Impact Assessment and Project Appraisal, volume 22, number 1, March 2004, pages 47–62, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, UK

Monitoring EIA

Environmental indicator frameworks to design and assess environmental monitoring programs

Tomás B Ramos, Sandra Caeiro and João Joanaz de Melo

Monitoring is fundamental to environmental impact assessment (EIA) both to assess adherence to standards and to support management options. The use of indicators assures that a monitoring program addresses only the key variables associated with significant environmental impacts and also improves monitoring communication and reporting processes. This paper develops a conceptual framework to design and assess an environmental post-decision monitoring program under EIA procedures – INDICAMP. It also discusses how current indicator frameworks can be used to design and evaluate the performance of environmental monitoring programs in projects. A coastal infrastructure case study demonstrates the usefulness of this methodology.

Keywords: environmental indicators; monitoring programs; performance evaluation; design; projects; EIA follow-up

Tomás B Ramos is in the Faculty of Marine and Environmental Sciences, University of the Algarve, Campus de Gambelas, 8000-117 Faro, Portugal; Tel: +351 289800900 (ext 7235); Fax: +351 289818353; E-mail: tramos@ualg.pt; Website: http://www.ualg.pt. Sandra Caeiro is at The Distance Learning University, Rua da Escola Politécnica, Palácio Ceia, nº 141, 1269-001 Lisbon, Portugal; Tel: +351 213916300; Fax: +351 213969293; E-mail: scaeiro@univ-ab.pt; Website: http://www.univ-ab.pt. João Joanaz de Melo is in the Faculty of Sciences and Technology, New University of Lisbon, 2829-516 Caparica, Portugal; Tel: +351 212948374; Fax: +351 212948374; E-mail: jjm@fct.unl.pt; Website: http://gasa.dcea.fct.unl.pt/.

Tomás B Ramos had a PRAXIS XXI/BD/15973/98 and Sandra Caeiro a 4/5.3/PRODEP/2000 scholarship, financed by the ESF (European Social Fund). The authors express their gratitude for constructive comments provided by anonymous reviewers.

IN RECENT DECADES, a great deal of experience has been built up at an international level in environmental impact assessment (EIA). However, emphasis has been mainly focused on pre-decision analysis, with little understanding as to whether EIA achieved its goals for environmental protection and management (Morrison-Saunders *et al*, 2001).

EIA follow-up is concerned primarily with the post-decision stage, including activities such as monitoring and auditing, for instance, post-evaluation or post-decision analysis, and so it is essential to keep track of the real effects that projects have on the environment. In addition, this follow-up is an incentive for improving the environmental management quality of projects as well as permitting and enforcement processes (Glasson *et al*, 1999).

Despite being well defined, the implementation of EIA follow-up is rather difficult to measure because of inadequate techniques, deficiencies in the environmental impact statement (EIS) and resource limitations (Morrison-Saunders, 1996; Arts *et al*, 2000; Arts *et al*, 2001). It also receives less attention in the literature than other aspects of the EIA process (Noble, 2000; Morrison-Saunders *et al*, 2001).

Among all the EIA follow-up activities, monitoring is the most continuous. It provides the data for the other activities and allows project and environmental performance objectives to be attained. Arts and Nooteboom (1999) define monitoring as a program of repetitive observation, measurement and recording of environmental variables and operational parameters over a period of time for a defined purpose.

Monitoring can be considered at a pre- or post-decision project stage. Pre-monitoring, also called baseline monitoring, measures the initial state prior

 1461-5517/04/010047-16 US$08.00

to implementation of a proposal. Post-decision monitoring includes monitoring activities undertaken to determine the impacts or changes to the environment caused by the proposal once it has been implemented (environmental effects monitoring). It equally covers activities undertaken to ensure that environmental components are not altered by human activity beyond a specific standard or regulation level (compliance monitoring) (Lohani *et al*, 1997; Morrison-Saunders and Bailey, 2001). Another type is area-wide monitoring, which measures the general state of the environment in an area (Arts *et al*, 2001).

Tomlinson and Atkinson (1987) also discussed extensively terminology related to environmental auditing and monitoring. One additional new monitoring level could be the meta-level, which evaluates the performance of a monitoring program. Later in this paper, this new approach is explained in more detail.

Follow-up not only provides information about the consequences of an activity as they occur, but also gives the responsible parties (proponent and/or competent authorities) the opportunity to take appropriate measures to mitigate or prevent negative effects on the environment. EIA follow-up can be seen then as the missing link between EIA and project implementation (Arts *et al*, 2000), giving essential feedback to improve the EIA process.

However, such follow-up in the post-consent decision stages is performed in only a minority of cases (Arts *et al*, 2001) and in many countries is probably the weakest step in the process (Glasson *et al*, 1999). Morrison-Saunders and Bailey (1999) found some weaknesses in the scope and rigor of environmental monitoring programs in Australian cases studies, where these programs have not been able to determine whether or not potential environmental impacts have occurred. Sample contamination, lack of training and expertise in sampling and data analysis, uncertainty over the scientific integrity of monitoring programs, unsuitable spatial and temporal distribution of sampling sites, and no replication of sampling can be the reasons for inadequate monitoring (Morrison-Saunders and Bailey, 2001).

Discretionary measures are not enough, and monitoring needs to be more fully integrated into EIA procedures on a mandatory basis (Glasson *et al*, 1999). Also, in places where EIA follow-up is a discretionary or even mandatory requirement (for instance, Canada, California, Hong Kong, Western Australia, the Netherlands and Portugal), it has proved difficult to put post-EIA monitoring and evaluation into practice (Arts *et al*, 2000; Morrison-Saunders and Bailey, 2001).

In Portugal, Decree-Law 69/2000 and Ministerial Order 330/2001 regulate ongoing EIA, where EIA follow-up is required. As already described by Jesus (2000), according to this law monitoring programs must be established in the EIS and proponents should periodically submit monitoring reports to the EIA authority. The EIA authority may impose project or management adjustments and/or additional mitigation in the case of unpredicted negative impacts. Additionally, EIA authorities can perform audits to verify compliance of project construction, operation or decommissioning with the original EIA decision and also to verify the accuracy of monitoring programs.

An important reason for the less than satisfactory performance of environmental monitoring programs may be that they were set up in the past for a variety of purposes, most of them derived from local or national priorities. They have not been designed to contribute to a synthesis of information or to evaluate project impacts, or analyze the complex cross-linkages between environmental quality aspects, impacts and socio-economic driving forces (RIVM, 1994).

