Ocean & Coastal Management 103 (2015) 63–77

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Review

# A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems

Sirak Robele Gari [a, c, *], Alice Newton [b, c], John D. Icely [c, d]

[a] FUECA, Oficina Erasmus Mundus, Aulario Norte, Campus de Puerto Real, 11519 Puerto Real, Cadiz, Spain
[b] NILU-IMPEC, Box 100, 2027 Kjeller, Norway
[c] CIMA-University of Algarve, Gambelas Campus, 8005-139 Faro, Portugal
[d] Sagremarisco, Apt 21, 8650-999 Vila do Bishop, Portugal

ARTICLE INFO

*Article history:*
Received 11 May 2014
Received in revised form
15 November 2014
Accepted 16 November 2014
Available online 22 November 2014

*Keywords:*
Driver-pressure-state-impact-response
Social-ecological systems
Coasts

ABSTRACT

The applications of the Driver-Pressure-State-Impact-Response (DPSIR) framework were reviewed for several Social-Ecological Systems (SES), with an emphasis on the coastal environment. The evolution of DPSIR was traced from the Stress-Response framework to its present form. Discrepancies in the definitions of the DPSIR's information categories are presented. The application of the framework was explored both as a discrete tool and combined with other methods for different coastal and estuarine systems and biodiversity. The overall merits and limitations of the DPSIR framework are discussed in a critique. Several recommendations are suggested for refining the framework to overcome its limitations. Finally it is concluded that an updated DPSIR framework is a useful adaptive management tool for analyzing and identifying solutions to environmental problems.


## 1. Introduction

A Social–Ecological System (SES) is formed when humans interact with their environment. Thus, an SES is an ecological system intricately linked with and affected by one or more social systems (Anderies and Ostrom, 2004). River catchments and coastal zones constitute one of the most vibrant social-ecological systems in which human societies and other organisms interact with the physical environment and with one another. Due to the proximity of water, coasts and river banks have always been cradles of human civilizations and sites of intense economic activities (e.g Rivers Tigris, Euphrates, Ganges and the Nile delta). Coastal zones comprise only 20% of the earth's surface but contain over 50% of the world's population (ICRI, 2005).

The need for more comprehensive environmental accounting frameworks is high (de Jonge et al., 2012) and adaptive management uses management framework tools to address existing and emergent problems. Several frameworks have been developed and used for the adaptive management of SES. For example, Olsen (2003) proposed the Outcome Approach to assess the progress of Integrated Coastal Management (ICM). The Millennium Ecosystem Assessment (MEA, 2005) uses a framework linking drivers, ecosystem services and human well-being. Ostrom (2009) constructed a general framework for analysing SESs. Similarly, a Systems Approach Framework (SAF) has been developed and used for the assessment of complex coastal systems to facilitate the implementation of European environmental policies while achieving sustainable development (Newton, 2012).

The Driver-Pressure-State-Impact-Response (DPSIR) framework is one of the original tools developed by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995) for the adaptive management of SESs. It links cause-effect relationships among the five categories of the framework and has been used for analysing and assessing the social and ecological problems of aquatic systems subject to anthropogenic influence. The information from the DPSIR analysis has been used to develop Integrated Coastal Zones Management (ICZM) (e.g. Pacheco et al., 2006) and Integrated Water Resources Management (IWRM) systems (e.g. Kagalou et al., 2012). Although the DPSIR framework is considered a valuable tool (e.g. Bidone and Lacerda, 2004; Caiero et al., 2004; Karageorgis et al., 2006), it has been proposed that it could be improved through combination with other methods (e.g. Pacheco et al., 2006; Maxim et al., 2009; Bell, 2012). The application of DPSIR for

* Corresponding author. FUECA, Oficina Erasmus Mundus, Aulario Norte, Campus de Puerto Real, 11519 Puerto Real, Cadiz, Spain.
*E-mail address:* sirakr@gmail.com (S.R. Gari).

http://dx.doi.org/10.1016/j.ocecoaman.2014.11.013
0964-5691/

environmental assessment, particularly for coastal SESs, is the main focus of this review; together with a critique and analysis of the evolving improvements to the framework.

## 2. Method

Of the 79 articles selected, from journals, reports, monographs, book chapters, books and conferences, 41 were on coastal issues (52%), 11 were related to terrestrial or general issues (14%), 9 considered the development and evolution of the DPSIR framework (11.4%), 9 covered biodiversity (11.4%), 5 considered sustainability (6.3%)) and 4 considered water resources in general (5%). Works dealing with the development and evolution of DPSIR served as a backbone by providing definitions and a history. Some materials dealing with biodiversity were used as they showed some innovations (e.g. combining DPSIR with other methods) and a distinct view with regard to the DPSIR (e.g discursive bias). 25 of the papers published since 2003 were used to demonstrate the application of DPSIR in more detail, with 21 and 4 focussing specifically on coasts and biodiversity, respectively.

## 3. History and evolution of the DPSIR framework

Statistics Canada developed the Stress-Response (S-R) framework in 1979 with the response category comprising both environmental and societal responses (Friend and Rapport, 1991). This evolved into the Pressure-State-Response (PSR) and subsequently the DPSIR frameworks (OECD, 1993; EEA, 1995; Klotz, 2007; Svarstad et al., 2008).

The OECD used the PSR framework for the evaluation of environmental performance, using a core set of selected indicators (OECD, 1993; OECD, 2004). The OECD (1993) provides clear messages through indicators representing the categories of the chain that simplify the information conveyed to broad groups of stakeholders and the general public, thus enhancing the transparency of decision-making. Indicators can also be used to assess the effectiveness of the actions and policies implemented, by measuring progress towards environmental targets (OECD, 1993). The PSR has also been used by other authors (e.g Bricker et al., 2003; Ou and Liu, 2010) for coastal issues.

EEA (2003) defines each category of the DPSIR framework as follows: driving forces describe the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption, and production patterns; pressure indicators describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities; state indicators give a description of the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric $CO_2$ concentrations) in a certain area; the changes in state produce impacts on the functions of the environment, such as human and ecosystem health, resources availability, losses of manufactured capital, and biodiversity; and finally responses are the actions taken by groups (and individuals) in society as well as the governments' attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment.

The DPSIR framework (Fig. 1) was first elaborated in the European Environment Agency (EEA) programme that sponsored the Dobris Assessment of Europe's environment (Air, Water, and Soil) and has been adopted subsequently for other environmental issues in Europe (EEA, 1995). This framework is an adaptive management tool used for analyzing environmental problems by establishing cause-effect relations between anthropogenic activities and their environmental and socio-economic consequences. It brings together natural science, social science including economics in one framework for adaptive management and considers human activities as an integral part of the ecosystem, (Zaldívar et al., 2008).

In the DPSIR framework, the causal links start with driving forces, pass through pressures to state of the environment and impacts on ecosystem functions and Human welfare, eventually leading to societal responses (EEA, 1999). The five categories of the framework occupy unique positions in the sequence and yet are connected and create feedback loops. The DPSIR framework has been modified by different researchers (see Table 1). Examples include mDPSIR, DPSWR, DPCER and DPSER.

## 4. Discrepancies in the application of the DPSIR information categories

Modification to the DPSIR terminology is one of the factors that has contributed to discrepancies in the application of DPSIR. In particular, the same variables are often placed under different categories (Table 2) even though the authors claim to use the same

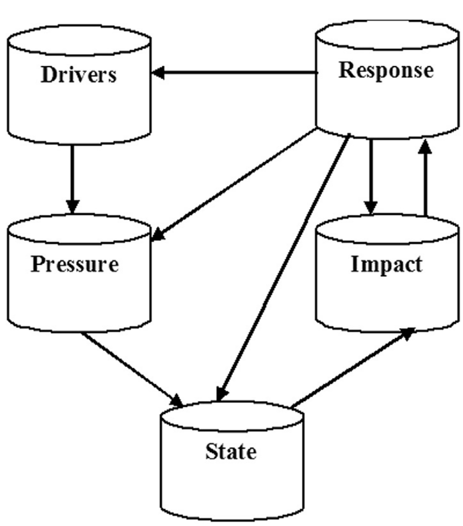


**Fig. 1.** DPSIR framework.

**Table 1**
Evolution of DPSIR.

| Reference | Evolution | Comment |
|---|---|---|
| Friend and Rapport, 1991 | S-R | Developed by Statistics Canada in 1979 with the Response category including both environmental and societal responses. |
| OECD, 1993 | P–S-R | Improved and used by OECD in 1993 for evaluation of environmental performance |
| EEA, 1995 | DPSIR | Further developed by EEA in 1995 and used in Dobris assessment of the European environment |
| Rekolainen et al., 2003 | DPCER | **C** and **E** indicate chemical and ecological State respectively. |
| Elliot et al., 2006 (also Turner et al., 1998) | DPSIR | State as change of state of the environment and/or ecosystem |
| ELME, 2007 | mDPSIR | The Impact category refers only to impact on human welfare |
| Cooper, 2012; O'Higgins et al., 2014 | DPSWR | Impact is replaced by Welfare, emphasizing impacts on Human welfare. |
| Kelble et al., 2013 | DPSER | Impact is replaced by Ecosystem services containing both negative and positive impacts on ecosystem |

**Table 2**
Examples of definitional discrepancies.

| Reference | Processes | | | | | |
|---|---|---|---|---|---|---|
| | Aquaculture | Urbanization | Species invasion | Eutrophication | Land use change | Water extraction |
| IMPRESS, 2003 | | | Pressure | | | |
| Newton et al., 2003 | | | | State | | |
| Bidone and Lacerda, 2004 | | Driver | | | | |
| MEA, 2005 | | | Driver | | | |
| Borja et al., 2006 | Driver | | | | | Pressure |
| | | Driver | Pressure | | | |
| Lin et al., 2007 | Pressure | Pressure | | | | Pressure |
| Spangenberg, 2007 | | | | Pressure | Driver | |
| Haase and Nuissi, 2007 | | | | | Pressure | |
| Zaldívar et al., 2008 | | Driver | | | Driver | Pressure |
| Omann et al., 2009 | | | | | Pressure | |
| Pinto et al., 2013 | | | Driver | | | Driver |
| Newton et al., 2014 | Driver | Driver | Pressure | State | | |

definitions for the categories (e.g the EEA, 1999). For example, Borja et al. (2006) suggest that aquaculture belongs to the driver category, whereas in Lin et al. (2007) it is included in the pressure category. Similarly, urbanization was identified as a driver (Bidone and Lacerda, 2004; Borja et al., 2006; Zaldivar et al., 2008), but it was a pressure for Lin et al. (2007). Species invasion is considered a direct driver (MEA, 2005) or a natural driver (Pinto et al., 2013) whilst others considered it as a pressure (Rapport and Whitford, 1999; IMPRESS, 2003; Borja et al., 2006).

Eutrophication is categorised as a state change in several works (e.g. Newton et al., 2003; Cooper, 2012) but as a pressure by Spangenberg (2007). Even studies on the same subject show definitional discrepancies. For example Spangenberg (2007), analysing driving forces and pressures on biodiversity considered land-use intensity as a driver; Haase and Nuissi (2007) studying the effect of urban sprawl on water balance and Omann et al. (2009) studying the threat of climate change on biodiversity considered land-use as a pressure.

