THE DPSIR FRAMEWORK APPLIED TO THE INTEGRATED MANAGEMENT OF COASTAL AREAS

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1 INTRODUCTION

Over the last decades numerous and diverse problems with ecological implications have challenged both environmental scientists and decision-makers. These problems have ranged in scale and magnitude: global climate change, loss of habitat and biodiversity, habitat destruction, and effects of multiple anthropogenic chemicals on ecological systems. Extant and emerging problems have highlighted the need for flexible approaches to deal efficiently with the problems by establishing a link between ecological data with the needs of decision-making environmental managers. Several methodologies and tools have been developed and used to face the multifaceted challenges posed by the management of resources where apparent conflicts of interest exist. Ecosystem function is affected by human activities through the disturbance of energy and matter flow (Ohl et al. 2007). These changes in ecosystem processes influence biodiversity, change the ecological state of ecosystems and impact both on society and the economy. Thus the inclusion of socio-economic dimensions into standard ecological research has been identified as a challenge in the new paradigm of sustainable development and management of natural resources. Efforts to expand the understanding of these interdependencies have led to improvements over the last decade Bowen and Riley 2003), mainly by using socio-economic indicators that link the changes in environment to social and economic drivers, and political responses. The challenge has been to understand the relationships between social/economic interests and associated environmental issues, which require practical evaluation techniques based on an interdisciplinary approach.

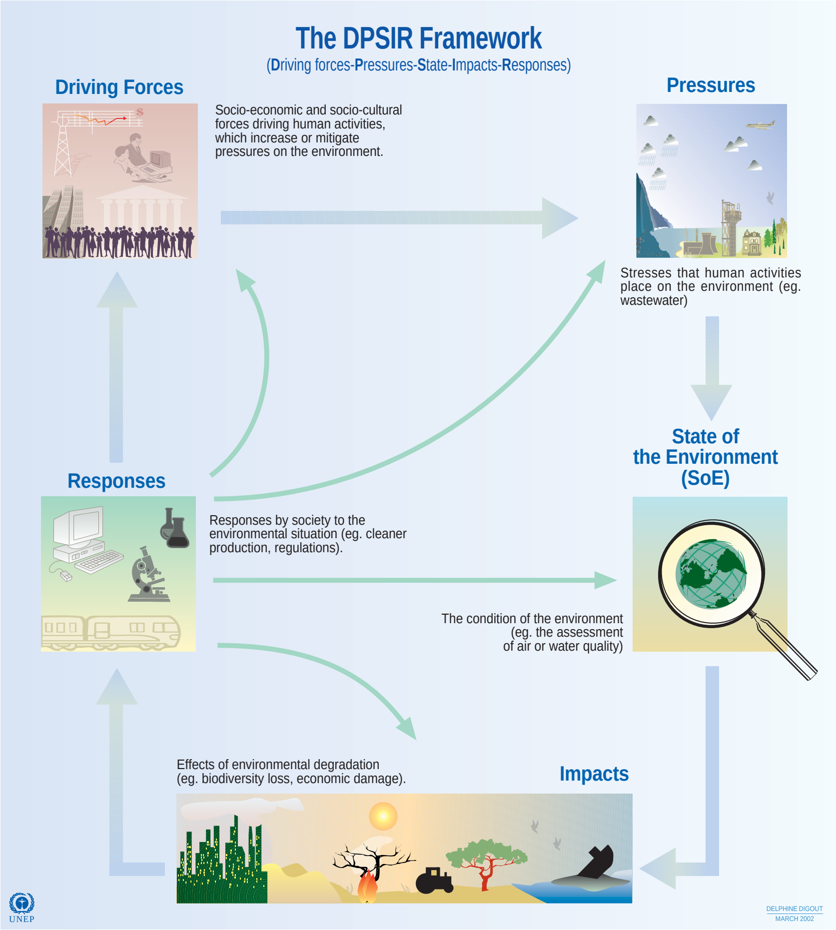
Together with the multidisciplinary approach required by the new demands on the management of resources with a holistic perspective, a multi-sectoral approach must also be considered. The parties involved in the process: scientists, civil servants and stakeholders all speak different languages, function in response to different reward systems, and work on different time scales. The realization of the magnitude of these problems led to the development of integrative approaches able to deal with these diverse requirements and still provide realistic solutions. The DPSIR (Drivers-Pressures-State-Impact-Responses) framework is such a tool (Figure 1), allowing the description of environmental problems by defining the relationships between anthropogenic activities and the environment. The framework provides a better context in which to integrate different types of indicators, opening the possibility of taking into account not only the environmental but also the socio-economic impacts that result from changes in the state of coastal systems. Also, it places side-by-side environmental and socio-economic interests. The DPSIR framework helps to allow sustained and routine provision of quality environmental data and information and the availability of sound scientific advice to enable responsive government decisions and to enhance the effectiveness of management actions.