Also, environmental monitoring initially focused on obvious, discrete sources of stress such as chemical emissions. It soon became evident that remote and combined stressors, while difficult to measure, also significantly alter environmental conditions. Consequently, monitoring efforts began to examine ecological receptors, since they expressed the effects of multiple and sometimes unknown stressors (Jackson *et al*, 2000). Because of the content of most stressor–response relationships, it is impossible to characterize completely all the variables, so a selected set of measurements should be made to reflect the most critical components. Such measurements, or indicators, should be included in monitoring programs to estimate trend, stressor source and magnitude of effects and lead to thresholds for management or restoration action (Fisher *et al*, 2001).

One of the main aims of environmental indicators is to communicate information about the environment and human activities. They can be especially useful to highlight emerging significant environmental impacts during monitoring programs. In an EIA process, public communication and participation, particularly monitoring data reporting, is a priority issue for strengthening post-decision monitoring that could be assured and improved by the use of indicators.

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Impacts of projects need to be monitored on a regular basis during the entire project life cycle. Such monitoring should provide an account of EIA performance, regulatory compliance, mitigation performance evaluation, validation of impact-prediction techniques, verification of residual effects and linkages into contractual permitting, licenses and other management systems (Canter, 1996; Morrison-Saunders *et al*, 2001). Targeting these factors and their lack of effectiveness in the monitoring programs is then crucial to evaluating their performance. This performance evaluation, though very important, is almost never done.

The measuring of management success is now required by the United States Government Performance and Results Act of 1993, whereby agencies must develop program performance reports based on indicators and goals (Jackson *et al*, 2000). Along with this present priority at US level, a global trend in environmental performance evaluation is emerging, applicable to all types of organization and especially supported by the ISO 14031 standard. This approach could be extrapolated to performance evaluation for project- or plan-monitoring programs.

The main goal of this paper is the development of a conceptual indicator framework to design and assess post-decision monitoring programs under EIA — INDICAMP. This framework aims to contribute to an improvement in monitoring program effectiveness, particularly in impact prediction accuracy and project environmental management activities. For that purpose, there is a discussion of current indicator frameworks developed by various authors and of how they can be used to design and assess environmental monitoring programs for projects.

The INDICAMP framework also includes indicators of monitoring performance, meta-level monitoring, aimed at evaluation of the quality and effectiveness of the monitoring program. This framework is applied to a coastal infrastructure case study in Portugal, and is submitted to an environmental assessment to test its applicability, advantages and drawbacks.

Conceptual frameworks for indicators

Despite the current importance of environmental indicators at international level, their development and use is not a very recent issue since the first important references date from the 70s, for instance, Thomas (1972); Inhaber (1976) and Ott (1978). More recently, several studies have presented guidance on developing environmental indicators, discussing indicator properties and criteria for their selection, for instance, Vos *et al* (1985); Jeffrey and Madden (1991); Braat (1991); Gouzee *et al* (1995); RIVM (1994); Ramos (1996); Melo *et al* (1996), HMSO (1996); FSU/USEPA (1996a; 1996b; 1996c; 1996d; 2001); Ramos *et al* (1998) and EEA (1996; 1998; 1999).

Despite all these studies, the terminology used in the area of environmental indicators is still rather confusing and is not well established. The term ‘indicator’ is sometimes used rather loosely to include almost any sort of quantitative information (RIVM, 1994). Equally, statistics are often called indicators without being carefully selected or reworked. Various initiatives try to clarify environmental indicator typology. In particular, the European Environment Agency (EEA, 1999) attempts to help policy-makers understand the meaning of the information in indicator reports and helps to define common standards for future indicator reports by the Agency.

To keep the concept of an environmental indicator clear in this paper, the definitions of Ott (1978) and Jackson *et al* (2000) were adopted: a sign that conveys a complex message, potentially resulting from numerous factors in a simplified and useful manner. An environmental indicator is derived from a single variable to reflect some environmental attribute.

Canter (1996) refers to the usefulness of using environmental indexes and indicators in terms of EIS, especially for baseline monitoring or monitoring studies in general, and also for prediction and impact assessment with regard to environmental components. The use of indicators is already being used in pre- and post-decision monitoring, as suggested in the works of Lohani *et al* (1997) and Glasson *et al* (1999). However, many of the studies under-explore the use of indicators in post-decision monitoring programs.

To ensure that indicators serve the purpose for which they are intended and to control the way they are specifically selected and developed, it is important to organize them in a consistent framework. Table 1 presents an overview of indicator frameworks based on the chronological frameworks evolution and covers: the scale they were ideally built for; their primary objective; the target system that they focus on; and) comments and/or drawbacks.

Despite the large variety of frameworks developed, many of them are quite similar in their methodological approaches and are mostly adaptations of the pressure–state–response (PSR) model, based on causality chains. Also, a variety of terms are used in different ways to cover similar categories, an issue that is broadly discussed by USEPA (1995) for some of the frameworks presented in Table 1. On the other hand, the same item can appear in different places in a single/the same framework, depending on which target system we are focusing on.

Table 1 shows how the frameworks evolve mostly from the assessment of the environmental systems to, more recently, the environmental performance of organizations/sectors or project evaluation. Many of them take into account not only the environment, but also the society and economy, attempting to measure sustainability. Generally, indicator frameworks were not developed with the purposes of EIA application, since the relation between them and EIA, post-decision in particular, is mostly non-existent. Nevertheless, some EISs use indicators and/or indices, especially in the pre-decision stage, although without any formal framework.

The classification of the different types of monitoring indicators and the causality chains used by many of the indicator frameworks can be relevant to fulfill the purposes of EIA follow-up. According to Arts *et al* (2001), one of the EIA follow-up objectives is to enhance scientific knowledge about environmental systems, particularly the cause–effect relationships. While cause–effect relationship