In addition to differences in the placement of variables, there is a multiplicity of terminology with regard to the categories. Driving forces are subdivided as primary and secondary (Smeets and Weterings, 1999) and as underlying and immediate (Cooper, 2012) to distinguish which drivers induce pressures indirectly and directly. Others split the driving forces as physical and socio-economic to distinguish between natural phenomena and human activities (e.g. Bidone and Lacerda, 2004) and as natural and anthropogenic drivers (Pinto et al., 2013). The latter also used the term ecological driver for water extraction, which is a pressure for other authors (e.g. Zaldívar et al., 2008). Moreover, resource extraction is placed under the pressure category by several authors (e.g Borja et al., 2006; Lin et al., 2007). MEA (2003) divides drivers as indirect and direct drivers of change. Elliot (2011) subdivides pressures as endogenic managed pressures, when they emanate from within the system and can be controlled, and exogenic unmanaged pressures when they emanate from the outside and hence cannot be controlled. Atkins et al. (2011) give examples of endogenic pressures such as power generation and land claim, whereas exogenic pressures are exemplified by climate change and geomorphic activities. Further, in the conceptual diagram of the DPSIR framework, unlike the traditional approach that targets response against the four categories, Atkins et al. (2011) link it with drivers and pressures only. Newton and Weichselgartner (2014) refer to natural hazards causing coastal vulnerability as environmental drivers.

## 5. Application of DPSIR

The DPSIR approach can be employed for all ecosystems, although most of our examples will be from aquatic systems and, where appropriate, a few from terrestrial systems. DPSIR has been used to explain the causal chains of environmental consequences of an off-shore wind farm (Elliot, 2002), to identify the social and economic pressures in an estuary (Caiero et al., 2004). It has been applied in the Water Framework Directive (WFD) for protection of ground water, inland surface waters, estuaries and coastal waters (Borja et al., 2006) and for assessment of the pressure of alien species (UKTAG, 2013). Similarly it has been applied: for assessment of impacts of development activities on the coastal environment and society (Lin et al., 2007), for assessment and evaluation of drivers, pressures and state in the pre- and post-intervention periods on a coastal lagoon (Nobre, 2009); for determining sustainability indicators at coastal zones (Bell, 2012); for exploring the causes and consequences of coastal vulnerability (Newton and Weichselgartner, 2014); for examining the effects of human mobility; and for the growth and restructuring of urban settlements in coastal areas (Secoa, 2014), among others. It has also been used in the freshwater environment, for example to assess the impact of urban sprawl on the water balance of a city (Haase and Nuissi, 2007); to identify several environmental problems in a river basin, with an aim of designing an Integrated River Basin Management plan (Kagalou et al., 2012).

Apart from the aquatic environment, the DPSIR framework has a wider application. Tsai et al. (2009) used it to establish indicators of sustainable development in the European environment in general. The DPSIR approach has been applied for assessment of land and soil degradation owing to land use (Gobin et al., 2002; Blum, 2004; Porta and Poch,2011) and to assess alternative management strategies for a national park (Nebyou, 2010). Several environmental reports sponsored by international and national organizations have made use of the DPSIR framework. Some examples are the assessment of the state of forests and biodiversity (SoER, 2007; Vacik et al., 2007); the worldwide assessment of environmental impacts arising from consumption and production (van der Voet et al., 2010) and the assessment of the state and trends of the environment (UNEP, 2012).

Two features that have contributed to the wide use of DPSIR are, (i) it structures the indicators with reference to the political objectives related to the environmental problem addressed; and (ii) it focuses on supposed causal relationships in a clear way that appeals to policy actors (Smeets and Weterings, 1999). Some examples of the application of DPSIR to coastal issues are presented in more detail, both as a discrete tool and also in combination with other methods.

### 5.1. DPSIR used as a discrete tool

Bidone and Lacerda (2004) used the DPSIR framework and employed cost-benefit analysis (CBA) and gross domestic product (GDP) correction in the Guanabara bay, Brazil. The aims of the application were to qualitatively and quantitatively express the biogeochemical materials carried by rivers in to the bay, to identify the main socio-economic drivers acting on its watershed and to assess the impacts of land-based sources. The authors were able to identify the major socio-economic drivers in the region as well as the associated pressures and the resultant state change. The impacts on drinking water supply, fishing, tourism and recreation were revealed. The CBA, performed on the Policy response directed against the pressures, showed that, despite 8 years of activity and an expenditure of over $600 million, the Guanabara bay recuperation program did not produce a significant change in the water quality of the bay.

Besides the identification and analysis of the DPSIR categories, the study detected the inverse relationship between the socio-economic status and the amount of pollutant released by the population. The lower the socio-economic status of a community, as revealed by Human Development Index (HDI), the higher the amount of pollutants released into the bay. This was associated with the lack of sanitary facilities. Moreover, the evaluation of the socio-economic features such as infant mortality, poverty, health, education and public safety in relation to environmental change, which according to the authors was not done before, is additional input made by the study.

Caiero et al. (2004) applied the DPSIR framework, supported by a geographic information system (GIS) to propose a coastal management system capable of resolving conflicts between development and conservation goals in the Sado estuary, Portugal. Having selected the appropriate DPSIR indicators, a series of homogeneous areas (management units) were identified within the estuary for which each of the DPSIR categories were quantified. Then the environmental quality of the estuary was assessed through the state and impact indicators, and the results were integrated with driver and pressure indicators. The homogenous areas were overlaid within the estuary coastline using ArcGIS® GIS software. The authors claim that integrating this management tool with ecological and dynamic models will facilitate the prediction of zones in the estuary that are vulnerable to a specific pressure and, based on this prediction; appropriate management responses can be implemented.

The advantages of the use of the DPSIR framework in this study were that the authors were able to use an extensive data set for the characterization of the environment. The extensive dataset for the Sado Estuary environmental characterization included: hydrography, geomorphology, contamination sources, water, sediment and biota quality, biodiversity, land use conflicts, social and economic aspects and land use planning. This dataset was then used to select an appropriate set of indicators and their units of measurement for each DPSIR category. The authors recognized the danger of making unique linkages between categories, for which DPSIR is always criticized. So, they attempted to describe the state of the estuary based on multiple pressures, which ultimately could create multiple impacts. Consequently, they dealt with this complexity by adopting an integrated approach using a cluster of indicators with multiple aspects interacting with one another. Finally, the authors proposed to include other indices that had already been developed to test aggregations of sediment chemistry and biota quality. These are a Pollution Index, a Biological Quality Index, a Trophic State Index, and a Pollution Load Index.

Karageorgis et al. (2006) used the DPSIR approach in the Axios river delta and Thermaikos gulf, Greece, to evaluate the past coastal changes, and predict the future challenges using three scenarios. The aim was to develop a proposal of policy and management options to improve the situation and achieve sustainable development. By analysing a century (1900–2000) of socio-economic and environmental situations with a hind-cast DPSIR application, they identified a number of drivers, pressures, the states of the coast, impacts and policy responses. The beginning, duration and intensities of the drivers, pressures and impacts were clearly presented in figures, although the intensities were only qualitatively shown. The authors stated that the DPSIR framework facilitated a view of the general picture, and based on the scenario test, they concluded that under the current trends pressures will continue to increase on the coastal zones of this region, maintaining or even reinforcing the negative economic and environmental outcome.

Additional to assessing both negative and positive impacts and the state of the coastal zone, Karageorgis et al. (2006) predicted the future trends in the evolution of the catchment-coastal environment. This strengthens an initiative for a coastal zone management plan. The hind-cast assessment provides lessons on which to base future actions, and the forecast of future events enhances awareness and raises willingness to tackle the possible negative outcomes and to nurture the positive ones. As the authors stated, reasonable prediction can reduce uncertainties by exploring a wide range of environmental changes and consequences and, thereby, provide options for a mitigation policy. Using DPSIR, the authors were able to show the policy makers what could happen under the business as usual scenario and propose other more favourable scenarios.

Borja et al. (2006) used the DPSIR approach to analyze the pressures and impacts in twelve transitional and three coastal water bodies in the Basque country, Spain. The main task was analyzing pressures and associated impacts, in order to assess the risk of the Water Framework Directive (WFD) not achieving its target by 2015. The drivers were identified in order to link with the pressures. After the identification of all existing pressures, the focus was progressively narrowed on relevant and then significant pressures.

The risk of failing the WFD (high, medium or not at risk) was used to classify the water bodies. Out of the 16 water bodies, 5 were found to be not at risk, 5 with moderate and 4 with high risk of not achieving the WFD target by 2015. Two water bodies were found to have high and moderate risks in their different parts.

All pressures do not have the same effects or degree of effects on the state. Therefore, the classification of the relevance of existing pressures followed by a consideration of the relative significance for each water body has important policy implications. It helps to prioritize response actions. The same is true with the determination of the most important drivers (through factor analysis), and their consequent influences on pressures. Further, the determination of the level of pressures on each water body, and their enumeration, is useful in resource mobilization and allocation when responding to the problems. As the authors claim, the work can serve as an example for other similar coastal studies.

Similarly, the DPSIR framework was used by Lin et al. (2007) to analyze the state change of the Xiamen coastal wetland in China during the last 50 years of economic development. They identified the drivers and the pressures responsible for the state change, the consequent impacts and the responses taken.

The overall change in the socio-economic developments (comparing 4 time periods) with the accompanying state change and impacts as well as the responses taken, were clearly presented in this study. The typology of the wetlands with their sizes and proportion in the total coastal wetland, the physical changes of the environment, the graphic description of the population and GDP developments as well as industrial and domestic discharges gives a clear picture of how the study site was affected in the last 50 years. The work shows a broad and inclusive assessment of the Xiamen coastal wetland, which is an important contribution to the physico-chemical, biological, socio-economic and legislative understanding of the study area.

DPSIR has been used in a slightly modified manner (mDPSIR = Modified DPSIR) where the impact element referred only to impacts on human welfare (ELME, 2007). A subsequent Driver-Pressure-State-Welfare-Response (DPSWR) approach has been used in the KnowSeas project (e.g. Cooper, 2012; O'Higgins et al., 2014). From the methodological point of view, this eliminated the diffuse boundary between state and ecological impact by solely focussing on human welfare when dealing with impact. The ecological impact was shifted to the state category, expressing itself through the impacts it produces on humans, as socio-economic and health effects.

Mangi et al. (2007) used the DPSIR framework to analyse socio-economic issues, environmental changes and policy measures in coastal fisheries in Kenya. The major problems arose from subsistent fishing practice that induced overfishing, and the use of destructive fishing gears in the coral reefs. The authors identified several variables belonging to the categories of DPSIR. Indicators were developed, together with their units of measurements that could provide objective information for fisheries management in Kenya and other parts of the tropics were developed. Moreover, barriers to change that may affect appropriate management practices were highlighted.

A broad socio-economic study was carried out; ranging from the population dynamics through culture and tradition to the economic status of the communities. The present state of the corals due to the pressure exerted by the socio-economic variables (drivers) was clearly presented. Though the time range the study covers was not explicitly indicated, it gives a fairly clear picture of the socio-economic and the ecological conditions of the Kenyan and by extension, the other tropical coral reef ecosystems.

Nobre (2009) applied a DPSIR approach termed differential DPSIR ($\Delta$DPSIR) to evaluate the changes in drivers, pressures and state (presumably impact) after a management response is made to these. The author employed the $\Delta$DPSIR in the Ria Formosa lagoon, Portugal to make an ecological and economic assessment of the lagoon. Then the change in D-P-S and the response was given an economic value. The whole process was divided in three stages termed characterization, quantification and overview stages. The first stage was the identification of the issue, drivers, pressures, state, impacts as well as responses, and the definition of the study period. The second stage involved quantification of the ecological and economic variables of the state, ecological variables of the pressures, and economic quantification of the drivers. The third stage was the synthesis of the first two stages involving quantification of the net value resulting from the cost-benefit analysis, regarding the management of the coastal ecosystem, pressures and state indicators.