2 THE BACKGROUND OF THE DPSIR FRAMEWORK

The origins of the DPSIR framework go back to the Stress-Response framework developed by Statistics Canada in the late 1970s (Rapport and Friend 1979). This first framework was later extended in the 1990s by, among others, the Organization for Economic Co-operation and Development (OECD 1991, 1993) and the United Nations (UN 1996, 2001), resulting in the PSR (Pressures, States and Responses) framework. Also during the 1990s, this paradigm was further extended to its present form of the DPSIR framework, originally in two studies by the European Environmental Agency (EEA 1995, Holten-Andersen et al. 1995). The objective of these frameworks has been to clarify multi-sectoral relationships and to highlight the dynamic characteristics of the ecosystems and socioeconomic changes (Elliott 2002). All these frameworks share the distinction between (i) forces that act on the environment, (ii) changes that, as a consequence, take place in the environment and (iii) the societal reaction to those changes. The DPSIR framework follows the same general model as previous frameworks but diverges in the sense that it distinguishes more steps in the process (Niemeijer and de Groot 2008). So while there are some differences between these frameworks in terms of terminology and the degree of detail, they are all based on the causal chain concept.

The DPSIR Framework is an instrument for analyzing environmental problems, with regards to sustainable development (Borja et al. 2006). The basic aims of its approach are: (i) to be able provide relevant information on the different elements of the DPSIR sequence, (ii) to clarify the ways in which they are connected and related to each other and (iii) to estimate the effectiveness of responses. The DPSIR framework provides helpful insights on the relationships between the origins and consequences of environmental problems and, at the same time, helps to understand their dynamics by addressing the links between DPSIR elements. This integrative approach presupposes substantial understanding of the underlying causal relationships between human activities and the resultant impacts on ecosystems, coastal economies and communities, and human response mechanisms. Nevertheless, the integrative nature of the framework leads to its wide use, especially by the European Environmental Agency, in selecting indicators for evaluating the implementation of EU environmental policies.

The DPSIR framework has rapidly become popular among researchers and policy makers alike as a conceptual framework for structuring and communicating relevant environmental policy research (Svarstad et al. 2008). For this reason it has been successfully implemented in different kinds of coastal management issues, and its contribution to highlight the dynamic characteristics of ecosystem and socio-economical changes has been validated (Turner et al. 1998). A presumed strength of the DPSIR framework lies in its simplicity to capture key relationships between factors in society and the environment. While simple in concept, the framework is flexible enough to be conceptually valid over a range of spatial scales (von Bodungen and Turner 2001). Consequently, it can be used as a communication tool between scientists from different disciplines as well as between researchers, on the one hand, and policy makers and stakeholders on the other.



Source : Global International Water Assessment (GIWA), 2001; European Environment Agency (EEA), Copenhagen.

