be applied to the new objective/s or task/s, as those will have a lower priority than the original objectives. Therefore, it is crucial to first define available opportunities for additional monitoring requirements within the existing survey, e.g. by a review of the current survey. If opportunities are available, an inventory should be made of personnel, expertise, time, and money needed for the additional data collection (template in Table 4.1; examples in Section 5.3). This is best done based on experience, either in-house or by asking for advice from external partners. If no information is available in the network, e.g. because it is a newly developed sampling methodology, searching for information on comparable sampling types can be helpful.

Depending on the available additional resources, in terms of funding or other forms of support, one or multiple new objectives or tasks may be feasible. However, only those activities that can be accomplished within the existing financial, personnel, and logistic frameworks should be considered.

4.3.3 Monitoring objectives

Since the original objectives remain as first-level priorities, logistic plans for new (second-level) sampling activities need to be developed. This requires an overview of the expertise needed to accomplish them. The plan will be an operational prioritization of all –existing and additional– tasks in the survey. Depending on the type of additional resources needed, the priority of additional objectives may differ.

For example:

- When a student joins a survey to carry out stomach sampling of fish in the catch, the sampling can be carried out whenever a fish trawl comes in. It is thus highly likely that the planned sampling will be achieved. However, it should be considered that stomach sampling needs to be done within a limited amount of time after the haul comes on-board. Therefore, this second priority task can only be fulfilled if the sorting of the catch is done in time, and if the student is not needed for any of the tasks related to the primary objectives.
- If the stomach sampling work of the student only focused on a specific fish species, the sampling plan might not be fulfilled if additional fishing activities cannot be scheduled.

4.3.4 Survey design

The general survey design will already be in place. However, the detailed sampling plan should be reviewed to ensure that the additional tasks are included, and that they do not jeopardize the primary goals of the survey.

4.3.5 Pilot study

When considering approach C, in most situations no time or resources will be available or needed for a pilot study. Therefore, it is recommended that either proven techniques are used for the additional sampling, or that new techniques are tested by e.g. using the first sampling year for a new variable as a pilot.

4.3.6 Conducting the survey/s

Operational practicalities need to be assessed when undertaking new sampling during the survey, with focus on integrating new gears, sample processing, and differences in time schedule. If necessary, the methodology employed or the prioritization of the new objectives should be reassessed.

4.3.7 Use of results

After the first survey, it is important to review the impact the new sampling may have had on the performance of the survey in addressing its primary objectives, and its success in collecting data for the additional task. The sampling can be considered successful if (a) it has had no detrimental impact on the original survey objectives, and (b) completion of the additional tasks is considered to be feasible and delivers useful information.

An evaluation should be carried out on whether the results meet the requirements of the new objectives. If samples or data are not immediately used, it must be ensured that proper storage is available and that plans are in place to make use of the samples/information, before continuing collection in the future.

If relevant, the prioritization of additional sampling objectives should be evaluated, in view of determining whether it could be feasible to address more additional objectives from the list of priorities.

If the addition has been a success, including the new task/s or objective/s to the primary objectives of the survey can be considered. If this happens, the new set of primary objectives should be reviewed to determine how to achieve the survey goals if some cutback is required. If the new objective/s or task/s will remain as a secondary goal, then the level of priority should be made clear.

5 Examples of practical application

5.1 Approach A: New ecosystem monitoring programme

As the wish for ecosystem monitoring programmes has arisen relatively recently, there is limited information on the developments of such programmes.

- In 2012, an evaluation of ecosystem surveys was carried out by the ICES Workshop Evaluation of current ecosystem surveys (WKECES; ICES, 2012b). The report presents the strengths and weaknesses for a number of surveys in different European ecoregions.
- For the Barents Sea, a survey-based ecosystem monitoring programme is under development (Eriksen and Gjøsæter, 2013). This is a monitoring programme defined as a set of ecosystem surveys covering different objectives per survey.

5.2 Approach B: Addition of new objectives to current monitoring

Although this approach is likely applied quite often in marine monitoring, specific documentation is not easily available on the process of implementing a new objective/s to existing monitoring. The list provided in this paragraph mainly contains of scenario studies that have not yet been fully implemented.