Separating the results of the study between the research and the management community, makes the study valuable both as a scientific output and a resource for coastal management. Moreover, defining the beginning ($t$) and the end ($t + \Delta t$) of the study period as an average over five years, and the response period for implementation ($\Delta t$) as 10 years can account for annual variations in the DPSIR variables and, at the same time, cover a relatively longer period of time (20 years). Choosing the relevant pressures, analysis of adopted responses in retrospect, and simulation and analysis of future responses, is a useful basis to decide which actions should be taken. Choosing the most important issues in the area, such as bivalve production and eutrophication, and assessing the lagoon in detail provides a stronger support for management initiatives both from the ecological and economic perspective.

Atkins et al. (2011) used the DPSIR framework to link with ecosystem services and societal benefits. They reasoned that ecosystem services deal with production and delivery of benefits for the society, and that DPSIR can show how these services are drivers that will ultimately produce the environmental state changes resulting in impacts necessitating a response. The researchers consolidate their argument with two case studies dealing with marine aggregate extraction in the UK waters, and management of biodiversity at Flamborough Head, UK.

Two points contribute to the scientific and management importance of this study. First, though earlier works have suggested integrating the ecosystem approach with DPSIR (e.g Turner et al., 1998), this work has explicitly included the ecosystem approach with suggestion of redefinition of ecosystem services (means) and benefits (end points). The clear division of ecosystem services as fundamental and final services that ultimately provide societal benefits may serve to evaluate the services and benefits by avoiding double counting. Second, the use of nested DPSIRs accounts for interactions and feedback loops among the DPSIR elements. It widens the system boundary so as to encompass different aspects of the system. It compensates for unidirectional, linear causality limitations of the framework. However, it does make the analysis very complex.

Although criticism of DPSIR abounds, it is resilient (Bell, 2012) and is still widely used. Sekovski et al. (2012) used it to assess the role that coastal megacities play in the environmental degradation and climate change. Having identified the DPSI in 14 megacities distributed in the Americas, Asia and Africa, they mentioned several management responses. These included regulations for ship cleaning, and their discharge, the banning of some hazardous compounds to prevent damage to coastal ecosystems, decentralized and private water management to provide water in adequate quantity and quality, relocation of industry to the peripheries of cities, utilizing modern technologies that minimize carbon emission to improve air quality, awareness creation and early warning systems to mitigate the effects of climate change and sea level rise. They concluded that megacities possess vast potential for environmental improvement, primarily due to their financial capacities.

Broad assessment of the DPSIR categories in the 14 megacities, consolidated with pertinent examples, reveals the anthropogenic damages done to the ecosystem. Moreover, the role of humans in climate change is highlighted. Besides summarising past responses, future response actions targeting the relevant problems were suggested. Since the importance of the role of coastal megacities in the environment emanates from the production and consumption patterns of humans, the study raises awareness, stimulating prompt actions towards sustainable use of coastal resources. The conclusion is that coastal megacities have a potential for environmental improvement and this can be stimulated and exploited as a positive aspect to rectify the situation.

The DPSIR approach was used by Pinto et al. (2013) to trace human induced changes of the structure and function of the transitional wetlands of the Mondego estuary, Portugal. The main objective of the study was to assist policy making by providing information on the interaction between the competing water uses of estuarine resources and their ecological functions. This can make an important contribution to the development of mitigation strategies aimed at reducing estuarine deterioration, thereby fulfilling the goals of WFD.

Besides the ecological assessment of the functions and uses of the Mondego estuary, the economic valuation of the use and non-use values of the basin was done. Despite its limitations (e.g not including environmental costs) the valuation of the water resources is very useful to encourage society to conserve water. Understanding a "value" is enhanced by the use of an easily understood term -Money. Analysis of scenarios of future trends provides useful information and a tool for forging future management plans.

The DPSIR approach was used to assess the decline of the sea grass ecosystem in the Ria de Aveiro lagoon, Portugal, Azevedo et al. (2013). Having identified the main driving forces, such as the harbour activities and fishing, these were linked to the pressures of dredging, breakwater construction and bait digging. These pressures caused changes in the sediment and hydrodynamics of the lagoon that ultimately led to the decline of the seagrass meadows. The impacts were loss of ecosystem goods and services associated with the loss of habitat and species diversity. The authors proposed more research and development of a decision support system in order to find the best management options for the recovery and preservation of this ecosystem.

The past and present drivers and pressures were related to the present state of the seagrass in the lagoon of Aveiro. The decline of the seagrass meadows across time and the causes were clearly presented. The ultimate impact on humans of the loss of the ecosystem goods and services was explained in some detail.

Newton and Weichselgartner (2014) identified four coastal hotspots of vulnerability, namely Arctic coasts, small islands, river-mouth systems and urban coasts. Then, using DPSIR to examine the anthropogenic causes of coastal vulnerability and consequences of coastal change, they recommended the appropriate responses that should be implemented. For example, with regard to small islands the recommended responses were boosting disaster mitigation capabilities, improving hazard forecasting and extending insurance cover as well as increasing the small islands' response and adaptation capacities through cross-scale connectivity. Furthermore, economic development infrastructures need to be adequately adjusted to potential hazards.

The work, beginning with the definition of vulnerability, identifies and describes the vulnerable coastal zones to natural hazards, enhanced by anthropogenic activities in relation to bio-physical changes and societal impacts. It associates the state changes and impacts specific to the particular coastal zone with the likely drivers and pressures. Moreover, the huge impact produced by natural hazards in 2011 was highlighted. Apart from pinpointing and describing valuable ways to reduce vulnerability, the study lists several lessons learnt from past experiences of extreme events. It calls for more research yet to identify and address the underlying causes and key drivers of vulnerability. The necessity of concentration of joint scientific, policy and practical efforts on coastal SES to strengthening assessment indicators and evaluation criteria is underlined. Moreover, a focus on the concept of "Coastal zone SES" to combine environmental and anthropogenic aspects in seeking empirical evidence of drivers of coastal vulnerability is considered important. The study raises awareness on global coastal zone vulnerability and prompts society to act for the reduction of vulnerability, to strengthening disaster mitigation and risk governance as well as to the sustainable utilization of coastal resources.

Newton et al. (2014) evaluated the five elements of DPSIR to assess the environmental problems affecting the European, shallow semi-enclosed coastal systems (SECS). Having addressed the formation and development, the ecological and economic importance of SECS, distributed across Europe, the authors identified common economic drivers (e.g. agriculture, fishery, aquaculture and tourism) in most of the 10 SECS as well as economic drivers of particular importance to specific SECS. For example, civil engineering works aimed at defending the Venice lagoon from the sea, rivers and man, has played a huge role in the morphological change of the city. In the SECS, the pressures (domestic and industrial effluents, nutrient inputs, dredging etc …), and the state changes (eutrophication, biological components change, and seabed structure change) were assessed. The impacts on human welfare as expressed through a decline in fishery, aquaculture and tourism were highlighted. A number of adopted responses (coastal defence, UWWTP, EU Policy) were shown. The study recommended that future responses should address all the drivers.

From the management point of view, the study raises valuable points. As the environmental problems affecting the SECS originate in the catchment, it stresses the need to deal with the problem in the river basins. Also, taking advantage of the better condition resulting from the changed political atmosphere in Europe after the fall of the Iron curtain, it calls for a trans-boundary cooperation to manage shared SECS. The study, using pertinent examples such as eutrophication and the pressures exerted on SECS by aquaculture, demonstrates that the cause-effect relationship is neither linear nor simple. Finally SECS are broadly assessed for their ecological, environmental, economic and morphological aspects, and most importantly as vulnerable natural resources of great value that should be protected both for the socio-economic development of humans and for their ecological value.

The state of the coastal systems of Palmachim area and Carmel coast, Israel, were assessed (1995–2009) by Felsenstein et al. (2014) making use of the DPSIR framework. The authors found that the main socio-economic drivers were population, migration (urbanization) and industry, causing an intense land-use pressure at the expense of natural vegetation cover. This was reduced by 75% in the Palmachin area and by 95% in the Carmel coast within 15 years. Agriculture and horticulture (mostly in Carmal coast) and fishing were also practiced to a lesser extent. The destruction of the natural vegetation cover caused huge ecological damage in terms of biodiversity loss. Salt ponds were also destroyed contributing a share of economic impacts on the population. A policy response was made by the Israeli government in 2004 such as the coastal environmental protection law. The authors summarized the impacts as a change in sustainability index from 1995 to 2009 and concluded that both study areas are unsustainable.

A wide spectrum of data sources was used in the study and the change in vegetation cover of both study areas across time was clearly presented. The analysis and comparison of the ecological sensitivity of the study areas alerts the coastal managers to take action and help to prioritize the area of action. Summarizing the impact in a sustainability index is a simple and useful way of informing policy makers to understand the environmental and ecological condition of the studied sites. For the geographical distribution of the case studies see Figs. 2 and 3.

### 5.2. DPSIR combined with other methods

To compensate for the perceived limitations of DPSIR several researchers have used it in combination with other methodologies. Rekolainen et al. (2003) slightly modified the framework as DPCER where C and E stand for chemical and ecological states, and identified several types of models that should be linked to the framework at different stages of the implementation of the WFD. The authors also incorporated 3 phases of the WFD implementation process. The first was formulation of scenarios and setting objectives, in which the identification and quantification of pressures and impacts, as well as the first assessment of water bodies at risk of failing the WFD is done. The national objectives are also set in this phase. The second phase, derivation of measures, consists of deriving measures to achieve the objectives. The third phase,

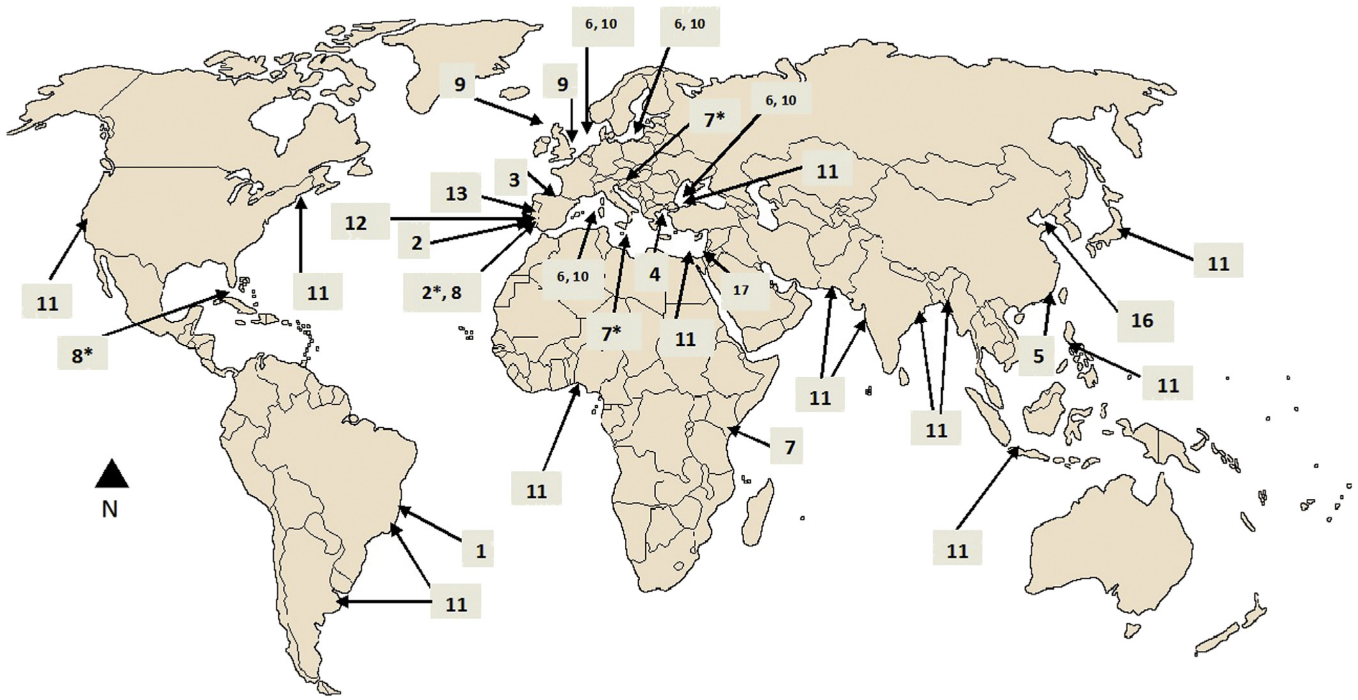


**Fig. 2.** Map showing the sites where the DPSIR framework was applied. The numbers correspond to the case studies listed in Tables 3 and 4. The asterisk indicates the case study in Table 4.
Source: www.outline-world-map.com.

assessment of the policies, evaluates the success of measures relative to the objectives. The authors explained the tasks to be executed by each type of model and concluded that this approach is dynamic and policy relevant, and applicable for different types and scales of problems, though it may not be applicable well to some special cases.