Table 1. The conceptual frameworks of environmental indicators

Author/year	Framework name: indicator categories	Scale*	[a] Primary objective(s) and [b] target system	Comments/drawbacks
Friend and Rapport (1979)	STRESS: stress – response	N	[a] Environmental statistics; resource accounting [b] Environmental	Physical basis for comprehensive environmental/resource accounts, which could be linked to the UN System of National Accounts. Unrealistic; tried to make one-to-one linkages among particular stresses, environmental changes and responses (USEPA, 1995). ‘Stress’ categories include natural as well as human influences and ‘responses’ stands on ecosystems responses (RIVM, 1994).
UN (1984)	FDES – Framework for the Development of Environmental Statistics: statistical ‘topics’	N	[a] Environmental statistics; resource accounting [b] Environmental	Expands and modifies STRESS framework. States the relation between information categories, representing a sequence of action and reaction to “environmental components” or “media” (Bartelmus, 1994). Incorporates social, demographic and economic statistics that are related to environmental concerns. Information categories are based on the recognition that environmental problems are the results of human activities and natural events.
Hamilton (1991)	PEP – Population Economy Process: stocks – processes – interactions	N	[a] Environmental statistics [b] Environmental/social/ economic	Shows the interaction between society, economics and the environment. Considers the world divided into the three indicator categories and attempts to identify the interaction represented by flows between these categories. Each is characterized by its stocks (or states), processes (or activities) (Cardno, 2000; Hodge, 1997). Has an explicit link with the UN System of National Accounts (USEPA, 1995).
OECD (1993)	PSR: pressure – state – response	N	[a] Countries’ environmental performance reviews [b] Environmental	Adapted from STRESS model. Based on a concept of causality: human activities exert pressures on the environment. These pressures modify the state of the environment, including socio-economic related aspects. Undesirable impacts lead to a response from society that results in the formulation of an environmental policy. According to Kelly (1998), fails to capture information about the structure and behavior of the systems in which decisions are made and fails to capture the complexity of the relationships in complex systems.
Barber (1994)	EMAP indicator framework: condition – stressor	L to N	[a] Estimate of the condition of the nation’s ecological resources [b] Environmental	Environmental Monitoring and Assessment Program (EMAP) framework includes linkage of indicators to ecological and human values. Conditions and stressors are strictly related with state and pressures from PSR model.
Bartelmus (1994)	FISD – Framework for Indicators of Sustainable Development: statistical ‘topics’	N	[a] Sustainable development statistics [b] Environmental/social/economic/ institutional	FISD are mostly FDES-based ‘statistical topics’. Links concerns and programs of Agenda 21 with data framework of FDES, to obtain a framework that combines sustainable development concerns with environmental and related socio-economic data.

(*continued*)

Table 1 (*continued*)

Author/year	Framework name: indicator categories	Scale*	[a] Primary objective(s) and [b] target system	Comments/drawbacks
RIVM (1994); RIVM (1995) Adopted by the European Environment Agency	DPSIR: driving forces – pressures – state – impacts – responses	L to C	[a] Environmental assessment [b] Environmental – includes human health, ecosystems and materials	Similar to PSR framework, but with two more categories: i) driving forces: referring to the 'needs' of individuals and institutions that lead to activities that exert pressures on the environment. The 'intensity' of the pressure depends on the nature and extent of the driving forces and also on other factors that shape human interaction with ecological systems; ii) impacts: on ecosystems and human well-being due to state modifications. The policy responses lead to changes in the DPSIR chain. Greeuw *et al* (2001)state that a key issue is that the same item can appear in different places in the framework, depending on which target we are focusing on.
USEPA (1995)	PSR/E: pressure – state – response – effects	L to N	[a] To produce an integrated system of environmental information [b] Environmental – includes human health and welfare	Adapted from PSR framework and a derivative category called 'effects' is added, for attributed relationships between two or more pressure, state, and/or response indicators; pressures of non-human origin are also included in the framework.
UN (1996); UN (2001)	DSR: driving force – state – response	N	[a] To make indicators of sustainable development available to decision-makers at the national level [b] Environmental/social/economic/ institutional	Adapted from PSR framework; driving force instead of pressure in order to encompass human activities, processes and patterns that impact on sustainable development; driving force allows for the impact on sustainable development to be both positive or negative, as is often the case with social and economic and institutional indicators. No causal relationships among the three types of indicator.
Dixon *et al* (1996); Segnestam (1999)	Indicator framework: input – output – outcome – impact	L to G	[a] To assess and evaluate the performance of World Bank projects in relation to environmental issues [b] Project	Based on the project cycle itself and is related with PSR framework. Input indicators monitor project-specific resources provided; output indicators measure goods and services provided by the project; outcome indicators measure the immediate, or short-term, results of the project implementation; impact indicators monitor the long-term or more pervasive results of the project.
Azzone and Noci (1996)	Performance Indicators Integrated Framework Integrated Framework of Performance Indicators: state – policy – EMS – eco-balance	L	[a] To evaluate corporate environmental performance [b] Organization – corporate	Integrated framework of which the main aim is to support environmental performance indicators at company level. Corporate environmental policy is the basis of the framework. Starts with the identification of the key environment-related factors to be included in the company environmental report and also defines how environmental performance can be expressed and how distinct measures can be aggregated to achieve a more complex picture.
Rotmans and Vries (1997)	PSIR: pressure – state – impacts – response	N to G	[a] Sustainability assessment [b] Environmental/social/economic/ institutional	Several authors present PSIR as one more variant of the PSR framework, adding the category 'impact', that can be seen as a measure of change in state. In some ways this framework has many similarities with DPSIR.
Federal Environment Ministry (1997)	Corporate Environmental Indicators: environmental performance – environmental management – environmental condition	L to G	[a] To evaluate corporate environmental performance [b] Organization – corporate	Despite similarities with the ISO 14031 indicator framework, presents different indicator categories and subcategories.

(*continued*)

Table 1 (*continued*)

Author/year	Framework name: indicator categories	Scale*	[a] Primary objective(s) and [b] target system	Comments/drawbacks
US Interagency Working Group on Sustainable Development Indicators (1998)	SDI framework: long-term endowments and liabilities – processes – current results	N	[a] Developing an experimental set of sustainable development indicators as a first look for key US economic, environmental and social well-being factors [b] Environmental/social/economic	Builds on the PSR model, but accommodates a range of processes (both positive and negative) related to economics, the environment and society. It divides the 'state' category into two separate categories: 'long-term endowments and liabilities' and 'current results'. Processes include human activities, natural earth systems processes and social, cultural or political/decision-making processes, related to driving forces, pressures and responses categories.
Meadows (1998)	Framework for sustainable development indicators: natural capital – built capital and human capital – human capital and social capital – well being	L to G	[a] To evaluate sustainable development [b] Environmental/social/economic	Based on a 'Daly triangle/pyramid', a diagram created by Daly (1973), which relates natural wealth to ultimate human purposes through technology, economics, politics and ethics.
Personne (1998)	PER Enterprise: pressures – state – responses	L to G	[a] Enterprise environmental performance evaluation [b] Organization – enterprises	Adapted from PSR framework to develop enterprise performance indicators.
ISO (1999)	ISO 14031: Environmental Performance Indicators (Operational Performance Indicators (OPIs) and Management Performance Indicators (MPIs)) – Environmental Condition Indicators (ECIs)	L to G	[a] To evaluate an organization's environmental performance [b] Organization–- private or public of any size or type	Despite the different nomenclature used, the main concepts are strictly related to a general PSR approach. The main difference is that in this model the main target is an organization and not the environment. The ECIs are the same as the state category. The OPIs (similar to the pressure category) provide information about the environmental performance of the organization's operations. The MPIs (similar to the response category) provide information about management efforts to influence the environmental performance of the organization. This framework was specially designed for organizations but in practice could be extrapolated to other types of 'entities', like a country or a project.
Chesapeake Bay Program/US EPA (1999)	Hierarchy of Indicators: Administrative (1. actions by federal or state regulatory agency; 2. responses of the regulatory community or society) – Environmental (3. changes in discharge of emission quantities; 4. changes in ambient conditions; 5. changes in uptake and/or assimilation; 6. changes in health, ecology of other effects)	L	[a] Environmental assessment [b] Environmental – includes human health and ecosystem	This framework is an indicator-driven planning process that successfully uses an extensive range of environmental indicators that focus actions on the improvement of the resource. Levels 1 and 2 correspond to response indicators, level 3 shows pressure indicators and levels 4, 5 and 6 are state and impacts indicators. To measure the quality of each indicator with respect to the strength of the type of data, they developed a six-point scale for rating indicators. This framework is used for the primary purpose of communicating the health of the Chesapeake Bay and its rivers to public audiences.
USEPA (1999)	Indicator framework of the environmental impact of transportation: activities – outcomes – outputs	R, N	[a] Identifying environmental impact of transportation [b] Sector – transport	This framework is based on three main stages. Transportation-related activities – such as infrastructure construction, travel, and maintenance – result in releases of pollutants or damage to habitats. These outputs, in turn, have human health and welfare effects – outcomes. Although developed for transport, can be used for other sectors; method based on causality chain approaches, such as PSR, DPSIR, PSR/E.