FIGURE 1: *DPSIR framework for State of Environment Reporting (UNEP/GRID-Arendal 2002).*

3 THE HEURISTIC DPSIR-CONCEPT

The Driving forces-Pressure-State-Impact-Response concept (DPSIR) provides a heuristic framework for the analysis of cause-effect relationships in complex systems which are subject to human action (Brandt 2000). The general idea behind the DPSIR concept is that human activities, i.e. the drivers, exert a certain pressure on a particular part of the natural environment causing a change in its components and/or in its overall state. The outcome of this process is an environmental impact, which usually results in certain responses by society. The response can run across different segments of society, from the political arena, to socio-economic and purely economic sectors. Eventually, responses can modify the nature of the driving forces (thus mitigating or even enhancing the actual pressure) and/or compensate for the impact. Finally, the driving forces may also be altered directly by the impact.

A clear example in many estuaries relates to sewage discharges in the system. The increased demand for housing (Driving force) can lead to the intensification of direct discharges of untreated sewage in the waters, resulting in the increase of nutrient loads and faecal contamination of nearby streams (Pressure), leading to the eutrophication of water bodies (State) and subsequent changes in aquatic life and biodiversity and contamination of food resources (Impact). One way to address this situation (Response) would be to improve the sanitary system; another would be to require changes in occupation practices and even to ban the consumption of contaminated marine organisms such as shellfish.

3.1 Drivers of (environmental) change

The first step in the DPSIR framework is the definition of the driving-forces that lead to environmental pressures. For this first step it is important to identify the major stakeholders, their values and interests, and also the potential conflicts between them. A driving force, also termed a driver, is an established social need that represents a factor and social force that may induce changes in the state of the environment. This social need usually arises from the economical sphere, which means that drivers are frequently linked to the financial system. As such, drivers are usually considered to be economic and social goals of those involved in the industry, as well as economic and social policies of governments. In coastal areas, shipping, fisheries, tourism and aquaculture are among the most commonly mentioned drivers of DPSIR models.

3.2 Pressures (on the environment)

Pressures can broadly be described as the means through which drivers are actually expressed, i.e, in the way they interfere and perturb the system. Inside the framework, pressures are the link between socioeconomic activities and the natural system. In a sense, all human activities end up by generating pressures on the environment, to a lesser or greater degree. The existing pressures on estuarine and coastal areas can be divided into four groups: (i) pollution, comprising urban, industrial, agricultural and aquaculture discharges; (ii) alteration of the hydrological regime, including water abstraction, flow regulation and restoration activities; (iii) changes in the morphology, including land reclamation and infrastructures; and (iv) biology and its uses, including all kind of resource exploitation, changes in biodiversity and recreation (Borja et al. 2006). As such, pressures fall into three general categories that range from simple interference to inducing changes in the natural functioning of ecosystems: (a) fluxes into water bodies, (b) excessive usage of natural resources, and (c) changes in the food web.

3.3 The state of the environment

The combination of physical, chemical and biological conditions defines the state of the environment in a given area. This state is affected by the pressures and eventually modified in its environmental conditions. The result of this induced change may be expressed as a loss of ecosystem services. So, if the state is changed, human dependence on the system may also be compromised (e.g., loss of fish stocks, bathing areas, etc.). Although there is a link between pressure and state, the relationship between them in estuaries is strongly influenced by geomorphology and hydrodynamics: estuaries subject to similar nutrient-related pressure often exhibit totally different eutrophication symptoms, and in some cases no symptoms at all. Factors such as flushing time, tidal range, and turbidity play a major role in determining the nature and magnitude of symptom expression.

3.4 Environmental and societal impacts

The state of the system needs to be assessed in terms of its physical, chemical and biological conditions, and this leads to the definition of impact on each component. Thus, impacts correspond to the effects resulting from the change in the state of the ecosystem. Usually these effects are studied by identifying changes in bio-physical-chemical conditions that lead to changes in the components of the environment (e.g. water quality, biodiversity etc.). However, this has also impacts on society. Hence, environmental impacts are related to the health of the ecosystem, while social impacts are linked to effects on human health and to the effects and resources that society identifies as valuable. An assessment of the impacts requires monitoring procedures and the definition and use of indicators of change.