Summarizing the WFD implementation process in three phases with respect to model application renders this complex process more understandable. Moreover, the time frame for the implementation was clearly shown with the help of a diagram. The use of models at different steps appears to make the whole application of DPSIR more dynamic.

The DPSIR framework, the Outcome Approach proposed by Olsen (2003) and the traditional Integrated Coastal Management cycle (ICM) were combined by Pacheco et al. (2006) to prepare a coastal management plan (CMP) for the barrier channels of the Ria Formosa, Portugal. DPSIR was used to identify and assess the problem whereas the four orders of the Outcomes Approach was used to implement the management plan and track the evolution of its cycle. In the process, the management performance could be assessed by developing performance indicators through the Outcomes Approach, which would further develop the scope of the DPSIR framework by incorporating additional indicators and assessing more environmental problems. This serves to create yet a larger ICM cycle until sustainability is achieved as the fourth order, long term outcome.

The ICM cycle and the Outcome Approach were clearly described. Positioning the stages of the former to corresponding levels of the later demonstrated the integration of the two components. As shown by the authors, the approach seems to revise the management actions by doing the DPSIR assessment at intervals. This can be seen as a true example of adaptive management, and can also serve to deal with multiple issues and not just dredging management, as was the case in this study.

Maxim et al. (2009) argued that DPSIR, while being a relevant tool for communication between scientists and end users of environmental information, is inappropriate as an analytical tool. So, based on the methodology proposed by O'Connor (2007) the framework was reframed based on the four spheres of sustainability (tetrahedron of sustainability) composed of environmental, economic, social and political spheres, and termed “four spheres-DPSIR framework” or “Tetrahedral DPSIR”. According to the authors, this method improves the communicative capacity of DPSIR by combining it with the analytical power of the four spheres of sustainability. This tool was proposed for analysis of the biodiversity risk in the ALARM (Assessing Large scale environmental Risks for biodiversity with tested Methods). The definitions of the five categories of DPSIR offered by EEA were rephrased to fit in the four key factors of change on biodiversity specified in the ALARM project, namely, biological invasion, climate change, loss of pollinators and environmental chemicals. Following that, the applicability of this approach was demonstrated by the identification of multilevel drivers of biological invasion, which led to the loss of biodiversity (Labajos et al., 2009), by identification and analysis of chemical risks to biodiversity (Maxim and Spangenberg, 2009), by assessment of the driving forces responsible for climate change that produce pressures on biodiversity, focussing on energy use and transportation (Omann et al., 2009).

The study highlights the different definitions given to the DPSIR categories by different authors. Mainly based on the definitions given by the EEA, some of them were rephrased so that, according to the authors, they fit better to the issue at hand. The combination of DPSIR with the other framework, namely four spheres of sustainability can be considered an innovation.

An example in which DPSIR was used as a problem structuring method (PSM) was in the Imagine methodology (Systemic Prospective Sustainability Analysis-SPSA) (Bell, 2012). This tool was used to develop sustainability indicators through the active

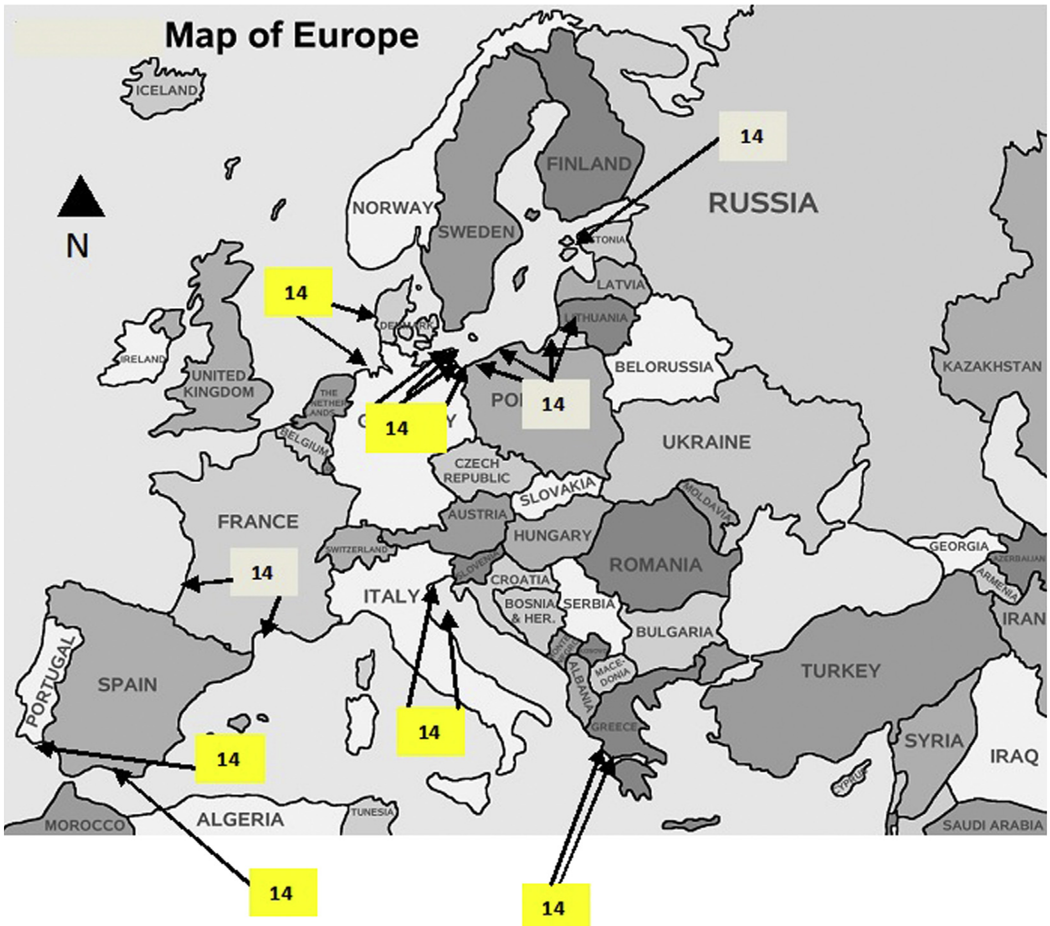


**Fig. 3.** Map showing the study case sites in Table 3 (listed #14) where DPSIR was applied.
Source: http://maps-portal.blogspot.com.es/2014/07/map-of-europe.html.

participation of stakeholders where the indicators were later defined in DPSIR terms. Citing two case studies in Malta and Slovenia, where the DPSIR framework was used retrospectively, the author stated that it can be applied as part of a methodology in a "bottom up and participatory manner", and asserted that it helped the participants realize that sustainability could be measured and assessed according to different criteria. The author claims that combining DPSIR with the Imagine methodology made it more available to wider stakeholders and thereby a flexible and useful PSM.

The study highlights the background of the development of PSMs. It exposes the information gap existing between scientific works, such that DPSIR is given little attention by some influential studies on PSMs as a method using indicators for decision making. Also the use of DPSIR was less documented in the Operational Research Literature. It explains in general terms the efforts done to develop indicators. This study attempted to make sustainability measurement simpler and understandable by the wider public, rather than an exercise for experts. The four distinct stages of applying the methodology and specifying tasks make the process of indicator development straightforward. The active stakeholder participation in viewing environmental change, selecting indicators and measurement units renders the methodology easier to grasp by the stakeholders. This may have an important implications for future policy when the informed stakeholders and the governance structures come together to solve problems of sustainability.

Kelble et al. (2013) claiming that the DPSIR framework does not explicitly include ecosystem services, proposed a merger with ecosystem based management (EBM). The conceptual framework created thus is EBM-DPSER, where **E** replacing Impact stands for ecosystem services representing both negative and positive changes of the ecosystem. The impact on humans is expressed only through the change in the ecosystem services. The authors inverted the visual representation of EBM-DPSER so that E is at the top and driver at the bottom to emphasize the ecosystem services. The traditional DPSIR, according to the authors, focuses too much on the drivers, which makes it difficult to capture the needs of the local and regional communities. Unlike the traditional DPSIR, each category has a feedback to response. This Framework was used in Florida Keys and Dry Tortugas, USA under the Marine and Estuarine Goal Setting for the south Florida project (MARES). The aim was to reach a science-based consensus about the defining characteristics and fundamental regulating processes of a South Florida coastal and marine ecosystems (Kelble et al., 2013).

Though the consideration of the ecosystem approach with the DPSIR is not new, the study explicitly integrated EBM with DPSIR. It attempted to evolve the DPSIR framework from a reactive management tool into a proactive one. In the DPSIR diagram, the fact that each category in the chain is connected by double arrows gives a conceptual impression that uni-directionality is eliminated. The recognition that each category could have a feedback to the response, in addition to its immediate outcome, appears to be a sensible observation. Moreover, linkages made among multiple drivers and multiple pressures can better explain the complexity of the ecosystem. The application of this integrated approach was demonstrated in a simple way choosing a specific pressure and a single response. Consequently the effect of the response at improving the targeted ecosystem service could be shown in combination to its negative effect on the other services. This illustrated that the EBM-DPSIR approach can illuminate tradeoffs.

Combining DPSIR and Analytic Hierarchy Process (AHP), Shao et al. (2014) developed an index system for the assessment of the ecological environmental security level of the Tianjin coastal system on the Bohai Sea, China. They used DPSIR to identify the environmental problems, their causes and consequences, and AHP for dividing the ecological environmental security into three levels as a target layer (composite ecological environmental security index), a criterion layer (DPSIR components) and an indicator layer (indicators of D-P-S-I-R). Having developed an array of indicators for the DPSIR categories, they used the fuzzy comprehensive evaluation method to weight each indicator according to its importance. Then they developed a composite evaluation index (0–1 scale) for individual DPSIR categories and for ecological environmental security of the whole study area. Making use of the composite criterion indicator for each DPSIR category, they evaluated the Tianjin ecological environmental security from 2005 to 2010 and found, with the exception of the response which showed an improving trend, that all the others exhibited deteriorating conditions. As a result, the overall ecological environmental security of this coastal system showed a downward trend. Despite the responses taken so far, based on the results of a prediction model used (2010–2020), the authors concluded that the downward trend of the ecological security of the coastal system will continue needing urgent, more effective management responses.

Extensive assessment of the Tianjin coastal system with respect to socio-economic developments, ecological and environmental conditions and developing ecological security index system is appreciable both as scientific output and a management tool. The study showed a image between the concepts of economic development and sustainability. In spite of the environment-friendly development plans, environment protection programs and practical measures, the fragile ecosystem is precipitating to the edge of the cliff is the overall cautionary message this work communicated, which is a real contribution to the general call for ecosystem-based approach. The recommendations forwarded by the authors should be heeded.