(*continued*)

Table 1 (*continued*)

Author/year	Framework name: indicator categories	Scale*	[a] Primary objective(s) and [b] target system	Comments/drawbacks
EEA (2000)	Sector-environmental integration indicators: Socio-economic performance of the sector – environmental performance of the sector – eco-efficiency performance of the sector – monitoring implementation of integration measures and policy effectiveness	R, N	[a] To provide a coherent system of integration indicators that ensures co-ordination between indicators [b] Sector-policy sector	Socio-economic indicators category measures the development in the sector size and shape, and how it is determined. The category 'environmental performance of the sector' is based on environmental pressure, state and impact indicators. The eco-efficiency category provides the relationship between economic and environmental performance. After sector integration strategy has been finalized and implemented, monitoring of implementation and success of the policy measures should follow integration of measures and policy effectiveness indicators. (Hertin *et al*, 2001) state that this framework is too focused on the environmental dimension of sustainability with too little consideration being given to the social and economic dimensions.
Hyman and Leibowitz (2001)	JSEM Judgment-based Structural Equation Modeling	L	[a] Environmental assessment [b] Environmental	Uses the framework of the Structural Equation Model (SEM), which combines path analysis with measurements models, to formalize available information about potential indicators and to evaluate their potential adequacy for representing an endpoint. Uses expert judgment regarding the strengths and shapes of indicator endpoint relationships.
FSU/USEPA (2001)	CAPRM Model: administrative – environmental	R to N	[a] Environmental assessment [b] Environmental	Based on the hierarchy of indicators and on the PSR/E framework.
Hertin *et al*, (2001)	Enterprise policy integration indicators: headline – integration – process	R to N	[a] To monitor the integration of environmental and sustainable development into enterprise policy [b] Sector – enterprises – industry	These indicator categories are concerned with economic, social, and environmental outcomes (headline indicators), with identifying significant overlaps between enterprise policy and sustainability (integration indicators), and with monitoring how enterprise policy processes take into account sustainability objectives (process indicators).
Berkhout *et al*, (2001)	MEPI indicator framework: physical – eco-efficiency – impact	L, R, N	[a] To measure the environmental performance of industry [b] Sector – industry	Includes primarily quantitative indicators and is focused on data generated by firms and production sites. Physical indicators measure mass, energy and waste flows through manufacturing processes; eco-efficiency indicators link physical data to data on business performance; impact indicators link physical data on inputs and emissions to measurable impacts on human population and the environment. Not developed for use by non-professional and lay audiences. Business and environmental analysts, policy makers, and business managers are potential user groups.
Marsanich (nd)	FEEM EMAS environmental indicators: environmental management – environmental absolute – environmental performance – potential effects – environmental effects	L to N	[a] To communicate companies' environmental performance in EMAS environmental statements [b] Organization	Based on ISO 14031 indicator framework. It established a modified classification of environmental indicators with modified and new categories and greater emphasis on environmental effect indicators.

Note: * Spatial scale: L = local; R = regional; N = national; C = continental; G = global

are difficult to establish, environmental decision-making commonly relies on assumptions about such linkages to determine appropriate management responses.

Thus, models and analyses, which show relationships among variables generally, have the most meaning for environmental decision-makers (USEPA, 1995). Nevertheless, special attention must be paid, when using these causality chains, not to suggest linear relations, to avoid obscuring the more complex relationships in the environment and the interactions among sub-systems.

Equally, monitoring should employ short feedback cycles and should quickly yield results in order to make the aim of EIA follow-up clear (Arts *et al*, 2000). The use of these indicator frameworks can help to give these quick responses and improve the existing lack of efficiency in monitoring follow-up. It can also help to evaluate the performance of the monitoring programs (meta-level monitoring).

Development of the conceptual framework

In the first stage of an EIA process, that is project planning and design, it is fundamental to measure the initial state prior to implementation of the project — pre-decision monitoring. Only when the project is being implemented can we undertake monitoring activities to evaluate the impacts on the environment caused by the project (post-decision monitoring). These impacts can be evaluated when compared with the pre-decision monitoring data (Figure 1). The main components of post-decision monitoring programs and the related goals can be described with indicators (see bottom text boxes on Figure 1). Three components are of particular importance (underlined in Figure 1): select and develop monitoring indicators; define methods of communicating and reporting results outputs; define reviewing procedures and indicators of monitoring performance evaluation.

The post-decision stage should be included in a flexible approach to EIA (adaptive management activities), to enable and actively encourage ongoing refinements and improvements to management and monitoring programs (Morrison-Saunders, 1996; Noble, 2000). Additionally, the post-decision monitoring program should be based on a series of components, essential to ensure its effectiveness and fulfillment of its goals. In the approach developed here, one of the principal components of monitoring programs is the selection and development of the monitoring indicators.