3.5 Societal responses

The DPSIR model assumes that all pressures degrade the ecosystem, and that this negative impact can only be reverted through subsequent responses. This means that the magnitude of the impacts may lead to a re-evaluation of current management policies and may eventually lead to the realization of the need of different management responses. In this sense, a response is a societal action related to an actual environmental problem or perceived risk. This action, often moved by public policies of governmental actors, can also be stimulated by other sectors of civil society such as NGOs, universities, etc. A response can be described as a reaction to the negative effects of impacts. The responses vary according to the scale of the impacts, becoming an attempt to mitigate the impacts or reverse them in an attempt to reestablish the ”normal” state of the system, if possible. If preventive measures are taken to eradicate or ameliorate the impacts of pressures in the system, then it will change the original drivers.

The human or societal response to the changes resulting from our activities has to be established to meet what we may call *six tenets for environmental management* (Elliott 2002). Some of these tenets are well-known in national and international strategies (the first three), while others need to be considered to guarantee that solutions to environmental change sit within our developed systems. Accordingly, our actions (Responses) have to be: (1) Environmentally sustainable (i.e. nature-friendly in the present and in the future); (2) Technologically feasible (i.e. with adequate methods and equipment); (3) Economically viable (i.e. at a reasonable and supportable cost); (4) Socially desirable (i.e. wanted by our societies); (5) Legally permissible (i.e. in compliance with national and international legislation); (6) Administratively achievable (i.e. carried out and enforced by our system of departments, agencies and governments).

4 METHODOLOGIES USED IN THE DPSIR ANALYSES

The integrative nature of the DPSIR framework in the study of human-ecosystem interactions means that a significant range of techniques, methodologies and tools must be used to achieve that end. The temporal scope of the framework, with processes spanning across different time scales, and addressing present and future states, requires these methodologies and tools to diagnose and predict. Some of the procedures are of a descriptive and static nature, i.e. they give a snapshot of the actual state of the system (e.g., environmental indicators, conceptual models), while others are dynamic, meaning that they can describe the temporal evolution of the system to some degree (e.g. mathematical models).

4.1 Environmental indicators

The use of indicators is fundamental in the DPSIR framework because they provide an objective system of information and evaluation. An indicator can be described as something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable (Hammond et al. 1995). In the DPSIR context, the European Environment Agency (EEA Glossary, 2007) describes an environmental indicator as "*a parameter or a value derived from parameters that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces and the responses steering that system.*" As such, an environmental indicator is a qualitative or quantitative parameter characterizing the current condition of an element of the environment or its change over time. Such environmental indicators have three basic functions (Aubry and Elliott 2006):

- To simplify, considering that only a few indicators are selected according to their perceived relevance for characterizing the overall state of the ecosystem.
- To quantify, because the value of an indicator is compared with reference values considered to be characteristic of the state of the ecosystems, thus quantifying the shifts from reference or expected conditions.
- To communicate, by facilitating the transmission of meaningful information on environmental issues to stakeholders and policy makers, by promoting information exchange and comparison of spatial and temporal patterns.

Indicators are increasingly being developed and used as management tools to address environmental issues. Over the last years, environmental indicators have taken on such importance because they provide a signal that communicates a complex message in a simplified and useful manner (Jackson et al. 2000). Also, environmental indicators provide an important source of information for policy makers and help to guide decision-making as well as monitoring and evaluation, because they can provide valuable information on complex issues in a relatively accessible way.

Environmental indicators have come to play a vital role in environmental reporting as prime assessors of pressures on the environment, of the evolving state of the environment, and of the appropriateness of policy measures (Niemeijer and de Groot 2008). But because they are so important, it is a major challenge to determine which set of parameters and values of ecological systems characterize the entire system and still are simple enough to be effectively and efficiently monitored and modelled (Dale and Beyeler 2001). Indicators, therefore, need to be properly selected and the methodology of their calculation specified if the dynamic parts of a given system are to be understood and appear compelling to the user communities (Bowen and Riley 2003).