## 6. Critiques

### 6.1. Critiques of DPSIR

The DPSIR framework has been extensively used, but it has also been subject to many criticisms. Though the DPSIR framework is useful, EEA (1999) warns that the real world is far more complex than can be expressed by simple causal relations, and stresses the need for clear and specific information on the five categories for the purpose of making policies. DPSIR is also useful for describing the origins and consequences of environmental problems, but the links between the categories should be focused in order to understand their dynamics (EEA, 1999). This is to elucidate, that the level of influence of each category on the other, is determined by ecological, technological and social factors. For example, in the presence of highly eco-efficient technology, several drivers may produce less pressure than might be expected. The impact on the society and the environment depends on the carrying capacity and thresholds of the state. Societal response depends on perception of the problem by the society. Furthermore, evaluation of the impact and the response's efficiency could vary.

With reference to Rapport et al. (1998) and Rapport and Whitford (1999), Rekolainen et al. (2003) mentions four shortcomings of the framework: (i) it creates a set of static indicators that serve as a basis for analysis, not taking into account the changing dynamics of the system; (ii) it does not capture trends except by repeating the study of the same indicators at a regular intervals; (iii) DPSIR does not illustrate clear cause-effect relations for environmental problems; and (iv) it suggests linear unidirectional causal chains in the context of complex environmental problems.

Carr et al. (2007) associated the DPSIR framework with the power difference between the so-called "developers" and the "developing". The "developers" refer to State mechanisms, NGOs and international organizations, which possess all the privileges and power to access resources and use knowledge to change the world. The "developing" are the local communities. The former are the ones which can effect responses to environmental problems. The latter do not have enough capacity to respond to environmental problems. So indigenous knowledge is only used if the developers consider it valuable. The authors provide examples of erroneous decisions taken by different international organizations (e.g. USAID in Egypt, World Bank in Lesotho) caused by the wrong assumption that the "developer" has a superior knowledge to the "developing".

The argument put forth is that the ability of DPSIR to assess sustainable development within the context of UNEP and other international sustainable development initiatives is not useful, as it undoubtedly inherited the power difference mentioned above and is biased in favour of the elite few – the developer and influential entities who can identify and respond to the drivers and pressures. The implication of this argument is that such an opinion highly undermines the valuable indigenous knowledge about the drivers, the pressures and a multitude of knowledgeable responses by the local communities and individuals. Nevertheless, DPSIR continues to be used by UNEP (e.g. Levy et al., 2012).

Svarstad et al. (2008) criticize the DPSIR framework for its shortcomings in establishing good communication between researchers, on the one hand, and stakeholders and policy makers on the other. They further argue that it does not find a satisfactory way of dealing with the multiplicity of attitudes and definitions of issues by stakeholders and the general public. Juxtaposing four discourse types regarding biodiversity they showed that DPSIR favours the Preservationist discourse type the most. In contrast, the Promethean (Business as usual) discourse is unrepresented in DPSIR. They concluded that this revealed the inability of DPSIR to produce neutral knowledge.

Another criticism runs as follows: although the didactic clarity is appealing, the apparent simplicity can be misguiding, ignoring the possible synergistic relations existing between the DPSIR categories. For example, a specific impact can be caused by several state conditions and by responses to other impacts (Maxim et al., 2009). Synergistic effects, so common in nature, are ignored by this framework. So, according to these authors DPSIR is not good enough as an analytical tool as it does not address the complexity of interdependencies in the real world.

Bell (2012) indicates that DPSIR lacks precision as a problem structuring method and is not easily available for wider stakeholders because it is fundamentally an expert device – devised by specialists, to be interpreted by specialists for application by policy makers. Criticising the DPSIR approach for its definitional limitations, Cooper (2012) presents the following arguments: (i) lack of a precisely defined set of information categories hinders comparability between studies, even of the same issue; (ii) the definitions of driver and pressure referring to "developments" necessarily reflect changes in level, so it is unclear how they can encapsulate steadystate activities that nevertheless result in ecosystem change; (iii) since the impact includes effects on Humans and the ecosystem the boundary between state and impact is unclear. Moreover, this disguises the link between them. A criticism by Kelble et al. (2013) is that since the impact category of DPSIR refers only to negative anthropogenic effects and the response focuses on these adverse environmental impacts, the DPSIR approach is unable to facilitate a proactive management to sustain or maximize ecosystem services.

### 6.2. Critiques of case studies

In section 5, the case studies applying DPSIR are evaluated on the basis of their overall achievement and contribution to the subject matter. In this section the following critiques focus only on the way the DPSIR framework was used. Using the evolution of the DPSIR terms given by the EEA (2003), as modified by Elliot et al. (2006) (State to State change), and ELME (2007) and Cooper (2012) and O'Higgins et al. (2014) (Impact as Human impact) allows a number of deviations and inconsistencies to be detected in most of the case studies.

In Bidone and Lacerda (2004), the study lacks some clarity as regards the DPSIR terminologies. For example, the socio-economic and physical drivers are designated as P (pressure indicators), and river material fluxes (pressures) as S (state indicators) in the Integrated model box. Even more confusing is the use of indicators. According to OECD (1993), indicators are values derived from parameters, providing information about a phenomenon, and should not be too large or too few. They should also be measurable. In Bidone and Lacerda (2004) a description of the whole study area is given under physical or primary environmental indicators. Comparably, under natural indicators the pressure, state and impact components are described. One of the two major drivers identified in the study is industrialization. Emission factor of pollutants from point sources is designated as its indicator. But emission, being a pressure, would have an indicator such as load of pollutants (mass/t). If an indicator should be assigned to industrialization, the number or type of industry may be appropriate.

Despite the scientific strength of the work by Lin et al. (2007), methodological problem with DPSIR regarding terminologies is discernible. For example, defining pressures as variables that directly cause the changes in the studied wetlands, the authors place socio-economic developments (drivers) such as urbanization, industrialization and aquaculture under the pressure category. But it is rather the domestic and industrial discharges (pressures), which emanate from these drivers that directly cause a state change. Several authors (e.g. EEA, 2003; Bidone and Lacerda, 2004; Borja et al., 2006: Newton et al., 2014) consider urbanization, industrialization and aquaculture as drivers, rather than pressures. Similar cases could be detected in several works (e.g. Kelble et al., 2013; Newton and Weichselgartner, 2014) where coral bleaching, ocean acidification, seabed change and eutrophication were placed under pressures; but which may also be used to describe the state. Similarly, Newton et al. (2014) included dredging in the driver category. Dredging is considered as a pressure by several authors (e.g. EEA, 2003; Pacheco et al., 2006; Borja et al., 2006; Azevedo et al., 2013).

Examples of double counting of variables in separate categories was also found out as in Pinto et al. (2013) where water extraction and waste water were considered both pressures and ecological drivers. Water extraction as a pressure is understood as it is created by the action of the drivers (population, agriculture, industry, and tourism) on water demand and supply. The pressure on water quality is also evident as shown by input of nutrients, industrial and domestic wastes. Furthermore, a whole set of variables previously referred to as drivers were placed under a column headed pressures. Comparably, marine aggregate extraction (Atkins et al., 2011), and sand extraction (Newton et al., 2014) were considered drivers, whereas resource use was defined as pressure by EEA (2003): wherefore the driver is the demand for infrastructural development (economic sector), the pressure is marine aggregate extraction (together with bed material removal), and the state change is increased suspended matter and any other pertinent variable indicating this change. Indeed, in Atkins et al. (2011), the variable increased suspended sediment was double counted as a pressure and a state change.

The definition of DPSIR terms is essential for the logical progression of the assessment and to make communication possible between multidisciplinary researchers and stakeholders using a clear and commonly understood language. In the face of confusing and multiple meanings, understanding is hampered. For example, if the term response were understood to mean both societal and ecosystem responses, the resulting communication gap is evident. This is an extreme example but enables us to understand the confusion that can result from arbitrary use of terms.

Identification of indicators depends on the definition of what one wants to indicate. Ojeda-M et al. (2009) state that indicators must provide clear and understandable information for managers and stakeholders that can support decision making. If the same variable is chosen by several workers to indicate multiple categories it would be difficult to communicate even among researchers of the same discipline, and it would be even worse with other stakeholders. One of the important attributes of a scientific work is comparability, and with the absence of a standard language, a study would lose this attribute. This, in turn, hampers the development of the particular discipline to which studies of this kind belong. Finally the fundamental objective of DPSIR is communication; and the framework will miss its goal of supporting sustainable management of natural resources whenever communication fails.

## 7. Discussion

Despite the availability of other frameworks, all the case studies presented here applied the DPSIR framework, convinced of its usefulness. All appreciated the framework from the perspectives of their studies. Bidone and Lacerda (2004) assert that a broad analytical framework such as DPSIR, capable of integrating natural, social and economic information, supports CBA on a policy response in a coastal area. This is particularly important where: there is a delay between the response and its result; there is sensitivity to regulatory measures; and there are a multiplicity of interests and stakeholders affected by a policy response. Caiero et al. (2004) also advocate the usefulness of the framework as a base for a coastal zone management. They argue that DPSIR leads both scientists and policy makers to think in terms of causality chains and allows linkages between environmental and macro-economic models. Therefore, it facilitates the integration of the conservation functions with socio-economic developments.

Karageorgis et al. (2006) praise DPSIR as a powerful scoping framework for complex environmental issues, on which scoping analysis within large-scale, multidisciplinary research teams is based. They further state that the framework also allows for future scenario-based analysis in which plausible future coastal zone contexts can be formulated and examined. The use of the DPSIR analysis in the Basque Country, together with the methodologies in identifying relevant pressures and impacts, has been demonstrated as a useful approach in assessing the risk of failing to achieve the objectives of the WFD (Borja et al., 2006). Nobre (2009) counts DPSIR as a powerful tool for integrated coastal management, and particularly useful for the evaluation of the cost effectiveness of management and policy scenarios.

The DPSIR framework is appreciated by many for its communicative power, cause-effect linkages of environmental problems, multidisciplinary approach and the provision for stakeholder participation (e.g. Bidone and Lacerda, 2004; Giupponi, 2007; Ojeda-M. et al., 2009; Atkins et al., 2011; Kelble et al., 2013). Its flexibility was attested to by several authors (e.g. Pacheco et al., 2006; Ojeda-M. et al., 2009; Bell, 2012).

It is possible to continue in a similar vein and present several more arguments in favour of DPSIR from earlier studies. Indeed, the framework continues to be used, despite the criticisms and recent development of derivatives. In developing integral indicators for the implementation of the EU directives with an ecosystem approach, de Jonge et al. (2012) argue that the measurement of the ecological functions, human activities and socio–ecological interactions could be facilitated by the DPSIR approach. Pinto et al. (2013) considers it an insightful framework for integrating quantitative and qualitative ecosystem/socio-economic interactions, hence, allowing for the assessment of the link between the ecological characterization of ecosystems and their economic valuation. Shao et al. (2014) present the framework as an investigative tool that analyses socio-economic and ecological issues answering the questions of what, why and how.

To assess the usefulness of the method, the results obtained by it should be juxtaposed against the objectives it was developed for. The main objective of the framework is to support building sustainable management of natural resources. Its specific aims are to provide a common forum and language for environmental managers, scientists of different disciplines and stakeholders. DPSIR is supposed to identify, analyze and assess environmental problems and consequences along with the responses needed to rectify the damages done to nature and society. Though doing so in the complex world is not an easy task, the cases so far presented have shown considerable success in identifying and assessing problems and suggesting solution measures. The fact that the method is still in use more than three decades after its creation also attests to its robustness. Researchers, instead of abandoning it are attempting to refine it through definitions, modifications and combinations with other methods including models and GIS softwares (e.g Rekoleinen et al., 2003; Caiero et al., 2004; Mysiak et al., 2005; Giupponi, 2007). Even its critics do not deny some usefulness; rather they often propose its improvement. Bell (2012) for example, having criticized this framework, recommends it as a flexible and useful tool if it is made more precise and available to stakeholders. Further, a number of research projects are still using it (e.g. SECOA, DEVOTES). Against this background of appreciations, and notwithstanding the criticisms presented earlier, it is safe to conclude that the DPSIR framework is a useful tool that can still be refined.

