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An analysis of risks for biodiversity under the DPSIR framework

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ABSTRACT

This paper reviews definitions and uses of the Driving Forces–Pressures–State–Impacts–Responses (DPSIR) framework and argues that it is a relevant tool for structuring communication between scientists and end-users of environmental information, while it is inappropriate as an analytical tool. An apparently deterministic 'causal' description of environmental issues inevitably downplays the uncertainty and multiple dimensions of causality inherent in complex environmental and socio-economic systems. Consequently, the paper comõplements and reframes 'DPSIR' using a complex system methodology based on the distinction between four 'spheres' of sustainability (environmental, economic, social and political) and the analysis of their functioning and relationships. The pair-wise interface aspects are characterised through investigation of the 'demands' and 'supply' of each sphere relative to the others.

Within the resulting conceptual framework, each of the five D, P, S, I and R concepts are specified, for application in integrative analysis of relationships between policy, society, economy and biodiversity in one of the world's largest European integrated research projects on biodiversity (ALARM).

1. Introduction

The abbreviation DPSIR stands for a conceptual framework for the description of the environmental problems and of their relationships with the socio-economic domain, in a policy meaningful way. According to its terminology, social and economic developments (Driving Forces, D) exert Pressures (P) on the environment and, as a consequence, the State (S) of the environment changes. This leads to Impacts (I) on ecosystems, human health, and society, which may elicit a societal Response (R) that feeds back on Driving Forces, on State or on Impacts via various mitigation, adaptation or curative actions (Smeets and Weterings, 1999; Gabrielsen and Bosch, 2003). Thus, the DPSIR is described as a "causal framework for describing the interactions between society and the environment" (EEA, 2006a) (Fig. 1).

Since 1995, the model has been used by the European Environment Agency and by EUROSTAT, for the organization of environmental indicators and statistics (EEA, 1995; Smeets and Weterings, 1999; Jesinghaus, 1999). The framework was applied to the issue of biodiversity by Delbaere (2002) and EEA (2007). Two features of the DPSIR model have contributed to its wide use. First, it structures the indicators with reference to political objectives related to the environmental management problem addressed; and second, it focuses on supposed causal relationships, in a clear way that appeals to policy actors (Smeets and Weterings, 1999; Giupponi, 2007).

However, for analytical purposes, the scheme is unsatisfying. The simple causal relations assumed cannot capture the complexity of interdependencies in the real world (Smeets and Weterings, 1999; Spangenberg et al., 2002; Gobin et al., 2004; Refsgaard et al., 2006). Although the didactic clarity is appealing, the apparent simplicity can be misguiding. The relations between the D–P–S–I–R categories may in reality be synergistic (for example, a specific Impact can be caused by a number of State conditions and, indirectly, by Responses to other Impacts; State conditions are influenced by diverse Pressures, each of which can originate from a range of Driving Forces, each contributing to several Pressures) and these connections cannot be understood when each DPSIR category is addressed separately (Mysiak et al., 2005). Given the different sources of multiple Pressures and their potential to act in synergic or antagonistic manner, the link between Driving Forces, Pressures, State and Impacts, as well as the effects of Responses back to each of these categories, may be difficult to assess in absence of a very clear methodological basis. This was shown for example by the analysis of indicators developed for monitoring Integrated Product Policy (Poll and Rubik, 2006) or by work on multicausal patterns of action of chemical contaminants on human health (Gee, 2005a,b). Moreover, many of the relationships between the human system and the environmental system are complex and may be not well understood. Thus clear 'anchoring points' have to be defined to specify the scheme and to make it suit to different discourses; we have done so for biodiversity risk analysis.

DPSIR does allow policy-makers to understand more easily the environmental problems. However, for scientific purposes, it has to be

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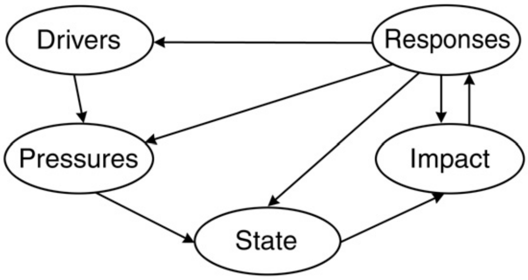

Fig. 1. The DPSIR model (Smeets and Weterings, 1999).

completed by aspects addressing uncertainty. Without these, the DPSIR framework may appear as a deterministic and linear 'causal' description of environmental issues, which inevitably downplays the complexity of the environmental and socio-economic systems. As well, the definitions of the DPSIR categories must be improved, and this is the focus of the present paper. The aspects regarding uncertainty are addressed in more detail in the cases studies of this volume.