4.2 Environmental modelling

Environmental modelling is an explicit treatment of our understanding of the deterministic and stochastic mechanisms that affect our studied object (Akçakaya et al. 1997). Numerical models stand as a way to look at real systems and to translate them into compartments, identifying the connection between them. They are versatile tools that enable an in-depth look at natural systems which cannot be achieved by the simple combination of analytical methods. The use of models makes it possible to explain cause and effect in environmental processes, distinguish between anthropogenic and natural contaminant sources and their respective impact, etc.. Modelling results are also important to complement and interpolate data from traditional observational research methods. Because models have the capability to bridge the gap between small scale and large scale processes, they become an essential tool for understanding complex processes that link different compartments of the system (e.g., benthic and pelagic systems) and run across the land-sea interface by linking catchment and estuarine processes. This is particularly relevant in eutrophication-related studies, where nutrient dynamics can be addressed in the vast context of major biogeochemical cycles (Harrison 1992).

Models are increasingly becoming indispensable tools in environmental studies and management decisions (Neves 2007). In the DPSIR framework, models are commonly used to elucidate each component and the relation between the different components (e.g., the pressures with the state). Combining the DPSIR with numerical models allows the generation of predictions on potential levels of selected impacts, making responses actions ”prior” to the full manifestation of those impacts in the environment. However, it is obvious that no model will ever be able to address all problems and answer all questions. For this reason there are so many types of models. Water quality models, ecological models, hydrodynamic and groundwater models are just a few examples.

Most models address specific disciplines of knowledge but can be coupled to other models to achieve an integrated model approach to the study of natural systems. The use of models in decision making must have the main objective of improving communication and understanding of the nature of the problems. If they achieve this goal, the results they produce will be integrated quite naturally with value judgments and political constraints. This will result in better decisions than would have been made if the models had not been used. To produce this outcome, models must be carefully and thoroughly documented, and limitations, sensitivities and assumptions must be explicitly stated. In addition, modelers must be sensitive to the needs and limitations of the people who intend to use them. It is as important, if not more important, for the ecologist to communicate the uncertainties and assumptions underlying the model, as it is to communicate the set of predictions. Ultimately, the relevance of models for environmental decision-making is in the mind of the policy maker, and not in the expert opinion of the modeler.

4.3 The role of conceptual models

It is questionable whether we will ever have fully validated numerical models that can adequately predict the ecological effects of human activities. Even so, models can be seen as serious attempts, and probably the most adequate, to relate human drivers with ecological states. The first step towards creating such models is to have some knowledge on the physical and biological features of the system and the definition of the problem, hence the production of conceptual models. Considering trends in marine environmental management, it is in fact fundamental to develop conceptual models. For simplicity, these can be regarded as diagrams which bring together and summarise information from many areas.

The schematic approach of conceptual models confer them the simplicity that lengthy and detailed descriptions cannot. As such, they have an educational significance and at the same time provide the basis for communicating the main message to managers and developers. Conceptual models are usually a good starting point for developing quantitative and dynamic numerical models, or to point to the limitation of such models and the available scientific knowledge. They also have the advantage of exposing gaps in knowledge, thus helping to define further field and laboratory studies to fill these gaps. In particular, they allow a problem to be deconstructed as a precursor to each aspect being assessed, prioritized and addressed (Elliott 2002). Under the DPSIR framework it is essential to be aware of the spatial and temporal links in the marine system. This, in turn, has to be coupled with the diverse nature of stressors on the systems which requires conceptual models to be linked together and further developed towards numerical and predictive models.

4.4 Stakeholder’s involvement through participation

”*Environmental issues are best handled with participation of all concerned citizens, at the relevant level*”. This is the introductory statement of Principle 10 of the Rio Declaration on

Environment and Development (1992). This principle states that individuals must have the opportunity to participate in decision-making processes and that States shall promote and encourage public awareness and participation by making information widely available. Coastal management programs must ensure strong public involvement of stakeholders, because they represent the people who are most affected by the coastal development process. This is best achieved by making public education and consensus-building important components of any initiative. The responsibility of stakeholders must go well beyond the awareness to participate in the decision making process; they must also be held accountable for such task.