New environmental indicator framework

Based on a rearrangement of the frameworks PSR/E, DPSIR and ISO 14031 presented in Table 1, a new environmental indicator framework to design and assess post-decision monitoring programs — INDICAMP — was developed (Figure 2). This framework attempts to incorporate a systems analysis

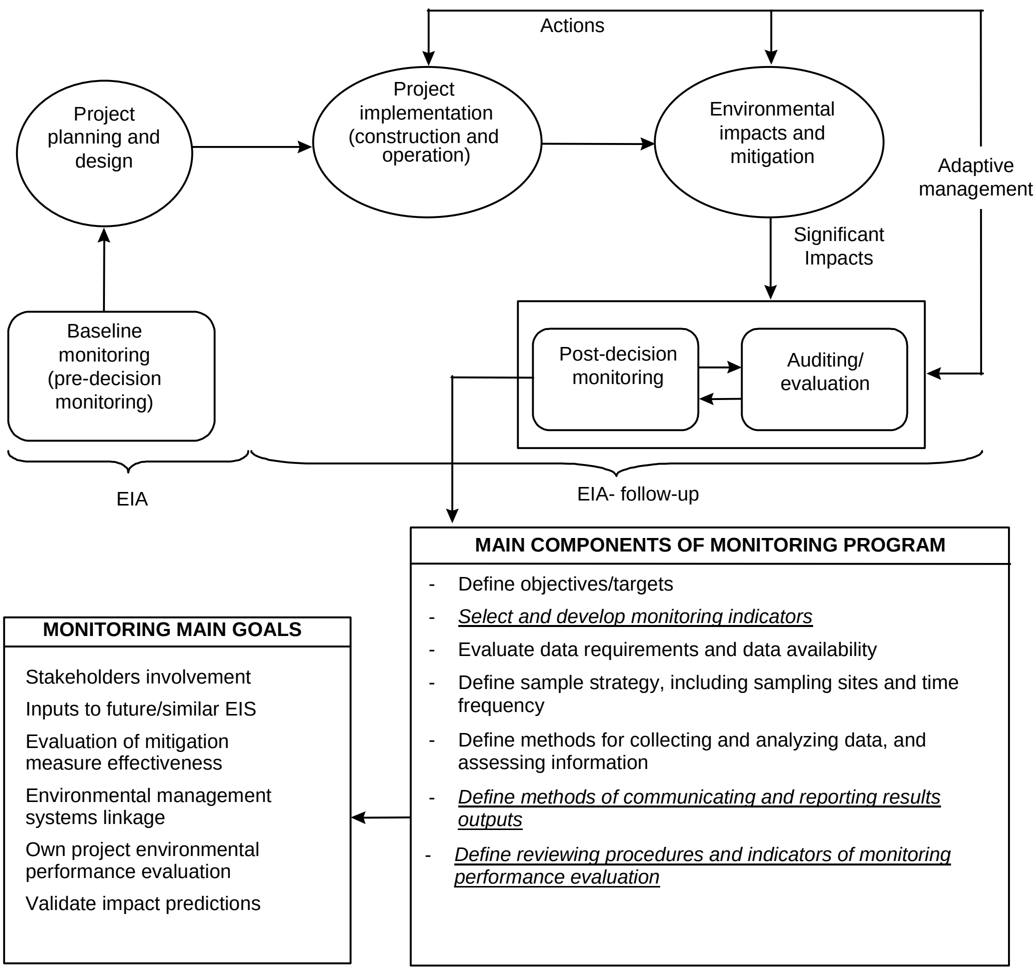

Figure 1. Environmental post-decision monitoring program: main components derived from an EIA with an indicator approach

approach, designing the main cause–effect relationships among the different categories of monitoring indicators (pressures, state, effects and responses). It also includes a monitoring performance indicators category to assess the effectiveness of the monitoring program itself. This kind of tool could help in applying the comprehensive or targeted environmental monitoring concept used by Canter (1996) (that is, the establishment of cause–effect relationships), as well as in impact management and related corrective action.

This model shows how each project activity produces pressures on the environment, which then modify the state of the environment. The variation in state then implies effects or impacts on human health and ecosystem receptors, causing project proponent and society to respond with various management and policy measures, such as internal procedures, information, regulations and taxes (see the dashed lines in Figure 2). The particular features of each of these categories follow the general methodology developed by RIVM (Netherlands Institute of Public Health and the Environment) (1995).

Within EIA, effects indicators are particularly important, since state indicators sometimes do not evaluate their impact on the environment by themselves. As an example, an increase in the heavy metal content of an environmental component as a result of project operation does not necessarily mean a pollution effect on organisms. Effects in some way concern relationships among two or more indicators within any of the pressures, state and responses categories.

The performance of the monitoring program can be evaluated at one main stage — the meta-level — when the monitoring performance indicators category represents the effort to conduct and implement the program, measuring also program effectiveness

The framework also shows that the performance of the monitoring program can be evaluated at one main stage — meta-level monitoring. At this level, the monitoring performance indicators category represents the effort to conduct and implement the program, measuring also program effectiveness. The monitoring performance indicators will allow evaluation of the following (see the dashed lines in Figure 2):

- how appropriate the environmental and social-economic monitoring indicators are (state, pressures, effects and responses categories), leading to a review of, and improvement in, these components;

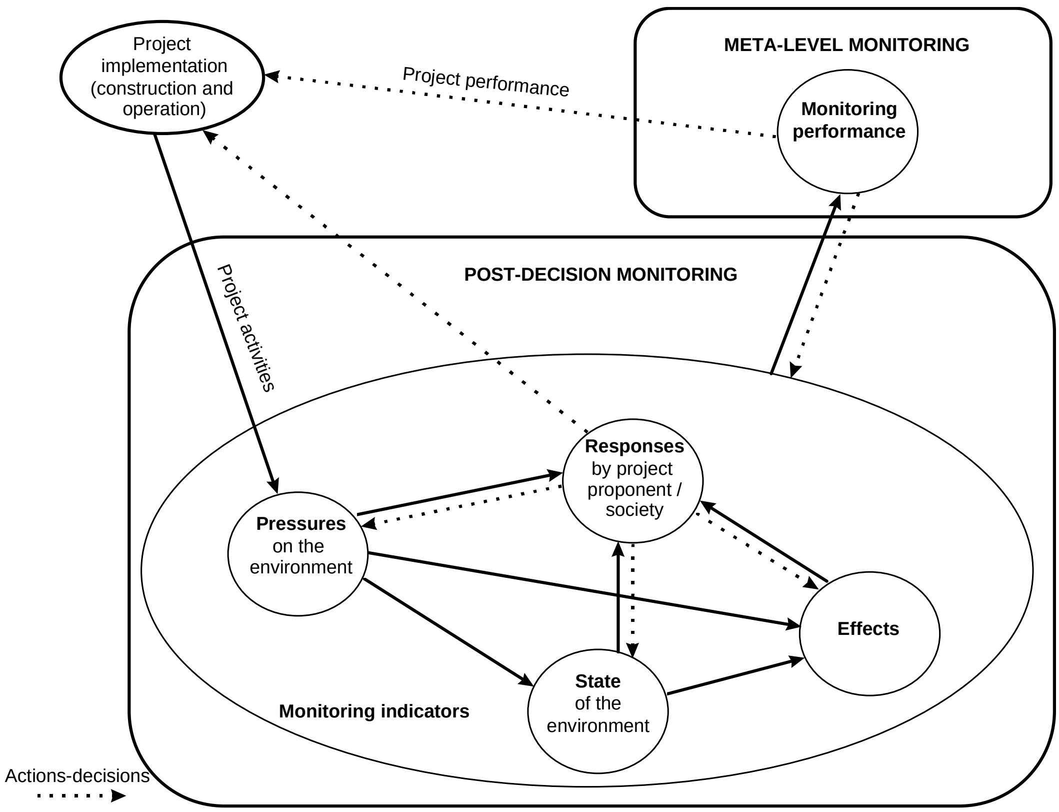

Figure 2. Environmental indicator framework to design and assess environmental post-decision monitoring programs (INDICAMP)

- evaluation of overall monitoring activities and results, including the environmental impact of the sampling process itself, to measure how well the monitoring program is going;
- evaluation of project environmental performance and impact mitigation action.