Environmental, social and economic systems are characterised, on the one hand, by causal relationships between their different components. On the other hand, uncertainty is intrinsic to complex biological and social systems (Risbey et al. 2005, 2007; Van der Sluijs, 2005; Van der Sluijs et al., 2005; Refsgaard et al., 2006; van der Sluijs et al., 2008). We have some knowledge about indeterminacies, and we are aware of the incompleteness of knowledge. Anyway, causality and uncertainty go hand in hand in influencing systems' dynamics. The DPSIR logic which privileges only deterministic causal relationships for describing these systems' functioning and interactions cannot on its own give us a framework for working with this amalgam of indeterminacy, cumulative causation, knowledge and ignorance.

The paper is structured in two parts. The first is represented by Section 2, which presents the results of the literature study on the mismatch between system characteristics and the conceptual tools used for addressing them. The second part is represented by Section 3, which presents opportunities for the amelioration of the DPSIR framework, through embedding it in a coevolutionary systems framework conceived in terms of 'four spheres'. Finally, Section 4 discusses the application of the proposed 'four spheres–DPSIR framework', and presents our conclusions.

2. Former uses of the DPSIR model: state of the art

2.1. Driving Forces

Many different meanings have been attached to the concept of Driving Force, depending on "where" the cause of an environmental problem is identified (either in the human or in the natural systems, or in both) and on the level of the chosen system at which one assumes that it appears.

Most literature sources consider only anthropogenic factors as Driving Forces (Gabrielsen and Bosch, 2003; EEA, 2005a; Giupponi, 2007; Rogers and Greenaway, 2005; Mysiak et al., 2005). For example, for the EEA, the Driving Forces are considered to describe "the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns" (Gabrielsen and Bosch, 2003, pp. 8; EEA, 2007, p. 13).

Some authors distinguish two levels of Driving Forces (Gabrielsen and Bosch, 2003; Mysiak et al., 2005; IAEA and IEA, 2001). Primary Driving Forces are technological and societal forces that motivate human activities (population growth, social structure, cultural attitudes, individual needs). They induce developments in Secondary Driving Forces, which are human activities triggering Pressures and Impacts (e.g., land use changes, urban expansion, industry and agriculture developments).

The Millennium Ecosystem Assessment (MEA) proposes that Drivers can be both anthropogenic and natural factors "that directly or indirectly cause a change in an ecosystem" (MEA, 2003, pp. 85). The MEA approach thus distinguishes between two types of Drivers: direct and indirect. But, beyond the differences in terminology, the meaning of MEA's direct Drivers is pretty much the same as that of most uses of Pressures in the DPSIR model. The direct and indirect Drivers of change can influence human well-being both directly and via their Impact on ecosystem services the indirect Drivers do so by influencing the direct Drivers. So indirect Drivers can be taken to be a subset of the