A way of incorporating stakeholders' opinions into the decision-making process has been through the methodology of participative experts' model (Failing et al. 2004). In this strategy, the model of the system, irrespective of the complexity, starts by being generated with the participation of some stakeholders or social actors. As a rule, the chosen stakeholders are those that the group of experts identifies as more relevant to the potentially analyzed problem. This degree of involvement confers common sense to the modelling exercise by keeping the aims of scientists at realistic levels, and assures that the model is not socially naive. An open dialogue between scientists and stakeholders is necessary in order to make decisions regarding what can be done and what shall be left either to other scientists or other modelling tools, or both. As addressed before, the most important feature about models is that they must be relevant to decision-makers. This means that if models do not include stakeholders in their development, the study on the availability of significant societal resources might be doomed to failure. If the process of model building is collaborative and iterative, and if it involves representatives of all stakeholders, it has a chance of being realistic, hence useful, i.e., will have the ability to answer the right questions.

A well-structured decision process involving stakeholders can typically be summarized in three key steps Keeney 1992, Clemen and Winkler 1999):

- Setting objectives and indicators for each of them. These indicators (also known as performance measures) become the criteria for evaluating and comparing policy alternatives. Since setting objectives is a deliberative and value-based activity, it demands input from a broad range of stakeholders. Defining indicators is both deliberative and analytical, requiring involvement from both technical specialists and stakeholders.
- Identifying policy alternatives and assessing their impact on the objectives. The impact of the policy alternatives is measured by the indicators. The description of impacts should explicitly characterize the uncertainty associated with the estimate. This is an analytical activity, conducted largely by technical experts, with input from stakeholders in the form of selecting the experts and defining their terms of reference.
- Evaluating and choosing a preferred policy alternative. Choices will most likely involve trade-offs among competing objectives and methods for making choices should allow stakeholders to state their preferences (value-based information) for different outcomes, based on good information (factual or technical information). This again is a deliberative task involving both scientific and stakeholder participation.

5 THE DPSIR FRAMEWORK AND THE INTEGRATED COASTAL ZONE MANAGEMENT

Integrated Coastal Zone Management (ICZM) promotes sustainable management of coastal areas in a dynamic, multidisciplinary and iterative process. It includes all the processes involved in this task, from information collection, planning, decision making, management and monitoring of implementation. It is also a process that involves the informed participation and cooperation of all relevant actors to evaluate the societal goals in a given coastal area, and to take actions towards meeting these objectives. In the long term, ICZM tries to achieve a balance between environmental, social, economic and cultural goals, always keeping within the limits set by natural dynamics. The integrative nature of this approach is in its range of objectives, but also in the integration of the many instruments needed to meet these objectives, as well as the integration of the terrestrial and marine components of the target territory, in both time and space.

In recent times, a few new concepts have come out related to coastal managemen, whose application has been encouraged by institutions (i.e. EU Parliament and council 2002/413/EC), and the DPSIR framework as a tool for the former. The ICZM concept is based on a holistic approach to manage conflicts between different coastal uses and interests (aquaculture, resource extraction, tourism, housing, etc.) and to facilitate the use and dissemination of information, especially between society, managers and scientists. Today, DPSIR is increasingly used as a framework for structuring case studies in relation to issues of human interferences in an effort to manage landscapes and seascapes (Elliott 2002, La Jeunesse et al. 2003, Scheren et al. 2004, Holman et al. 2005). The DPSIR approach has become increasingly accepted and applied to different case studies to solve problems involving a range of coastal marine environments: coastal areas, coastal lagoons, deltaic systems, estuaries, river basins. A summary of applications of the DPSIR framework to marine environments is presented in Table 1. In this sense, the DPSIR framework has received much attention and use in ICZM strategies and programs.

ICZM efforts worldwide face major challenges. This is particularly evident in estuarine management, where the goal is to balance environmental constraints with social needs, while maintaining the habitual fragile balance between ecosystem performance and human-related activities. Because of their nature, societal goals can only be achieved together with environmental goals with the development of an integrated and holistic approach. The DPSIR framework is an effective way to deal with complex issues, such as the management of nutrient fluxes (Smith et al. 1999) and the impact of development in catchment areas (Cave et al. 2003), inside the broader scope of the ICZM programs.