- In 2016, a first exercise was carried out in the ICES Workshop to Plan an Integrated Monitoring Programme in the North Sea in Q3 (WKPIMP: ICES, 2016) to investigate the possibilities for changing the regular International Bottom Trawl Survey (IBTS) in the third quarter into the first component of an ecosystem monitoring programme. Although not carried out yet, this report gives an idea of potential approaches, shows the steps to be taken, and demonstrates where gaps can occur in such a transition. WGISUR reviewed the outcomes of that workshop in 2017, highlighting room for improvement (ICES, 2017). In spring 2019 a follow-up of this workshop will take place.
- In 2014–2015, three EU-funded projects (BALSAM, JMP NS/CS, and IRIS-SES) were carried out. The scenarios studied in these projects followed the approach of optimizing current monitoring, keeping current objectives, and in some cases adding new objectives (Shepherd *et al*., 2015).

In some cases it is necessary to keep an existing time-series but there is no room for it in the new design. Under these circumstances, in internationally coordinated surveys, a number of countries could continue the survey as is, while others countries could start the new ecosystem monitoring. After a given period of time, the parallel time-series can then be compared and potentially translated into each other.

5.3 Approach C: Add data collection to existing monitoring

Concrete examples for this approach are widely available, and some are listed below. As this approach is always carried out on top of existing monitoring, it is important to have a good insight into the additional requirements before, during, and after the survey. A table with standard topics that should be checked before deciding if the additional sampling can take place during the existing survey has been developed (Table 4.1). This table is meant as an inventory of the additional resources needed to accomplish the additional task/s. As a demonstration, the table has been filled out for all examples below (tables 5.1, 5.2, 5.3 and 5.4). An inventory of the additional resources for more tasks than those mentioned below is available in the Annex table (based on ICES, 2010).

5.3.1 Marine litter during IBTS

Litter from the catch of the standard fish trawl used in the IBTS, the GOV, is being collected, sorted, identified, and measured during the IBTS in the North Sea, as part of data collection for the European Marine Strategy Framework Directive (MSFD).

The data collection started as a pilot, but during the implementation phase of the MSFD, funding from national governments became available in France, the Netherlands, and England. As a result, this data collection is now one of the survey objectives at an international level, and is part of the IBTS survey manual. It requires no extra sampling, but does need some extra manpower on-board. Knowledge on the transfer of the litter data to the ICES trawl survey database (DATRAS) had to be made available to the institutes involved.

Table 5.1. Additional requirements for litter data collection from fish trawl hauls.

Sampling type/objective: Litter from fish trawl			
	Before survey (preparation)	**During survey**	**After survey**
Sampling equipment	-	Compact camera	-
Analytical instruments	-	-	-
Analysis software	-	-	-
Preservatives	-	-	-
Data storage facilities	-	Pictures	Sustainable storage of pictures and data
Sample storage facilities	-	-	-
Laboratory facilities	-	-	-
Personnel	-	Additional effort for sorting and identification of litter and taking pictures (< 1 person)	Data transmission to ICES database DATRAS
Expertise	Preparing guidelines	-	Knowledge of data format for ICES database
Skills	-	-	Data conversion from input sheet to DATRAS format
Ship time	-	-	-
Permit/s for sampling activity	-	-	-

5.3.2 Two-meter beam trawl sampling during North Sea IBTS and BTS

For the EU project Managing Fisheries to Conserve Groundfish and Benthic Invertebrate Species Diversity (MAFCONS, 2003–2006) and its predecessor, the EU project Monitoring Biodiversity (1999–2000), additional samples were collected using a two-meter beam trawl (both projects) and a grab (MAFCONS) to collect benthic epifauna and infauna, respectively, during the Q3 North Sea IBTS and the Dutch North Sea Beam Trawl Survey (BTS). Additional personnel and approximately a week of additional ship time was funded via these projects to complete the task.

Sampling, with the regular fishing gear and the additional gear/s for the EU projects, was carried out at the location of a standard survey trawl, because information on the fish and benthic communities obtained from the different gears had to be combined in the data analyses to create the best possible overview of species indicators (e.g. species richness, biodiversity).

The time-loss caused by adding activities on a trawl station was compensated by funding some additional ship time. The full survey could be carried out, including additional objectives, for a relatively low additional budget.

Table 5.2. Additional requirements for additional two-meter beam trawl sampling during the IBTS or Dutch (or international) Beam Trawl Survey.