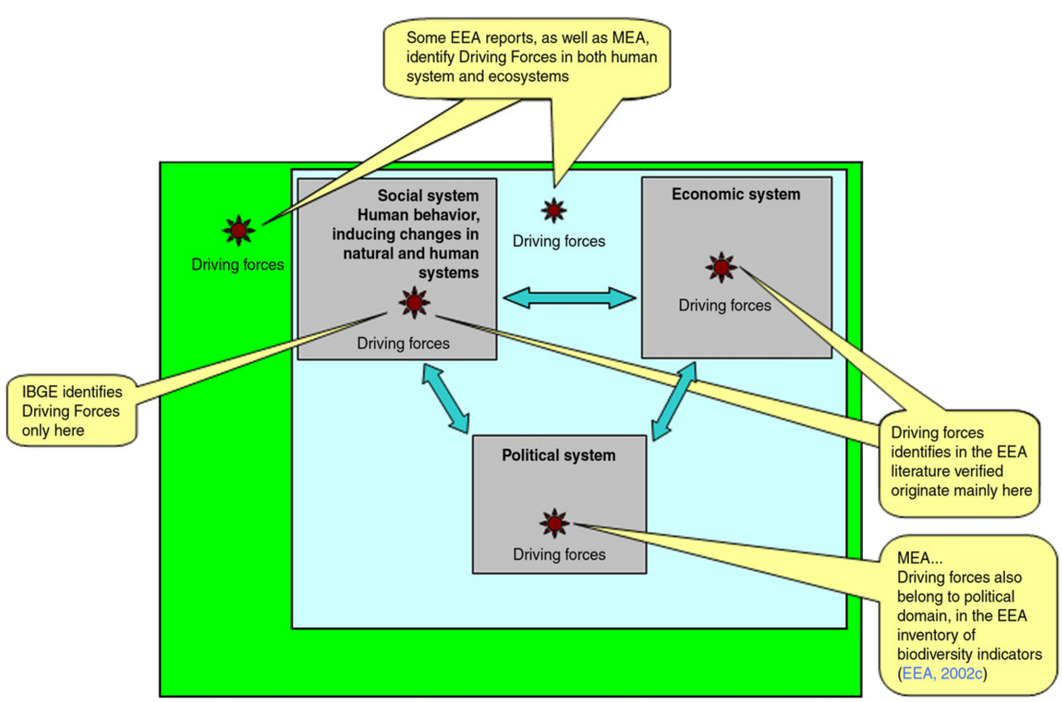

Fig. 2. Driving Forces 'locations': results of the literature study.

Driving Forces, noting that the MEA defines the indirect Drivers on the level of framework conditions, not as policies and politics.

In many studies, the term Driving Forces is employed for describing economic sectors that engender Pressures, such as industry, agriculture and transport. Some others describe Driving Forces:

- through mixes of descriptors for the economic sectors, structural features of the economic system, demography and social characteristics (EEA, 2002),
- through patterns of resource use, quantities of polluting products and intrinsic properties of such products (EEA, 2000),
- through societal trends (EEA, 2005b),
- through demography, developments in economic, socio-political, science and technology domains, cultural and religious factors (MEA, 2003) (Fig. 2).

Less frequently, the term Driving Forces refers to social and political aspects. An "environmental problem" can come from the relationships between stakeholders (power balance), from the inefficiency of institutional arrangements in implementing an established regulation, from social inequality (dumping waste in poor areas may be cheap) or from the inadequacy of policy actions for a given social context. The examination of human motivations, behaviors and attitudes that induce, are affected by or respond to the changes in environmental conditions can be highly relevant for framing policy Responses (cf. O'Connor, 1994a; Spangenberg et al., 2002; Bowen and Riley, 2003). A description of an environmental issue that ignores employment, social receptiveness for the environment or the relative distribution of Impacts between social groups and economic players may lead to a framing of Responses that disregards such aspects.

2.2. Pressures

Pressures are anthropogenic factors inducing environmental change (Impacts). Usually these changes are unwanted and seen as negative (damage, degradation, etc.). According to EEA, Pressures are "developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities" (Gabrielsen and Bosch, 2003, pp. 8). Nonetheless, the definitions of Pressures encountered in literature differ in respect to at least four points:

1. The object of change: some definitions focus on the influence of Pressures on the State of the environment based on the idea that any change in the environment under the influence of the human activity is damaging (Gabrielsen and Bosch, 2003). Some other definitions draw a line between changes in the State of the environment that are "acceptable"[3] and changes that are not, for example based on the concept of "carrying capacity" (EEA, 2005a). Finally, Pressures may be factors that diminish the benefits that humans get from the environment; in this last case Pressures are defined by making reference directly to the socio-economic Impacts that they produce (Jesinghaus, 1999).
2. The relationship between the Pressure and the changes it induces. Each Pressure can have different effects, some of which emerging already on the short-run (e.g., land use, deforestation), while others mainly on the long-run (e.g., climate change). Some other Pressures may become effective in certain conditions of environmental exposure (Jesinghaus, 1999; Bowen and Riley, 2003). As far as the relationship between Pressure and effects is known with sufficient certainty, it is expressed as a probability (e.g., chemical risk).
3. The character of the Pressure: Pressures may refer to emissions (of pollutants, wastes or other disturbances), the use of resources (all use or uses above a threshold), to the intensity or the efficiency of human activities, to changes in lifestyles and activities, or even to general socio-economic features (EUROSTAT, 2001; Gabrielsen and Bosch, 2003; OECD, 2003; EEA, 2006b).
4. The level of detail of the definition: Pressures may be defined either in a very generic manner (Smeets and Weterings, 1999; Mortensen et al., 2005) or, on the contrary, very narrowly, according to the objective of a specific study (Mourelatou and Smith, 2002).