The specified shortcoming of DPSIR by Carr et al. (2007), as a tool which privileges the elite response makers, seems more in the actors themselves than in the method. An inherent characteristic of any tool is that it can be used or misused. A hammer is useful in construction but can also be used for murder. Governments and international organizations are peopled with educated classes that have a tendency to value knowledge in reports and scientific articles more than the traditional knowledge of indigenous people. But since the DPSIR framework does not exclude the participation of the local communities and individuals, to use this feature to the maximum is the responsibility of the user. So, experts using the framework should reorient the relationship of these organizations with the local communities so that indigenous knowledge occupies its rightful place. Bell (2012) criticised DPSIR as a device used only by experts, but this does not indicate its weakness as a tool. Tools should be used by those who have learnt how to handle, use and adapt them.

Considering the limitation of DPSIR as a tool with discursive bias (Svarstad et al., 2008), a question arises: is there any single tool that is satisfactory to all, and efficient in every application? The answer is surely negative; a fork is a useful tool, but not to eat soup! And DPSIR is not an exception. The tool was developed to analyze environmental problems arising from human activities with an objective to assist in achieving sustainable development. So it seems reasonable that it leans towards preserving nature. But it should be noted that it also favours the win–win discourse approach, which is in the best interest of the society.

It appears that this bias instead of being a weakness could be strength. It gives a signal to the different discourse types to modify their content in consideration of the well-being of both the society and nature. This is fundamental to environmental management based on ecosystem approach, as suggested by several authors (e.g. Turner et al., 1998; Rapport et al.,1998; Rogers and Greenaway., 2005; Elliot et al., 2006; Atkins et al., 2011; de Jonge et al., 2012; Kelble et al., 2013).

In order to implement the EU Directives (e.g. WFD, MSFD), de Jonge et al. (2012) advocate a systems approach to studying the ecological and socio-economic systems, rather than fragmented sectoral approaches. According to the authors, the DPSIR framework couples human activities with ecological systems and integrates intermediate services with final services. In combination with other approaches and techniques, they propose its application at the habitat level where the ecological and economic systems could integrate to further evaluate the ecosystem structure and functioning and to quantify the impact of human interventions. Therefore, the DPSIR elements can be quantified and put in models describing the cause-effect relations in the integral ecological and socio-economic system. Using ecosystem network analysis per habitat and linking it with the relevant pressures, and then summing up state changes and related impact, will result in an integrated societal response to the total impact (de Jonge et al., 2012).

Many authors have mentioned DPSIR with respect to sustainability (e.g. Bidone and Lacerda, 2004; Karageorgis et al., 2006; Borja et al., 2006; Bell, 2012). Sustainability implies a win–win scenario between nature and society. So, several researchers have included the social impact such as job losses (e.g. Zaldívar et al., 2008) in their DPSIR analysis. Therefore, the way is already open to fill the gap in the biased discourse approaches like that of the Preservationists by including the social impact and providing for compensation as a response. As DPSIR was initially developed to find ways of managing the environment sustainably, it is understandable that it may not be represented in the Promethean discourse approach. This, however, does not diminish its importance, given the objectives it was developed for.

In the Preservationist discourse approach, impacts are understood as effects on nature, whereas economic costs and other negative impacts on human beings arising from preservation are largely ignored. This casts a doubt on the assertion of Svarstad et al. (2008) that the DPSIR framework, as traditionally applied, is well suited to examine all aspects of the Preservationist concern. This is because traditional DPSIR is not complete without addressing both environmental and social impacts. Furthermore, despite the authors' reluctance to fully endorse it, DPSIR is fully compatible with a Win–Win discourse type as a framework because it includes both environmental and social impacts.

Cause-effect relationships in the real world are neither always linear nor unidirectional. Synergy plays an important role in environmental changes. This calls for a deeper understanding of the system under study when using DPSIR, at least to reduce uncertainties and wrong conclusions if not to totally remove them. It also facilitates decisions by either improving the method or by combining it with other methods, as it has already been demonstrated by several researchers (Pacheco et al., 2006; Maxim et al., 2009: Bell, 2012; Kelble et al., 2013). In fact, as shortcomings of DPSIR become apparent, the trend is to use it by integrating it with other methods.

Dynamism and complexity are properties of both society and nature. DPSIR supported by models can address the dynamic ecosystem–societal interactions. Several authors have supplied empirical evidence for this. For example, Lee and Lin (2014) used DPSIR with the modelling software Stella to simulate different management scenarios ranging from no action to multiple strategies on coastal tourism in Cijin, Taiwan. The management option with multiple strategies was found to improve the environment while upholding the economic development of the study area. The authors argue that DPSIR supported by models can address the dynamics of socio-economic and environmental interactions and help decision makers to simulate any situation and view the long-term performance by adjusting variables. Combinations of DPSIR with different models was proposed to develop robust decision support system during the implementation of the WFD (e.g. Rekolainen et al., 2003; Mysiak et al., 2005; Fassio et al., 2005; Giupponi, 2007).

Natural drivers (Pinto et al., 2013) and environmental drivers (Newton and Weichselgartner, 2014) address the criticisms that DPSIR ignores key non-human drivers. The claim of DPSWR which evolved from the DPSIR framework (Cooper, 2012) to address the definitional and conceptual limitations of the latter in an improved manner deserves special attention. This innovative approach is important from two points of view. First, it was tested in the ELME project, eliminating the diffuse boundary between state and ecological impact by solely concentrating on humans when dealing with impact. Second, it suggests a change of terms, from Impact (I) to Welfare (W), meaning human welfare. Indeed the first point is important, but the change of term suggested by the second point might not be necessary because it is possible to use the old term with improvements to the definition.

Splitting the driving force into underlying driver and driver activity might be useful as it gives wider freedom to the user to include more variables. But it is not different from what has already been stated on the subject except for a change of terms. Primary driving forces are population growth and development in the needs and activities of individuals (EEA, 1999) that induce developments in secondary driving forces, which are human activities triggering pressures and impacts (Maxim et al., 2009).

It is noteworthy that contrary to DPSWR, which explicitly focuses on the Impact on humans, the EBM-DPSER conceptual model deals with the Impact on the ecosystem. Human impact is only implicit in it. This kind of difference in attitude contributes to the confusion with the terminology and difficulty to apply the DPSIR framework uniformly.

Some variables have been found to be ambivalent according to the EEA definitions. For example, use of resources is considered a pressure. Economic developments are drivers. However, extractive industries (oil, marine aggregate, timber, fisheries) are activities that are economic drivers, but, when the use of resources is the issue, they are often considered as pressures.

The reasons for the differences in using variables under the same categories seem to emanate from differences of opinions, the characteristics of the cases under study (context), from misunderstanding of the concepts and an unclear understanding of the system under consideration. The contextual differences seem to be interesting. For example, climate change can be considered as a natural driver. But, the current consensus is that Human activities (economic sectors) produce Green House Gases (GHG); can this be considered as a pressure? An increased sea temperature (part of global warming) could be considered a state change when caused by GHG emissions (P) and could be a pressure when it causes coral bleaching (S). Similarly some terms may be placed in the response category; however, if they caused a state change they would be pressures. For example, a waste water treatment plant (WWTP) is a response when constructed to deal with water pollution, but the effluent may cause eutrophication and this is a pressure. Furthermore, a policy response that encourages non-environmentally friendly economic developments to reduce poverty can act as a driver. In such cases, explaining the context might help to reduce the subjectivity and hence the confusion.

**Table 3**
Application of DPSIR to coastal issues.

| No | Reference | Issue | Site |
|---|---|---|---|
| 1 | Bidone and Lacerda, 2004 | Identification of socio economic Drivers, description of the biogeochemical Pressures and assessment of Impacts to evaluate development and sustainability. | Guanabara Bay, Brazil |
| 2 | Caiero et al., 2004 | Identification and quantification of the DPSIR indicators for Proposal of Coastal Management System | Sado Estuary, Portugal |
| 3 | Borja et al., 2006 | Analysis of Pressures and Impacts to assess the risk of the water framework directive (WFD) failing its target by 2015. | Transitional/coastal waters in Basque country, Spain. |
| 4 | Karageorgis et al., 2006 | Post- evaluation of the coastal zone changes to make policy proposal and management options to improve the current situation and achieve sustainable development. | The Axios river delta and Thermaikos gulf, Greece. |
| 5 | Lin et al., 2007 | Analysis of the State change during the last 50 years of economic development. | Xiamen coastal wetland, China |
| 6 | ELME, 2007 | Predicting the likely Impacts of socio economic and institutional changes within Europe on marine ecosystem. | NE Atlantic, Baltic sea, Black sea and Mediterranean sea. |
| 7 | Mangi et al., 2007 | Analysis of socio-economic issues, environmental changes and policy measures in coastal fisheries | Kenya |
| 8 | Nobre, 2009 | Evaluation of the changes in Drivers, Pressures and State (presumably Impact) after a management response is made. | Ria Formosa lagoon, Portugal |
| 9 | Atkins et al., 2011 | Evaluation of environmental State changes and Impact by integrating DPSIR with the concepts of Ecosystem services and societal benefits. | UK waters, Flamborough Head, UK |
| 10 | Cooper, 2012; O'Higgins et al., 2014 | Providing a comprehensive scientific knowledge base and practical guidance for the application of the ecosystem approach to the sustainable development of Europe's regional seas | NE Atlantic, Baltic sea, Black sea and Mediterranean sea |
| 11 | Sekovski et al., 2012 | Assessing the roles of coastal megacities in environmental degradation and climate change | 14 Coastal megacities |
| 12 | Pinto et al., 2013 | Tracing human induced changes of the structure and function of the wetlands to assist policy making. | Transitional wetlands of the Mondego river estuary, Portugal. |
| 13 | Azevedo et al., 2013 | Assessment of seagrass decline | Ria de Aveiro lagoon, Portugal |
| 14 | Newton et al., 2014 | Assessment of the ecological status and vulnerability of European Shallow semi-enclosed coastal systems(SECS) | Several European SECS and Lagoons |
| 15 | Newton et al., 2014 | Examination of hotspots of coastal vulnerability | Arctic coasts, Small islands, river-mouth systems, urban coasts |
| 16 | Felsenstein et al., 2014- | Natural resources assessment for sustainable development | Carmel coast & palmachim, Israel |

One important point to make is that a thorough understanding of the system under study makes application of DPSIR more accurate. For example, in the case of eutrophication, the causal chain is agriculture (or any other activity using nutrients) acting as a driver that releases nutrients (pressure), which causes eutrophication (state change). But due to the physical and biological characteristics of the system which Cloern (2001) terms filters, eutrophication might not result, which can be considered a negative feedback loop between pressure and state. The feedback loop can be incorporated at a point in the DPSIR chain where it is discovered. Therefore, the negative feedback loop action of filters may be incorporated between pressure and state. Thus, understanding the interactions between the physical forces and the nutrients, between the biological forces (grazers) and the phytoplankton, and discovering the resulting feedback loops in the framework will facilitate a better application of DPSIR, instead of finding the framework to be inadequate to address certain phenomena.

Finally, improvement and evolution is the integral part of science. The framework should continue to evolve into a more refined tool for the analysis and assessment of environmental problems. The categories of DPSIR must be clearly defined so that they may be used uniformly for similar cases and contexts.