Sampling type / objective: two-meter beam trawl sampling during beam trawl survey			
	Before survey (preparation)	**During survey**	**After survey**
Sampling equipment	-	two-meter beam trawl, sieve	-
Analytical instruments	-	Microscope	-
Analysis software	-	-	-
Preservatives	-	Ethanol for storing rare or unknown species	-
Data storage facilities	-	Data files	Durable storage of data collected
Sample storage facilities	-	Rare and/or unknown species in jar	Rare and/or unknown species in jar
Laboratory facilities	-	Place to work safely with ethanol	Place to work safely with ethanol
Personnel	-	Sorting catch, identification of species	Identification of unknown/difficult species
Expertise	Preparing guidelines	Small epifauna species	Small epifauna species
Skills	-	Species identification (use of dichotomous keys)	Species identification (use of dichotomous keys)
Ship time	-	Depending on the amount of samples	-
Permit/s for sampling activity	Yes, bottom disturbing activity	-	-

5.3.3 Additional plankton sampling during North Sea IBTS MIK

During the Q1 North Sea IBTS, sampling for larvae from winter-spawned herring was added to the traditional sampling for autumn-spawned herring larvae with the Mid-water Ringnet (MIK net). To catch the smaller winter spawned larvae, an additional net was placed on the MIK net (so-called MIKey-M net; van Damme *et al.*, 2014). The sampling in itself did not require extra resources, but financial resources were needed for the analysis in the lab after the survey.

Table 5.3. Additional requirements for MIKey sampling during IBTS.

Sampling type / objective: MIKey-M on MIK net			
	Before survey (preparation)	**During survey**	**After survey**
Sampling equipment	-	MIKey net	-
Analytical instruments	-	-	-
Analysis software	-	-	-
Preservatives	-	Formaldehyde	-
Data storage facilities	-	-	Durable storage of data
Sample storage facilities	-	All preserved samples	All preserved samples for at least 5 years
Laboratory facilities	-	Place to work safely with formaldehyde	Place to work safely with formaldehyde
Personnel	-	-	Sorting samples and identification of species
Expertise	Preparing guidelines	-	Small fish larvae
Skills	-	-	Identification of small fish larvae
Ship time	-	-	-
Permit for sampling activity	-	-	-

5.3.4 Multibeam hydroacoustic data collection during fish trawl surveys

The installation of a dropkeel on the Dutch RV "Tridens II" created the possibility for multibeam data collection during fish trawl surveys. In 2016, multibeam data were collected during the Dutch North Sea BTS. This required increased data processing thereafter, and storage of large amounts of data on-board as well as ashore. No extra resources were needed for the data collection itself, but additional funding was required for the data processing.

Table 5.4. Additional requirements for the collection of multibeam data during the 2016 Dutch North Sea BTS.

Sampling type / objective: Collecting multibeam data during non-acoustic surveys			
	Before survey (preparation)	**During survey**	**After survey**
Sampling equipment	-	Multibeam	Computer including processing software and license
Analytical instruments	-	-	Computer to process data
Analysis software	-	-	Processing software, including license
Preservatives	-	-	-
Data storage facilities	-	Storage of large amounts of data	Durable storage for large amounts of data
Sample storage facilities	-	-	-
Laboratory facilities	-	-	-
Personnel	-	-	Processing and analysis of raw data
Expertise	Preparing guidelines	-	-
Skills	-	-	Data analysis of multibeam data
Ship time	-	-	-
Permit for sampling activity	-	-	-

6 Conclusion

Moving towards ecosystem monitoring can take place based on three different approaches:

a) starting ecosystem monitoring from the very beginning;

b) redesigning existing monitoring by combining new objectives with existing objectives; or

c) adding data collection to existing monitoring without changing the design.

The approaches are not mutually exclusive but should be considered as the starting point for the change towards ecosystem monitoring. There is no "good" or "bad" choice as to where to start when moving towards integrated ecosystem monitoring, but there is always a "most suitable" approach.

The most suitable way forward depends heavily on the current local situation, and the specific needs for long-term data collection required for the changed marine management insights or regulations. Other important factors are the time available for development or adaptation of monitoring, and the available resources (e.g. vessels, remote instruments, money, time, and expertise).