This category of monitoring performance indicators may be viewed as a response and management category (see ISO 14031 indicator framework in Table 1), linked with the organization responsible for the monitoring program, where the target is the post-decision monitoring system. This should be distinguished from response-type indicators, which describe the responses of the project proponent/society as a whole and in which the targets are the environmental, social and economic systems.

This framework was designed to cover the main stages of project implementation: construction; operation; and decommissioning. Five fundamentals support monitoring indicator system development: project type and dimension; baseline environmental sensitivity; major significant environmental impacts identified/predicted and related mitigation measures; impacts that have poor accuracy or lack of basic data; and other environmental monitoring programs near the project area.

To relate the results from post-decision monitoring to the pre-decision monitoring a comparison is essential. The pre-decision monitoring could be ideally developed using the same pressure, state, effects and response categories, for a more efficient comparison, although the pressure indicators should consider the existing pressures without project.

Development of indicators

Besides the main criteria presented above for monitoring indicator selection and development, various concepts, criteria and general guidelines must also be taken into account, namely those defined by Ott (1978); Barber (1994); RIVM (1994); Ramos (1996); HMSO (1996) and Jackson *et al* (2000). The implementation of INDICAMP therefore requires the definition of a set of indicators aimed at the different parts of the framework. Some of the most important criteria for indicator selection are:

- social and environmental relevance;
- ability to provide a representative picture of significant environmental impacts;
- simplicity, ease of interpretation and ability to show trends over time;
- responsiveness to change in the environment and related project actions;
- capacity to give early warning about irreversible trends;
- ability to be updated at regular intervals;
- present or future availability at a reasonable cost/benefit ratio;
- appropriateness of scales (temporal and spatial);
- acceptable levels of uncertainty;
- data collection methods comparable with other data sets;
- a good theoretical base in technical and scientific terms.
- existence of a target level or threshold against which to compare it, so that users are able to assess the significance of the values associated with it;
- minimal environmental impact of the sampling process itself.

The development of environmental indicators is in most cases stimulated by information producers, with little involvement of information users. Therefore the adopted indicators should reflect the different perspectives of the EIA stakeholders. Morrison-Saunders *et al* (2001) present and discuss the importance of stakeholders and their roles in the EIA follow-up, and Noble (2000) emphasizes the importance of incorporating the public into all stages of the monitoring process.

In this framework, monitoring indicators can be aggregated into environmental indices, to reflect the composite monitoring results of each category of the framework. The aggregation functions (mathematical or heuristic) must be selected or developed for each particular case. Since there are many different functions with several advantages and disadvantages, this step must be carried out with special caution to avoid significant losses of information and ensure meaningful results.

To avoid a too complex and resource-demanding post-decision monitoring program, the INDICAMP indicators could be scored according to a qualitative expert knowledge assessment of their relevancy and feasibility. The relevancy classification covers: technical and scientific importance; synthesis capability; and usefulness for communicating and reporting. The feasibility classification covers: sensibility; robustness; cost; and operability of the determination methods.

In the first phase of the post-decision monitoring program, only the indicators with the highest classification should be included. Each indicator is classified from 1 (lowest classification) to 3 (highest classification) and the more important indicators to use in INDICAMP should be the ones with a score of 6 (the sum of relevancy and feasibility). Relevancy should be the main criterion for selection of indicators, followed by the feasibility of the indicator determination method. The other scored indicators should be considered depending on a first results evaluation (Table 2).

Overall indicators and their results should be reviewed periodically to identify opportunities to improve and achieve the monitoring objectives. Noble (2000) also stresses that an effective monitoring strategy must support the monitoring system designers in revising the monitoring design. One particular feature of this framework is the possibility of obtaining a significant part of the review

Table 2. Score of indicators according to their relevancy and feasibility (classified from 1 to 3)

Score	Relevancy	Feasibility
1	3	3
2	3	2
3	3	1
4	2	3
5	2	2
6	2	1
7	1	3
8	1	2
9	1	1

information on the basis of the monitoring performance indicators.

Some steps for the reviewing process can include a review of several points similar to those presented in ISO 14031 (ISO, 1999), namely: the appropriateness of the monitoring scope and objectives; the cost effectiveness and benefits achieved; progress towards meeting environmental criteria; the appropriateness of environmental criteria; the appropriateness of indicators; and data sources, data collection methods and data quality.

Coastal infrastructure at the Sado estuary

Because mandatory post-decision monitoring is recent in Portuguese EIA regulations, few projects have developed and implemented monitoring programs. For this reason we choose to present a case study where the post-decision monitoring program was not implemented and where the indicators are selected and developed for the first time in this case study (see Table 3). However, this is a proposal to submit to local authorities as a decision-making support tool for project management in the estuary. Only the impacts on the aquatic system will be evaluated in this case study.

An EIS of the enlargement of a fishing harbor project was carried out in 1997. This harbor, with an area of 0.024 km^2, is located in the Sado estuary near the city of Setubal (Figure 3), and its enlargement was only concluded recently, in 2003. It aims to improve fishery conditions through the construction of an outside protection infrastructure and improvements in surrounding areas of the existing harbor.

Most of the estuary is classified as a nature reserve but also plays an important role in the local and national economy. The Setubal fishing harbor is located in the estuary's north channel, under the direct influence of the Setubal urban area and upstream industries. Near the fishing harbor, the urban sewage outfall is discharged and pleasure boat, fishing boat and ferryboat traffic is heavy. Near the project location, the Setubal and Sesimbra Harbours Administration has monitoring programs in the upper north and south channel prior to maintenance dredging works.