## 8. Recommendations

Recommendations such as the use of models, combination with other methods and theoretical explanations have been forwarded by several authors. Details of the works can be found in the cited papers (Table 5). Our Recommendations build on these.

(i) Definitions: The different actors using DPSIR for an analysis should clearly define their terminology before using the framework. Regarding the definitional discrepancies, we suggest that the EEA definitions (and the recent modifications of state and impact) to be fundamental. When dealing with complex issues it may be hard to assign variables to one category. In these cases, the researchers should highlight why they chose the category. In the case of ambivalent variables, such as the use of resources included under pressure by EEA, it might be better to shift these to the driver category when resources are used as raw materials to be industrially processed.

(ii) Conceptual model: A thorough understanding of the system under study is fundamental before applying the DPSIR framework to identify the underlying causes of the state change and feedback loops using field, laboratory and modelling studies.

**Table 4**
Application of DPSIR-combined with other methods-to biodiversity/coastal issues.

| No | Reference | Method | Issue | Site |
|---|---|---|---|---|
| 1 | Rekolainen et al., 2003 | DPCER + Models | WFD implementation process | European water bodies |
| 2[a] | Pacheco et al., 2006 | DPSIR + Outcome Approach + ICM | Coastal Management Plan | Ria Formosa, Portugal |
| 3 | Maxim et al., 2009 | DPSIR + Tetrahedron of sustainability | Analysis of biodiversity risk | ALARM project (Europe) |
| 4 | Maxim and Spangenberg, 2009 | DPSIR + Tetrahedron of sustainability | Identification and analysis of chemical risks of biodiversity | ALARM project (Europe) |
| 5 | Labajos et al., 2009 | DPSIR + Tetrahedron of sustainability | Identification of multilevel drivers of biological invasion | ALARM project (Europe) |
| 6 | Omann et al., 2009 | DPSIR + Tetrahedron of sustainability | Assessment of the driving forces responsible for climate change | ALARM project (Europe |
| 7[a] | Bell, 2012 | DPSIR + Imagine | Developing sustainability indicators | Malta and Slovenia |
| 8[a] | Kelble et al., 2013 | DPSER + EBM | Defining characteristics and l regulating processes coastal & marine ecosystem | Florida Keys & Dry Tortugas, USA |
| 9[a] | Shao et al., 2014 | DPSIR + AHP | Developing an index system for the assessment of the ecological environmental security level of coastal system | Tianjin coast, China |

[a] Refer to Fig. 2.

**Table 5**
Summary of the limitations of DPSIR and suggested recommendations for improvement. Unless otherwise indicated the recommendations are forwarded by the present authors.

| Reference | Limitations | Recommendations for improvement |
|---|---|---|
| EEA, 1999 | Cause-effect link might not be clear | Focus on the links between categories to understand the dynamics (EEA, 1999)<br>Understand the system better through scientific means and discover feedback loops. |
| Rekolainen et al., 2003 | Relies on static indicators | Integrate with methods revealing the dynamics of ecology and society.<br>Link with appropriate models (Rekolainen et al., 2003; Giupponi, 2007; Vacchi et al., 2014). |
| | Repeats the study to analyze environmental trends | Use model simulations on the basis of the currently obtained data to analyze future trends (e.g. Shao et al., 2014) |
| | No clear cause-effect relationship | Focus on the links between categories to understand the dynamics (EEA, 1999)<br>Link with appropriate models (Rekolainen et al., 2003; Giupponi, 2007; Vachi et al., 2014).<br>Understand the system better through various means and discover feedback loops |
| | Linear unidirectional chains of environmental problems | Link with appropriate models (Rekolainen et al., 2003; Giupponi, 2007; Vachi et al., 2014).<br>Understand the system better and discover feedback loops |
| Carr et al., 2007 | Hierarchical bias | Improve user's Objective<br>Include indigenous knowledge |
| Svarstad et al., 2008 | Weak communication between researchers and public | Develop participatory process and develop stakeholder mapping |
| | Discursive bias | Develop co-learning mechanism through a multidisciplinary mode |
| Maxim et al., 2009 | Does not address synergy | Understand the system better and address multiple issues<br>Use models to simulate synergy |
| | Does not address multiple issue | Use nested-DPSIR cycles to address multiple issues (Atkins et al., 2011) |
| Bell, 2012 | Imprecise tool | Combine it with other methods (Bell, 2012)<br>Refine it so that it possesses precisely defined categories |
| | Un available for the wider public (Expert device) | Make it understandable through participatory approach prior to a project (Bell, 2012). |
| Cooper, 2012 | Imprecise definitions | Develop universally agreed definitions |
| | No clear boundary between State and Impact | Move Environmental Impact to State category (ELME, 2007; Cooper, 2012)<br>Understanding that Impact means an effect on Human Welfare. |

(iii) Multiple issues: Indicate the nature of causes–effect relations (synergistic, multiplicative, cumulative, additive effects), thereby encouraging the use of different methods such as nested DPSIRs and models as discussed above.
(iv) Issue identification and stakeholder mapping: Hierarchical bias is determined by the objectives and it is fundamental to include all the relevant stakeholders in the evaluation.
(v) Local knowledge and capacity: Indigenous knowledge and the capacity of the local communities to respond to the maintenance of the resources should be considered in the relevant policy recommendations and responses.
(vi) Bridging the science-society gap: Encouraging more participation by involving multidisciplinary experts and stakeholders contributes to narrowing the gap between different discourse types in the context of sustainability. It also makes DPSIR available to the wider public

## 9. Conclusion

The DPSIR framework, with several criticisms and appreciations, is still a useful tool. DPSIR is supposed to analyse and assess environmental problems, bring together different scientific disciplines, environment mangers and stakeholders, and come up with solutions in light of sustainable development. So far it has succeeded in its task; hence it is useful and fit for its purpose. However, the making and implementation of policies rests in the hands of governments and concerned institutions, requiring political will, democratic atmosphere and clear governance.

The innovative approach of the application of the framework that considers the impact as affecting the human welfare, and expands the state change to the impact on the environment gives it greater clarity. For the best performance of the DPSIR, a sound knowledge of the system under study and the objectives of the researcher are important. For example where the system characteristics are little known, synergies may not be considered, a clear cause-effect relations may not be apparent. Likewise, the degree of clarity and focus of the researcher's objectives is liable to affect the extent to which environmental problems in relation to the human welfare are addressed. Some of the criticisms of the framework such as hierarchical bias may truly be re directed at the users themselves. Though DPSIR does consider the local community, a researcher might opt to focus only on the elite groups as important response makers. Thus, the DPSIR tool can be used or misused.

The DPSIR framework should be rendered easier to understand by the stakeholders. However, it should be understood that as a management tool it can never be a layman's device but a tool to be familiarized with. To bridge the Gap among different discourse approaches, a multidisciplinary co-learning forum should be provided whereby all discourse approaches could achieve mutual understanding for the benefit of both Humans and nature.

In the presence of differences of opinions, multiplicity of characteristics of the cases under study (with countless variables), definitional discrepancies might prove difficult to surmount. However, DPSIR requires adopting commonly accepted definitions for a set of variables to be placed under each of the five categories. As there is always a room for improvement, the DPSIR framework is yet to evolve in a complete tool for management of natural resources in general and coastal resources in particular.

## Acknowledgements

This research was financially supported by the ERASMUS MUNDUS programme EMJD MACOMA, in the design of the study by the EC 7FP Grant agreement 282845 (COMET-LA, http://www.comet-la.eu) and in the preparation of the article by Development Of Innovative Tools for Understanding marine biodiversity and assessing good Environmental Status(DEVOTES).

## References

Anderies, J.M., Ostrom, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecol. Soc. 9 (1), 18.
Atkins, J.P., Burdon, D., Elliot, M., Gregory, A.J., 2011. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. Mar. Pollut. Bull. 62, 215–226.
Azevedo, A., Sousa, A.I., Silva, J.D.L., Dias, J.M., Lillebo, A.I., 2013. Application of the generic DPSIR framework to seagrass communities of Ria de Aveiro: a better understanding of this coastal lagoon. J. Coast. Res. 65, 19–24.
Bell, S., 2012. DPSIR = a problem structuring method? an exploration from the "Imagine" approach. Eur. J. Oper. Res. 222, 350–360.
Bidone, E.D., Lacerda, L.D., 2004. The use of DPSIR framework to evaluate sustainability in coastal areas. Case study: Guanabara Bay basin, Rio de Janeiro, Brazil. Reg. Environ. Change 4, 5–16.
Blum, W.E.H., 2004. Soil Indicators for Decision Making: Sharing Knowledge between Science, Stakeholders and Politics. International Soil Conservation Organization Conference, Brisbane, 5pp.
Borja, A., Galparsoro, I., Solaun, O., Muxika, I., Tello, E.M., Uriarte, A., ValenciaV, 2006. The European water framework directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. Estuar. Coast. Shelf Sci. 66, 84–96.
Bricker, S.B., Ferreira, J.G., Simas, T., 2003. An integrated methodology for assessment of estuarine trophic status. Ecol. Model. 169, 39–60.
Caeiro, S., Mourão, I., Costa, M.H., Painho, M., Ramos, T.B., Sousa, S., 2004. Application of the DPSIR model to the Sado Estuary in a GIS context – social and Economical Pressures. In: 7th AGILE Conference on Geographic Information Science 29 April-1May 2004, Heraklion, Greece Parallel Session 4.3-Environmental/Social Modelling, 13pp.
Carr, E.R., Wingard, P.M., Yorty, S.C., Thompson, M.C., Jensen, N.K., Roberson, J., 2007. Applying DPSIR to sustainable development. Int. J. Sustain. Dev. World Energy 14, 543–555.
Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol. Prog. Ser. 210, 223–253.
Cooper, P., 2012. The DPSWR Social Ecological Accounting Framework; Notes on its Definition and Application. School of Management University of Bath. Bath BA27AY. 13pp.
de Jonge, V.N., Pinto, R., Turner, R.K., 2012. Integrating ecological, economic and social aspects to generate useful management information under the EU directives' 'ecosystem approach'. Ocean Coast. Manag. 68, 169–188.
EEA, 1995. Europe's Environment: the Dobris Assessment. European Environmental Agency, Copenhagen, 8pp.
EEA, 1999. Environmental Indicators: Typology and Overview. European Environment Agency, 19pp.
EEA, 2003. Environmental Indicators: Typology and Use in Reporting. European Environment Agency, 20pp.
Elliot, M., 2002. The role of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. Mar. Pollut. Bull. 44, iii–vii.
Elliot, M., 2011. Marine science and management means tackling exogenic unmanaged pressures and endogenic managed pressures – a numbered guide. Mar. Pollut. Bull. 62, 651–655.
Elliot, M., Burdon, D., Hemingway, K.L., 2006. Marine ecosystem Structure, Functioning, Health and Management and Potential Approaches to Marine Ecosystem Recovery: a Synthesis of Current Understanding. Institute of Estuarine and Coastal Studies, University of Hull, 122pp.
ELME, 2007. European Lifestyles and Marine Ecosystems, Description of Work. European Union, 85pp.
Fassio, A., Giupponi, C., Hiederer, R., Simota, C., 2005. A decision support tool for simulating the effects of alternative policies affecting water resources: an application at the European scale. J. Hydrology 304, 462–476.
Felsenstein, D., Lichter, M., Vinokur, T., 2014. Assessment of natural resources use for sustainable development – DPSIR framework for case studies in palmate (Tel Aviv Metropolitan area) and Carmel coast (Haifa Metropolitan area), Israel. In: Lan, T.D., Olsson, E.G.A., Alpokay, S. (Eds.), Environmental Stresses and Resource Use in Coastal Urban and Peri-urban Regions. DPSIR Approach to SECOA's 17 Case Studies, vol. 6. Casa Editrice, Universita La Sapienza, Rome, p. 430pp.
Friend, A.M., Rapport, D.J., 1991. Evolution of macro-information systems for sustainable development. Ecol. Econ. 3, 59–76.
Giupponi, C., 2007. Decision support systems for implementing the european water framework directive: the MULINO approach. Environ. Model. Softw. 22, 248–258.
Gobin, A., Govers, G., Jones, R., Kirkby, M., Kosmas, G., 2002. Aseessment and Reporting on Soil Erosion; Background and Workshop Report. European Environment Agency. Technical Report 131pp.
Haase, D., Nuissi, H., 2007. Does urban sprawl drive changes in the water balance and policy? the case of Leipzig (Germany) 1870–2003. Landsc. Urban Plan. 80, 1–13.