Independently of the starting point, there is a fair chance that the monitoring will keep on developing. Initially, added tasks may become monitoring objectives with equal importance to the original ones. The addition and reprioritization of objectives may deliver ecosystem information needed to move towards (more) integrated ecosystem monitoring. Fully integrated ecosystem monitoring is flexible by nature, and so, its setup may change based on new insights.

In all cases, it is recommended that a systematic approach is taken during monitoring development. Doing so decreases the chances of overlooking important aspects or people. The described framework provides guidance for a systematic approach and includes the major important steps. However these guidelines can be altered for specific situations.

The level of practical experience for the implementation of the different approaches towards integrated ecosystem monitoring highly varies. The design of marine ecosystem monitoring programmes only started recently, as a consequence of an increase in data requirements for marine ecosystem assessment. As a result, a relatively high level of experience exists for the most pragmatic approach (approach C), but there is limited experience in developing a new fully integrated ecosystem monitoring programme (approach A). As the data requirements for marine ecosystem assessment and management become clearer, more experience will be built up regarding the development of ecosystem monitoring programmes.

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9 Appendix: Inventory of resources needed for additional tasks during fish-related surveys (after ICES, 2010)

The following appendix table is split into four parts: part 1 details the tasks, the priority assigned to them by ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO, adjusted) and ICES Working Group on Operational Oceanographic Products for Fisheries and Environments (WGOOFE), and the EU Marine Strategy Framework Directive (MSFD) descriptor they relate to (details can be seen in the repective caption); part 2 details the type of fisheries survey and additional equipment required in preparation for the survey; part 3 describes additional skills, personnel, shiptime and facilities reaquired for each task during the survey; and part 4 details all requirements needed for each task after the survey.

Table A1 (part 1 of 4). Survey tasks, the priority assigned to them, and the MSFD descriptor they relate to. MSFD descriptors: 1 – biodiversity, 2 – non-indigenous species, 3 – commercial fish and shellfish, 4 – food webs, 5 – eutrophication, 6 – sea-floor integrity, 7 – hydrographical conditions, 8 – contaminants, 9 – contaminants in seafood, 10 – marine litter, 11 – energy incl. underwater noise.

	MSFD descriptor											Priority assessed by Strategic groups	
Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**WGECO**	**WGOOFE**
Fish and shellfish (survey specific)													
Organism collection (e.g. for contaminants, fatty acids analysis etc.)	x	x	x	x				x	x			1	
Stomach sampling	x		x	x								3	
Additional biological data (e.g. isotopes, liver/gonad weight, otoliths, scales, fin-rays, length-weight data of other than standard species)	x	x	x	x				x				3	
Disease/parasite registration	x	x	x		x			x	x			2	
Genetic information	x		x									2	
Lipid content				x								2	
Sonar observations pelagic fish			x									1	
Tagging			x									2	
Bioactive materials in marine species (e.g. for medical purposes)												1	
Echosounder observations pelagic fish	x	x	x										
Other sampling of fish/shellfish not taken in main gear	x	x		x									
Physical and chemical oceanography (e.g. CTD, chlorophyll, oxygen, nutrients, turbidity, etc.)													
Continuous underway oceanographic measurements (from the ship)							x					2	3
Station oceanographic measurements							x					1	3
Continuous underway oceanographic measurements (autonomous devices)							x					1	3
Water movement							x					1	3

Table A.1 – part 1 (continued)	**MSFD descriptor**											**Priority assessed by Strategic groups**	
Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**WGECO**	**WGOOFE**
Station nutrient samples					x							2	3
Biological oceanography													
Station microbiological samples	x	x	x	x				x				2	2
Station phytoplankton samples	x	x	x	x	x			x				3	1
Continuous phytoplankton samples	x	x	x	x	x			x				3	3
Station zooplankton samples (towed)	x	x	x	x				x				3	3
Station zooplankton samples (dipped)	x	x	x	x				x				3	3
Continuous zooplankton samples	x	x	x	x				x				2	3
Gelatinous zooplankton samples	x	x	x	x									
Invertebrates													
Infauna	x	x		x		x						3	
Epifauna (towed)	x	x		x		x						3	
Epifauna (video)	x	x		x		x						3	
Pelagic	x	x		x								3	
Megafauna													
ESAS sampling (birds, sea mammals)	x	x		x								3	
Towed hydrophones	x	x		x								1	
Habitat description													
Camera (towed/dropped)	x	x				x						3	
Side-scan sonar	x					x						3	
Multi beam echosounder	x					x						3	
Ground truthing	x					x						2	
Pollution													
Floating litter										x		2	
Sinking litter										x		3	
Pollution in the water column								x	x	x		2	
Pollution in the sediment								x	x	x		2	
Pollution in organisms								x	x	x		2	
Environmental conditions													
Weather conditions							x					1	3
Sea state							x					1	3

Table A1 (part 2 of 4). Type of fisheries survey used to collect data for each task and additional equipment required in preparation for the survey.