The Setubal fishing harbor enlargement will improve the uses of the aquatic system, in particular the fishery-related activities. Nevertheless, this project will have the typical significant negative

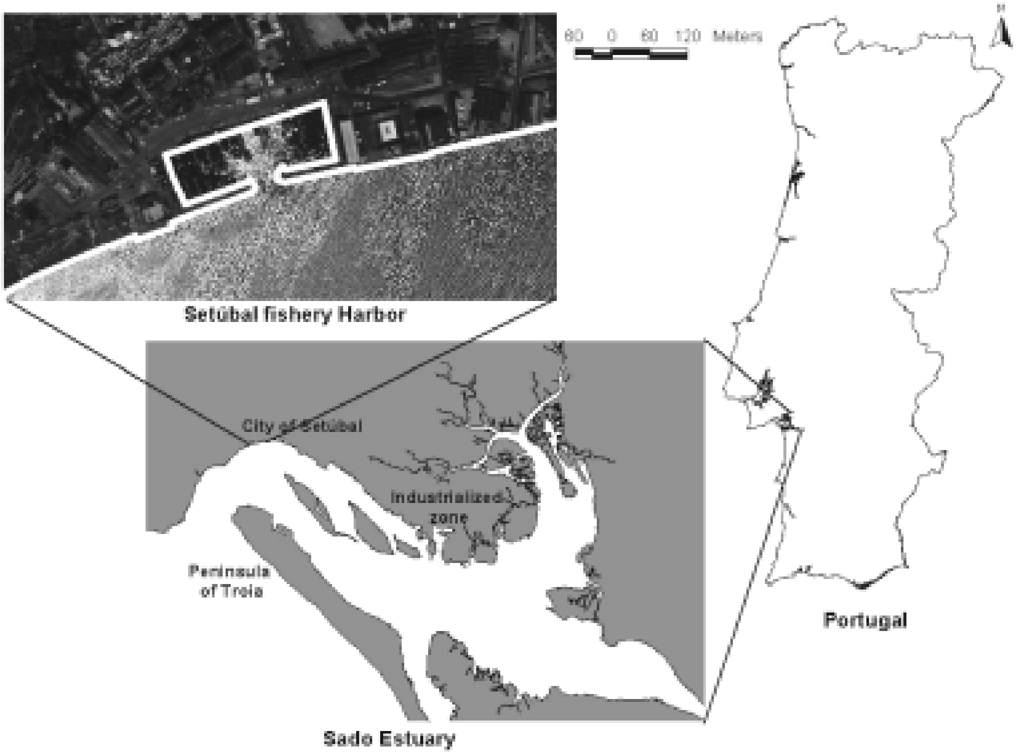

Figure 3. Setubal fishing harbor location in the Sado Estuary, Portugal
Source: Adapted from Caeiro *et al* (2003)

impacts on the aquatic systems related to this type of infrastructure (see USEPA, 2001).

A set of indicators for each INDICAMP category was chosen to apply to the Setubal Fishing Harbor Enlargement Project. Some were also chosen on the basis of USEPA (2001), EUROSTAT (1999) and ERM (1997) and of Portuguese and European environmental legislation.

Table 3 lists the indicators chosen for five INDICAMP categories and attributes a score of 1 to 3 according to their relevancy and feasibility. In the first phase of the post-decision monitoring program, only the indicators with a score of 6 will be included. The other indicators scored according to Table 2 can be added to the monitoring program, depending on the first results campaign. During the monitoring reviews, adjustments should be made to respond to the results obtained. In this process, the indicators not initially chosen, in accordance with the scoring previously established, should be taken into account. This ordering of indicator values makes this methodology less expensive and more effective.

Some of the pressure, state, effects and responses indicators, although with high relevancy classification, have low feasibility classification as a result of high determination costs and/or difficult operability (for instance, macrozoobenthic community structure or sediment quality assessment). For that reason, they should only be measured after first monitoring results evaluation. In the case of the monitoring performance indicators, almost all of them have a maximum classification in terms of relevancy and feasibility. This does not mean that more effort is put into monitoring performance indicators, only that they are easier and less expensive to quantify.

The indicators belonging to the categories in Table 3 could be produced by classification and aggregation of one or more indicators, by means of mathematical or heuristic algorithms. For example, the Pollution Load Index is calculated through the aggregation of contaminants such as heavy metals or polyaromatic hydrocarbons. For a review of these and other indicators see, for example, Ramos (1996).

An in-depth analysis of these indicators shows the difficulties that arise in the application of the INDICAMP framework to complex environmental problems, such as marine resources. These difficulties may be due to several factors such as (Ramos, 1996; Antunes and Santos, 1999):

- several causes contributing to a single effect;
- multiple effects resulting from a single pressure;
- interrelations among ecosystem components;
- indirect, synergistic or cumulative effects;
- identification of the mathematical equations that best represent parameter behavior.

One of the difficulties in accomplishing monitoring objectives is to assess whether the environmental changes observed are caused by that specific project or activity or whether other factors have intervened. The difficulties with causality can be problematic when, on the basis of the monitoring results, an authority decides that mitigation measures have to be taken. Besides, the environmental problems may not originate from a single activity but from the cumulative processes and synergetic effects of the combined polluting activities in an area. In that event, the mitigation measures implemented as part of the EIA follow-up of a single project can only be partial solutions to the environmental problems in an area that need concerted action.

Nevertheless, an integrated area-oriented approach can help to identify the cumulative and synergetic character of environmental problems, since the total impact of the various activities in an area is monitored. That is why it is important to be aware of other monitoring programs in the study area. Furthermore, methodological problems of causality are less relevant to area-oriented monitoring because the state of the environment in a particular area and the environmental changes taking place there can usually be adequately assessed on, and compared with, the prevailing environmental policy for that area (Arts *et al*, 2000).

This post-monitoring approach attempts to measure project pressures (for instance, harbor pollution loads) and focuses on the timely prevention, restriction or remediation of environmental damage. This strategy identifies the pollution source instead of only evaluating the impact on the state of the environment and, thus, may avoid some serious problems relating to causality, as Arts *et al* (2000) argue.