ICRI, 2005. Global Forum on Oceans Coasts, and Islands [Online]. www.icriforum.org/secretariat/seycdoc/ICRI_GM3_Item4_9.pdf.
IMPRESS, 2003. Common Implementation Strategy for the Water Framework Directive, Guidance Document No 3: Analysis of Pressures and Impacts. Working Group 2.1., 156pp.
Kagalou, I., Leonardos, I., Anastasiadou, C., Neofytou, C., 2012. The DPSIR approach for an integrated river management framework. A preliminary application on a Mediterranean Site (Kalamas River-NW Greece). Water Resour. Manag. 16pp.
Karageorgis, A.P., Kapsimalis, V., Kontogianni, M., Skourtos, M., Kerry, R., Wimsalomons, T., 2006. Impact of 100-year human interventions on the deltaic coastal zone of the inner Thermaikos Gulf (Greece): a DPSIR framework analysis. Environ. Manage. 38 (2), 304–315.
Kelble, C.R., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Cook, G.S., Lorenz, J.J., Boyer, J.N., 2013. The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PLOS One 8 (8), 1–12.
Klotz, S., 2007. Drivers and pressures on biodiversity in analytical frameworks. Environ. Sci. Technol. 25, 252–262.
Labajos, B.M., Binimelis, R., Monterroso, I., 2009. Multi-level driving forces of biological invasions. Ecol. Econ. 69, 63–75.
Lan, T.D., Olsson, E.G.A., Alpokay, S. (Eds.), 2014. Environmental Stresses and Resource Use in Coastal Urban and Peri-urban Regions. DPSIR Approach to SECOA's 17 Case studies, vol. 6. Casa Editrice, Universita La Sapienza, Rome, 430pp.
Lee, M.-T., Lin, T.-F., 2014. In: Developing an Interactive Decision Support System for Sustainable Coastal Tourism of Cijin, Taiwan. International Symposium on Computer, Consumer and Control. IEEE Computer Society, pp. 682–685.
Levy, M.A., Morel, A.C., Adamo, S.B., Barr, J., McMullen, C.P., Dietz, T., López-Carr, D., Rosa, E.A., 2012. States and Trends of the Environment. GEO-5 Report, 30pp.
Lin, T., Xue, X.-Z., Lu, C.-Y., 2007. Analysis of coastal wetland changes using the DPSIR model: a case study in Xiamen, China. Coast. Manag. 35 (2), 289–303.
Mangi, S.C., Roberts, C.M., Rodwell, L.D., 2007. Reef fisheries management in Kenya: preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators. Ocean Coast. Manag. 50, 463–480.
Maxim, L., Spangenberg, J.H., 2009. Driving forces of chemical risks for the European biodiversity. Ecol. Econ. 69, 43–54.
Maxim, L., Spangenberg, J.H., O'ConnorM, 2009. An analysis of risks for biodiversity under the DPSIR framework. Ecol. Econ. 12pp.
MEA, 2003. Summary; Ecosystems and Human Well-Being: A Framework for Assessment, 25pp.
MEA, 2005. Ecosystems and Human Well-Being: Biodiversity Synthesis, 100pp.
Mysiak, J., Giupponi, C., Rosato, P., 2005. Towards the development of a decision support system for water resource management. Environ. Model. Softw. 20, 203–214.
Nebyou, A.E., 2010. Applying the DPSIR Approach for the Assessment of Alternative Management Strategies of Simen Mountains National Park, Ethiopia. MSc Thesis. University of Natural Resources and Life Sciences, Vienna, Austria.
Newton, A., 2012. A systems approach for sustainable development in coastal zones. Ecol. Soc. 17 (3), 41.
Newton, A., Weichselgartner, J., 2014. Hotspots of coastal vulnerability: a DPSIR analysis to find societal pathways and responses. Estuar. Coast. Shelf Sci. 140, 123–133.
Newton, A., Icely, J.D., Falcao, M., Nobre, A., Nunes, J.P., Ferreira, J.G., Vale, C., 2003. Evaluation of eutrophication in the Ria Formosa coastal lagoon. Portugal Cont. Shelf Res. 23, 1945–1961.
Newton, A., Icely, J.D., Cristina, Sónia, Brito, A., Cardoso, A.C., Colijn, F., Riva, S.D., Gertz, F., Hansen, J.W., Holmer, M., Ivanova, K., Leppäkoski, E., Canu, D.M., Mocennim, C., Mudge, S., Murray, N., Pejrup, M., Razinkovas, A., Reizopoulou, S., Pérez-Ruzafa, A., Schernewski, G., Schuber, H., Carr, L.C., Solidoro, C., Viaroli, P., Zaldívar, J.M., 2014. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. Estuar. Coast. Shelf Sci. 95, 95–122.
Nobre, A.M., 2009. An ecological and economic assessment methodology for coastal ecosystem management. Environ. Manage. 44, 185–204.
O'Connor, M., 2007. The "Four Spheres" framework for sustainability. Ecol. Complex. 3, 285–292.
O'Higgins, T., Farmer, A., Daskalov, G., Knudsen, S., Mee, L., 2014. Achieving good environmental status in the Black Sea: scale mismatches in environmental management. Ecol. Soc. 19 (3), 54.
OECD, 1993. OECD Core Set of Indicators for Environmental Performance Reviews. Organization for Economic Cooperation and Development, Paris, France, 93pp.
OECD, 2004. OECD Key Environmental Indicators. Organization for Economic Cooperation and Development: Environment Directorate, Paris, France, 38pp.
Ojeda-M, C., Casalduero, F.G., Bayle-S, J.T., Cebrian, C.B., Valle, C., Sanchez-L, J.L., Forcada, A., Sanchez-, J.P., Martin-, S.P., Falcon, J.M., Salas, F., Graziano, M., Chemello, R., Stobart, B., Cartagena, P., Perez-R, A., Vandeperre, F., Rochel, E., Planes, S., Brito, A., 2009. A conceptual framework for the integral management of marine protected areas. Ocean Coast. Manag. 52, 89–101.
Olsen, S.B., 2003. Frameworks and indicators for assessing progress in integrated coastal management initiatives. Ocean Coast. Manag. 46, 347–361.
Omann, I., Stocker, A., Jäger, J., 2009. Climate change as a threat to biodiversity: an application of the DPSIR approach. Ecol. Econ. 69, 24–31.
Ostrom, E., 2009. A general framework for analyzing the sustainability of social-ecological systems. Science 325, 419–421.
Ou, C.-H., Liu, W.-H., 2010. Developing a sustainable indicator system based on the pressure-state- response framework for local fisheries: a case study of Gungliau, Taiwan. Ocean Coast. Manag. 53, 289–300.
Pacheco, A., Carrasco, A.R., Vila-Concejo, A., Ferreira, O., Dias, J.A., 2006. A coastal management program for channels located in back barrier systems. Ocean Coast. Manag. 50, 119–143.
Pinto, R., de Jonge, V.N., Neto, J.M., Domingos, T., Marques, J.C., Patrício, J., 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. Ocean Coast. Manag. 72, 64–79.
Porta, J., Poch, R.M., 2011. DPSIR analysis of land and soil degradation in response to changes in land use. Span. J. Soil Sci. 1 (1), 100–115.
Rapport, D.J., Whitford, W.G., 1999. How ecosystem responds to stress: common properties of arid and aquatic systems. BioScience 49 (3), 193–203.
Rapport, D.J., Gaudet, C., Karr, J.R., Baron, J.S., Bohlen, C., Jackson, W., Jones, B., Naiman, R.J., Norton, B., Pollock, M.M., 1998. Evaluating landscape health: integrating societal goals and biophysical process. J. Environ. Manag. 53, 1–15.
Rekolainen, S., Kamari, J., Hiltunen, M., 2003. A conceptual framework for identifying the need and role of models in the implementation of the water framework directive. Int. J. River Basin Manag. 1 (4), 347–352.
Rogers, S.I., Greenaway, B., 2005. A UK perspective on the development of marine ecosystem indicators. Mar. Pollut. Bull. 50, 9–19.
Sekovski, I., Newton, A., Dennison, W.C., 2012. Megacities in the coastal zone: using a driver-pressure-state-impact-response framework to address complex environmental problems. Estuar. Coast. Shelf Sci. 96, 48–59.
Shao, C., Guan, Y., Chu, C., Shi, R., Ju, M., Shi, J., 2014. Trends analysis of ecological environment security based on DPSIR model in the coastal zone: a survey study in Tianjin, China. Int. J. Environ. Res. 8 (3), 765–778.
Smeets, E., Weterings, R., 1999. Environmental Indicators: Typology and Overview. Technical report No 25. EEA, 19pp.
SoER, 2007. Forests and Biodiversity. State of the Environment Report for Rajasthan. Ministry of Environment for Forests, Delhi, India.
Spangenberg, J.H., 2007. Biodiversity pressure and the driving forces behind. Ecol. Econ. 61, 146–158.
Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H., Watzold, F., 2008. Discursive biases of the environmental research framework DPSIR. Land Use Policy 25, 116–125.
Tsai, H.T., Tzeng, S.Y., Fu, H.H., Wu, J.C.T., 2009. Managing multinational sustainable development in the European Union based on the DPSIR framework. Afr. J. Bus. Manag. 3 (11), 727–735.
Turner, R.K., Lorenzeni, I., Beaumont, N., Bateman, I., Langford, I.H., McDonald, A.L., 1998. Coastal management for sustainable development: analyzing Environmental and socio-economic changes on the UK coast. Geogr. J. 164 (3), 269–281.
UKTAG, 2013. Guidance on the assessment of alien species' pressures. U. K. Tech. Advis. Group Water Framew. Dir. 20pp.
UNEP, 2012. State and Trends of the Environment. Report of the fifth global environmental outlook (GEO-5), 30pp.
Vacchi, M., Montefalcone, M., Parravicini, V., Rovere, A., Vassallo, P., Ferrari, M., Morri, C., Bianchi, C.N., 2014. Spatial models to support the management of coastal marine ecosystems: a short review of best practices in Liguria, Italy. Mediterr. Mar. Sci. 172–180.
Vacik, H., Wolfslehner, B., Seidl, R., Lexer, M.J., 2007. Integrating the DPSIR – approach and the analytic network process for the assessment of forest management strategies. In: Reynolds, K., Thomson, A., Shannon, M., Kohl, M., Ray, D., Renolls, K. (Eds.), Sustainable Forestry. From Monitoring and Modeling to Knowledge Management and Policy Science, Wallingford, pp. 393–411.
van der Voet, E., Suh, S., Tukker, A., Huijbregts, M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y. (Eds.), 2010. Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, a Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. UNEP, Hertwich, 112pp.
Zaldívar, J., Cardoso, A., Viaroli, P., Newton, A., Wit, R., Ibañez, C., Reizopoulou, S., Somma, F., Razinkovas, A., Basset, A., Holmer, M., Murray, M., 2008. Eutrophication in Transitional Waters: an Overview (JRC-EU).Transitional Waters Monographs, 1, pp. 1–78.