Task	Fisheries survey for data collection	Survey preparation
		Additional equipment
Fish and shellfish (survey specific)		
Organism collection (e.g. for contaminants, fatty acids analysis etc.)	trawl, acoustic and ichthyoplankon	no
Stomach sampling	trawl, acoustic and ichthyoplankon	no
Additional biological data (e.g. isotopes, liver/gonad weight, otoliths, scales, fin-rays, length-weight data of other than standard species)	trawl, acoustic and ichthyoplankon	no
Disease/parasite registration	trawl, acoustic and ichthyoplankon	no
Genetic information	trawl, acoustic and ichthyoplankon	sampling equipment, ethanol
Lipid content	trawl, acoustic and ichthyoplankon	Fat meter; calibation series for the species should be available
Sonar observations pelagic fish	all	scientific sonar
Tagging	trawl, acoustic and ichthyoplankon	Tags and fish handling
Bioactive materials in marine species (e.g. for medical purposes)	trawl, acoustic and ichthyoplankon	no
Echosounder observations pelagic fish	all	no
Other sampling of fish/shellfish not taken in main gear	trawl, acoustic and ichthyoplankon	Alternative appropriate gear
Physical and chemical oceanography (e.g. CTD, chlorophyll, oxygen, nutrients, turbidity, etc.)		
Continuous underway oceanographic measurements (from the ship)	all	dependent on variables being collected
Station oceanographic measurements	all	dependent on variables being collected
Continuous underway oceanographic measurements (autonomous devices)	all	dependent on variables being collected
Water movement	all	ADCP
Station nutrient samples	all	Water sampler

Table A1 – part 2 (continued)

Tasks	Fisheries survey for data collection	Survey preparation – additional equipment
Biological oceanography		
Station microbiological samples	all	Water sampler
Station phytoplankton samples	all	Water sampler
Continuous phytoplankton samples	all	CPR/fluorometer
Station zooplankton samples (towed)	all	Towed samplers
Station zooplankton samples (dipped)	all	Dipped samplers
Continuous zooplankton samples	all	CPR
Gelatinous zooplankton samples	all	Various plankton nets towed/hauled slowly
Invertebrates		
Infauna	all	Grab/corer, sieve
Epifauna (towed)	all	Beam trawl/dredge/sledge/bottom trawl
Epifauna (video)	all	Video
Pelagic	all	Trawl, seines and plankton nets
Megafauna		
ESAS sampling (birds, sea mammals)	all	binoculars
Towed hydrophones	all	Towed hydrophone
Habitat description		
Camera (towed/dropped)	all	Towed/dropped camera
Side-scan sonar	all	Side-scan sonar
Multi beam echosounder	all	Multi beam echosounder

Table A1 – part 2 (continued)

Tasks	**Fisheries survey for data collection**	**Survey preparation – additional equipment**
Ground truthing	all	Grab/corer, sieve
Pollution		
Floating litter	all	no
Sinking litter	trawl and tv/video	no
Pollution in the water column	all	dependent on variables being collected
Pollution in the sediment	all	Grab/corer
Pollution in organisms	trawl, acoustic and ichthyoplankon	Selected gear appropriate for sampling the study organism
Environmental conditions		
Weather conditions	all	no
Sea state	all	no

Table A1 (part 3 of 4). Additional requirements for each task during the survey.