6 FUTURE PERSPECTIVES

There are no straightforward answers to the question of what is best for a particular system when there are potential conflicts between natural and economic interests. It is the task of scientists from different disciplines to present as complete as possible a picture to those who make decisions or have the capacity for lobbying in the decision-making process. To achieve a holistic view of these systems and fully incorporate the needs of policy-makers, frameworks such as the DPSIR framework are essential. In complex ecosystems like estuaries, where the human presence and activity is growing at an alarming pace, there is an urgent need to link science (the knowledge on the system functioning) to the causes of change in its state and to the social, economic and legal responses by Man to that change. This necessity is behind the increasing use of the DPSIR approach (Elliott 2002).

TABLE 1: *A summary of applications of the DPSIR framework in ICZM strategies.*

Study site	Area	Subject	Reference
Guanabara Bay basin (Brazil)	River Basin	Sustainable Development	Bidone and Lacerda (2004)
Thermaikos Gulf (Greece)	River Basin	Hindcasting coastal evolution	Karageorgis et al. (2006)
Po Catchment-Adriatic Sea (Italy)	River Basin & Coastal area	ICZM	Pirrone et al. (2005)
Aixos River catchment and Thermaikos Gulf (Greece)	River Basin & Coastal area	Eutrophication	Karageorgis et al. (2005)
Southern European Coastal Lagoons	Coastal Lagoons	ICZM	Aliaume et al. (2007)
Sacca di Goro (Northern Adriatic Sea, Italy)	Coastal Lagoon	Aquaculture impacts	Marinov et al. (2007)
UK Coast	Coastal area	Offshore wind power	Elliott (2002)
Nestos Delta (Greece)	Coastal area	Environmental status indicators	Karakos et al. (2003)
Italian Coast	Coastal area	Coastal environment assessment	Casazza et al. (2002)
Ria Formosa (Portugal)	Coastal Area	Dredging activities	Pacheco et al. (2007)
Ria Formosa (Portugal)	Coastal Area	Eutrophication	Newton et al. (2003)
Bay of Gdansk (Poland-Russia)	Coastal Area	Eutrophication	Kannen et al. (2004)
German Coast	Coastal Area	Future Planning	Kannen (2004)

DPSIR was projected to explicitly relate environmental changes driven by socio-economic pressures with the required socio-economic measures to mitigate adverse impacts of change caused by human actions. For estuaries and coastal areas in general, the DPSIR analysis has the ability to link large-scale human drivers of change and their impacts on the systems, with management responses (e.g., sewage treatment, preservation of mangrove areas, modifying dredging activities, etc.). A major advantage of the framework lies in its capacity to integrate socio-economic aspects with ecological impacts, addressing not only the consequences of human activities on the system, but also its feedback.

The DPSIR framework works well at simplifying the complexity of natural systems management, such as estuarine areas, at the same time informing policy makers, scientists and the general public on the actions that can cause changes in the status of the system and the nature and consequences of those changes. Several shortcomings have been ascribed to the DPSIR framework as a tool for establishing effective communication between environmental scientists of different disciplines, and between stakeholders and policy makers. One of these shortcomings seems to be the lack of efforts to find a satisfactory way of dealing with the multiple attitudes and definitions of issues by stakeholders and the general public (Svarstad et al. 2008). Nevertheless, this framework has proven to be an effective way to deal with the complex task of managing natural system when real conflicts exist in regard to their use and transformation and, most important, a central methodology for establishing cause-effect relationships in the use and exploitation of natural resources and their status. The DPSIR framework is a practical tool for testing observations and hypotheses. It is being used successfully and increasingly as a research aid to interpret ecological relationships in ongoing evaluations of management alternatives and to develop effective ecological and societal targets for a meaningful, conflict-free, sustained and sustainable development.

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