Like the PSR framework (OECD, 1993), INDICAMP tends to suggest linear relationships in project activities/environmental effects. This should not, however, obstruct the view of more complex relationships between project pressures and environmental-impact interactions. The INDICAMP framework does not attempt to make one-to-one linkages between specific pressures, environmental changes and responses. The state of the environment depends on the total effects of multiple pressures. As stressed by USEPA (1995), diagnosis of the causes of particular environmental or societal changes is usually difficult and multiple causation is the norm rather than the

The post-monitoring approach measures project pressures and focuses on the timely prevention, restriction or remediation of environmental damage: this strategy identifies the pollution source instead of only evaluating the imact on the state of the environment

Table 3. Indicators belonging to the INDICAMP categories and their score (from 1 to 3)

Indicators: Categories	Indicators: Units	Relevancy	Feasibility
Pressure			
Oil spill	kg/year	3	2
Fish discharge	tons live weight/year	3	3
Dredging operation	m^3/year	3	3
Dredge material disposal	m^3/year	3	3
Harbor pollution loads:			
- Discharges of domestic wastewater without suitable	m^3 discharged/year	3	2
treatment	m^3/year	3	2
- Water runoff from harbor activities (boat operation, repair and			
maintenance, cleaning, fueling station, adjacent building	t/year	2	2
areas, including parking) measured through modeling	t/year	2	1
estimations			
- Waste fish discharges			
- Solid waste discharges			
State			
Water quality:			
- pH	m	1	3
- Turbidity	mg/l O_2	3	3
- Dissolved oxygen	MPN/100 ml	3	3
- Faecal contamination indicator	mg/l NH_4, N and PO_4	3	3
- Nutrients (Nitrogen and phosphorus)	µg/l	2	3
- Heavy metals: Zn, Cu, Cd, Pb, Ni, Cb and Cr	µg/l	3	3
- Polyaromatic hydrocarbons	mg/l	3	3
- Surfactants	mg/l	3	3
- Oils	µg/l	3	3
- Polychlorinated biphenyls	µg/l	3	3
- Organotin (TBT)	nº/ m^2	2	3
- Debris and litter		3	3
Sediment quality			
- Faecal contamination indicator	MPN/100 mg	2	3
- Organic matter	%	3	3
- Redox potential	mV	3	3
- Heavy metals: Zn, Cu, Cd, Pb, Ni, Cb and Cr	µg/g	3	2
- Polyaromatic hydrocarbons	µg/g	3	2
- Polychlorinated biphenyls	µg/g	3	2
- TBT	µg/g	2	2
Macrozoobenthic community structure (assessed through species richness, abundance, biomass, species diversity, evenness, and *k*-dominance curves, among others)		3	1
Effects			
Sediment quality assessment (eg toxicity tests, macrozoobenthic communities disturbance assessment, Sediment Background Approach, Sediment Quality Triad Approach, Equilibrium Partitioning Approach)		3	2/1
Effects on the quality of organisms used in human diet:			
- presence of faecal contamination in bivalvia	MPN indicator of faecal	3	3
- ictiofauna deformations	contamination/g FW	1	3
- molluscs/crustaceans, bioaccumulation of cont.	% deformations in vertebrae or ural	3	2
- bivalvia, biotoxines accumulation	plates	2	2
	µg contaminant/g FW		
	µg biotoxine /100 g FW		
Organism mortality – fish	visual inspection of the number of deaths/species/year caused by project activities	3	3
Beach quality	number of beaches with bad quality water/year	2	2
Responses			
Environmental law compliance	eg Nitrate, Water Framework and Sewage Sludge Directives (yes/no) or % regulatory requirements enforced	3	3
Dredging management program	eg m^3 of dredged material under management program	3	3
Waste management program	eg % of solid waste collected in appropriate containers	3	3
Waste water and water runoff management program	eg % of heavy metals removed by runoff control systems, like filtering practices	3	2
Boat washing and repair management program	eg % of boats washed without using toxic cleaners	3	3
Fueling station and petroleum control management program	eg oil spills near fueling station	3	3
Fish waste management control	eg % of fish reused as bait	3	2

(*continued*)

Table 3 (*continued*)

Indicators: Categories	Indicators: Units	Relevancy	Feasibility
Monitoring performance indicators			
Training personnel	Number of persons allocated to the monitoring program submitted to environmental monitoring training courses	3	3
Monitoring investments and expenses	10^3 euros/Environmental Component of the Monitoring Program (ECMP)	3	3
Environmental monitoring activities	Number of sampling monitoring campaigns/ECMP	3	3
Institutional cooperation with other monitoring activities	number/ECMP	3	3
Harbor monitoring staff with environmental diary tasks	number of persons/ECMP	3	3
Environmental education and awareness campaigns	number of citizens/voluntary ECMP campaigns	3	3
Stakeholders' feedback to monitoring information	number of messages received by mail/ECMP	3	2
Monitoring reporting and communication to stakeholders	reports; workshops; Internet; e-mail lists/ECMP	3	3
Average cost of monitoring indicator	euros/indicators used in ECMP	3	3
Chemical use in monitoring activities	eg loads of monitoring reagents reaching harbor waters/ECMP	3	2
Use of environmentally preferable products and equipment in monitoring activities	number of environmentally preferable products /ECMP	3	2
Identification of unexpected environmental impacts under EIS	number/ECMP	3	2
Monitoring results used to validate impact prediction methods	number of predictions methods validated/ECMP	3	2
Effectiveness of mitigation measures	number of mitigation measures redesigned/ECMP	3	3
Implementation of environmental practices on the basis of monitoring results	number/ECMP	3	3
Analytical measurements and related detection levels	eg number of indicator measurements under analytical detection level/ECMP	3	3

exception. One way to deal with this complexity when designing monitoring programs is to avoid analyzing unique linkages, and to try to adopt an integrated approach that relates different indicators as clusters with multiple aspects that interact with each other.

Conclusions

Post-decision monitoring is an essential step in the EIA process if the predicted impacts, the efficiency of mitigation measures and the shortcomings of prediction methods, measures and even regulations are to be verified and EIA practice improved. However, post-decision monitoring programs within EIA are fairly undeveloped compared to the pre-decision stages, as various problems arise at this stage, particularly related to financial and time constraints and proponent negligence.

Environmental indicators could contribute to designing and evaluating monitoring programs, thus improving establishment of the cause–effect relationship and the reporting and communication of environmental data, as the early-warning signals of a prevention strategy.

Based on the environmental indicator frameworks PSR/E, DPSIR and ISO 14031, a conceptual methodology to design and assess post-decision monitoring programs — INDICAMP — has been presented and discussed. This tool allows the incorporation of a systems analysis approach and the identification of the main cause–effect relationships between the different categories of monitoring indicators.

A remaining issue of EIA follow-up is to assure the effectiveness of monitoring programs. To accomplish this, a performance assessment tool such as the one included in the INDICAMP method appears to be useful. Moreover, the use of INDICAMP within EIA follow-up could contribute to increasing research activity in this domain.

The case study showed examples of the indicators belonging to the different categories and also illustrated the benefits and drawbacks of the INDICAMP framework. Some difficulties arise in choosing the indicators for each category and in finding system interactions. Despite this, the method seeks to represent an area-oriented approach, focus on prevention and find simple relationships in project activities/environmental effects. Multiple causalities have also to be analyzed to diagnose the causes of particular environmental or societal changes.

The baseline monitoring data and the preconditions to support the INDICAMP monitoring-indicators system are fundamental to assure that the pressure, state, effects and responses categories assess project activities, and not other activities.

This framework could be adapted to other kinds of environmental monitoring programs, thus making the reporting of monitoring data easier for the general public.

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