Task	During survey – additional requirements			
	Skills	Personnel	Shiptime	Facilities
Fish and shellfish (survey specific)				
Organism collection (e.g. for contaminants, fatty acids analysis etc.)	no	dependent on the amount of samples	no	sample storage
Stomach sampling	no	yes	dependent on the amount of samples	preservation facilities, sample storage
Additional biological data (e.g. isotopes, liver/gonad weight, otoliths, scales, fin-rays, length-weight data of other than standard species)	dependent on sampling type additional skills might be required	dependent on the amount of samples	no	no
Disease/parasite registration	knowledge of fish diseases/parasites	dependent on the amount of samples	dependent on the amount of samples	dependent on data request: preservation facilities, sample storage
Genetic information	training required to prevent cross-contamination	dependent on the amount of samples	no	dependent on data request: preservation facilities, sample storage
Lipid content	skills for operation of the device	dependent on the amount of samples	no	dependent on data request: preservation facilities, sample storage
Sonar observations pelagic fish	skills for operation of the device	dependent on variables being collected	no	data storage, synchronisation unit

Table A1 – part 3 (continued)

Task	**Skills**	**Personnel**	**Shiptime**	**Facilities**
Tagging	tagging skills	dependent on the amount of samples	dependent on the amount of samples	fish handling facilities
Bioactive materials in marine species (e.g. for medical purposes)	no	dependent on the amount of samples	no	preservation facilities, sample storage
Echosounder observations pelagic fish	no	dependent on variables being collected	yes (equipment calibration)	data storage, synchronisation unit
Other sampling of fish/shellfish not taken in main gear	no	dependent on variables being collected	dependent on the amount of samples	preservation facilities, sample storage
Physical and chemical oceanography (e.g. CTD, chlorophyll, oxygen, nutrients, turbidity, etc.)				
Continuous underway oceanographic measurements (from the ship)	skills for operation of the device	dependent on variables being collected	no	dependent on the device used, pumped clean seawater supply
Station oceanographic measurements	skills for operation of the device	dependent on variables being collected	yes (deploy/recover)	dependent on the device used
Continuous underway oceanographic measurements (autonomous devices)	skills for operation of the device	operation of the device	yes (deploy/recover)	no
Water movement	skills for operation and analysis	no	no	no
Station nutrient samples	skills for operation of the device	no	yes (deploy/recover)	no

Table A1 – part 3 (continued)

Task	Skills	Personnel	Shiptime	Facilities
Biological oceanography				
Station microbiological samples	skills for operation of the device	yes	yes (deploy/re-cover)	lab facilities, preser-vation facilities
Station phytoplankton samples	skills for operation of the device	yes	yes (deploy/re-cover)	preservation and storage facilities
Continuous phytoplankton samples	skills for operation of the device	yes	yes (deploy/re-cover)	preservation and storage facilities
Station zooplankton samples (towed)	skills for operation of the device	yes	yes (deploy/re-cover)	preservation and storage facilities
Station zooplankton samples (dipped)	skills for operation of the device	yes	yes (deploy/re-cover)	preservation and storage facilities
Continuous zooplankton samples	skills for operation of the device	yes	yes (deploy/re-cover)	preservation and storage facilities
Gelatinous zooplankton samples	skills for operation of the device		yes (deploy/re-cover)	preservation and storage facilities
Invertebrates				
Infauna	sorting and identifi-cation skills	yes	yes	preservation and storage facilities
Epifauna (towed)	sorting and identifi-cation skills	dependent on the amount of samples	yes, except for beam trawl sur-veys	preservation and storage facilities
Epifauna (video)	skills for operation of the device	operation of the device	yes	no
Pelagic	sorting and identifi-cation skills	dependent on the amount of samples	yes, except for pelagic trawl (acoustic) surv.	preservation and storage facilities

Table A1 – part 3 (continued)

Task	Skills	Personnel	Shiptime	Facilities
Megafauna				
ESAS sampling (birds, sea mammals)	identification, knowledge of methodology	yes (expert)	no	observation platform
Towed hydrophones	skills for operation of the device	yes (expert)	yes (deploy/recover)	data storage
Habitat description				
Camera (towed/dropped)	skills for operation of the device	yes	yes	data storage, synchronisation unit
Side-scan sonar	skills for operation of the device	yes (expert)	yes (deploy/recover)	data storage, synchronisation unit
Multi beam echosounder	skills for operation of the device	yes (expert)	no	data storage, tide gauge (costs), synchronisation unit
Ground truthing	knowledge on positioning of stations, dependant on level of analysis required	yes (expert)	yes	storage facilities dependant on analysis required
Pollution				
Floating litter	no	yes	depends on gear selected and num. of samples	observation platform/preservation and storage dependant on analysis
Sinking litter	no	no	depends on gear selected and number of samples	preservation and storage facilities

Table A1 – part 3 (continued)

Task	Skills	Personnel	Shiptime	Facilities
Pollution in the water column	skills for operation of the device	dependent on variables being collected	yes (deploy/re-cover)	dependent on varia-bles being collected
Pollution in the sediment	skills for operation of the device	dependent on variables being collected	yes (deploy/re-cover)	dependent on varia-bles being collected
Pollution in organisms	skills for operation of the device	dependent on variables being collected	yes (deploy/re-cover)	dependent on varia-bles being collected
Environmental conditions				
Weather conditions	no	no	no	no
Sea state	no	no	no	no

Table A1 (part 4 of 4). Additional requirements for each task during the survey.

	After survey						
Task	**Additional personnel**	**Facilities**	**Laboratory facilities**	**Sample storage**	**Data storage**	**Analytical instruments**	**Analysis software**
Fish and shellfish (survey specific)							
Organism collection (e.g. for contaminants, fatty acids analysis etc.)	yes	yes		x	x	x	
Stomach sampling	yes	yes	x	x	x	dependent on analysis	
Additional biological data (e.g. isotopes, liver/gonad weight, otoliths, scales, fin-rays, length-weight data of other than standard species)	yes	yes	x	x	dependent on analysis (e.g. otoliths)	dependent on analysis	dependent on analysis (e.g. otoliths)
Disease/parasite registration	yes	yes	x	x	x		
Genetic information	yes	yes	x	x	x	x	x
Lipid content	yes	yes	x	x	x	x	x
Sonar observations pelagic fish	yes	yes			x		x
Tagging	yes	yes			x		
Bioactive materials in marine species (e.g. for medical purposes)	yes	yes	x	x	x	x	
Echosounder observations pelagic fish	yes	yes			x		x
Other sampling of fish/shellfish not taken in main gear	yes	no			x		
Physical and chemical oceanography (e.g. CTD, chlorophyll, oxygen, nutrients, turbidity, etc.)							
Continuous underway oceanographic measurements (from the ship)	yes	yes			x		
Station oceanographic measurements	dependent on variables being collected	no			x		
Continuous underway oceanographic measurements [autonomous devices]	dependent on variables collected	yes			x		

Table A1 – part 4 (continued)

Task	Additional personnel	Facilities	Laboratory facilities	Sample storage	Data storage	Analytical instruments	Analysis software
Water movement	yes	yes			x		x
Station nutrient samples	yes	yes	x	x	x	x	x
Biological oceanography							
Station microbiological samples	yes	yes	**x**	x	x	x	
Station phytoplankton samples	yes	yes	x	x	x	x	
Continuous phytoplankton samples	yes	yes	x	x	x	x	
Station zooplankton samples (towed)	yes	yes	x	x	x	x	
Station zooplankton samples (dipped)	yes	yes	x	x	x	x	
Continuous zooplankton samples	yes	yes	x	x	x	x	
Gelatinous zooplankton samples	yes	yes	x	x	x	x	
Invertebrates							
Infauna	yes	yes	x	x	x	x	
Epifauna (towed)	yes	yes	x	x	x	x	
Epifauna (video)	yes	yes			x		x
Pelagic	yes	yes	x	x	x	x	
Megafauna							
ESAS sampling (birds, sea mammals)	no	no					
Towed hydrophones	yes	yes			x		x
Habitat description							
Camera (towed/dropped)	yes	yes			x		x
Side-scan sonar	yes	yes			x		x
Multi beam echosounder	yes	yes			x		x

Table A1 – part 4 (continued)

Task	**Additional personnel**	**Facilities**	**Laboratory facilities**	**Sample storage**	**Data storage**	**Analytical instruments**	**Analysis software**
Ground truthing	yes	yes	x	x	x	x	
Pollution							
Floating litter	yes if analysis not conducted at sea	yes if analysis not conducted at sea	x	x	x	x	
Sinking litter	yes if analysis not conducted at sea	yes if analysis not conducted at sea	x	x	x	x	
Pollution in the water column	yes	yes	x	x	x	x	x
Pollution in the sediment	yes	yes	x	x	x	x	x
Pollution in organisms	yes	yes	x	x	x	x	x
Environmental conditions							
Weather conditions	no	no			x		
Sea state	no	no			x		