For declaring that an anthropogenic factor is a Pressure and in order to associate it with an Impact perceived in the socio-economic system, there is need for causal evidence of the relationship between the two (Rogers, 2003). However, it is sometimes difficult to bring conclusive evidence of a cause–effect relationship as is needed for the application of the DPSIR logic (EEA, 2005a). Given the complexity of ecological phenomena, uncertainties in the knowledge base might not be solved through additional research (Muradian, 2001; Craye et al., 2005; Van der Sluijs, 2005). In the meantime, potentially adverse factors can cause severe harm to the environment. This can lead to policy–science difficulties if the DPSIR logic is extended to Pressures that are made the subject of the precautionary principle (Helsinki Commission, 2002). European experience in environmental problems shows that, when the "proof of a link" serves for decision making, the scientific production of knowledge is strongly interdependent with the social and economic context in which it is realized. Even when scientific evidence exists, the influence of stakeholders on policy-makers can downgrade, or upgrade, the importance of an environmental stressor (whose status as a Pressure will be, consequently, questioned) (Harremoës et al., 2001; Maxim and van der Sluijs, 2007).

The definition given by the EEA (Gabrielsen and Bosch, 2003) for Pressures does not specify the conditions under which anthropogenic factors become stressors of the environment. Is it when they exceed a certain threshold? In particular conditions? At certain times? Given the complexity and the non-linear dynamics of the environmental processes involved, and the temporal and spatial variability that characterise the interplay with physico-chemical parameters (climate, soil), the thresholds above which "nature cannot cope anymore" with the consequences of human activity (the so-called "carrying capacity") are actually poorly known and intrinsically "fuzzy" (Muradian, 2001; EEA, 2005a). Also, "cannot cope anymore" is a description of ecosystems responses to external Pressures which are declared unacceptable, as the result of a societal discourse. The judgment of "negative" (or "positive") is a normative statement, based on an anthropogenic value system. "Negative" always implies the questions "for which desiderata?" and "for whom?". In many studies, neither these questions nor their answers are made explicit. Yet, thresholds of social acceptance are fuzzy and can be highly dependent on the particular socio-political context. Pressures depend on the kind, level and technology involved in source activities, which can be very different between countries or regions. The approaches and implementation criteria for their control may vary from country to country, as it is, for instance, the case of Nitrate Directive (Giupponi and Vladimirova, 2006). Such factors render the averaging or aggregation of Pressures at European scale difficult.

2.3. State

Some definitions found for State are either tautological (UN CSD, 2001) or issue-specific (OECD, 2003). For the EEA, the State is "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." (Gabrielsen and Bosch, 2003, pp. 8).

[3] The content of the "acceptability" of the environmental consequences of human activities is a socially defined moving target and can be very different from one stakeholder to another. Declaring that an environmental change is an Impact is the result of complex social interactions between the scientific analysis and stakeholders' involvement (e.g., Impacts of climate change on human health).

For biodiversity, the EEA (2007, p. 13) defines the State as being "the abiotic condition of soil, air and water, as well as the biotic condition (biodiversity) at ecosystem/habitat, species/community and genetic level".

In the DPSIR literature, the State may refer either to natural systems alone (Bowen and Riley, 2003; Giupponi and Vladimirova, 2006) or to both natural and socio-economic systems (Rogers and Greenaway, 2005). Depending on the system(s) chosen for description, indicators of State can be very different in kind from one study to another. They describe a wide range of features, from physico-chemical characteristics of ecosystems, quantity and quality of resources or "carrying capacity", to management of fragile species and ecosystems, living conditions for humans, exposure or the effects of Pressures on humans, or even larger socio-economic issues (Jesinghaus, 1999; UN CSD, 2001; IAEA and IEA, 2001; OECD, 2003; EEA, 2006b).

Some studies adopt the concepts of vulnerability and risk for defining the State and the Impacts. For Fassio et al. (2005), the State of the environment is described by a specification of the spatial intrinsic vulnerability spatially combined with Pressures and is expressed as a risk (e.g. of nitrogen leaching). The changes in this risk pattern (State) may determine Impacts (e.g. eutrophication). Giupponi and Vladimirova designate the State as the environmental vulnerability to a Pressure in a given location (e.g., chemical characteristics of groundwaters) (Giupponi and Vladimirova, 2006), *before* the Pressure acts. The environmental result of a specific combination of Pressures and State is an Impact (e.g., changes in eutrophication status) (for a detailed discussion on the relationship between vulnerability/resilience terminology and the DPSIR framework, see Maxim and Spangenberg, 2006).

2.4. Impacts

Depending on the discipline and the methodology used, the notion of Impact may focus on completely different target points. In biosciences, an Impact can refer to effects on living beings and non-living compartments of ecosystems (aquatic, terrestrial and atmospheric) (Mortensen et al., 2005; Borja et al., 2006). These changes are often "negative", in the sense that they affect adversely the functioning of ecosystems relative to their potential performance, under otherwise plausible conditions (Nunes et al., 2003). Examples are genetic, physiologic or behavioral anomalies, modifications in the chemical composition of air or water, changes in the ecosystem's functioning (e.g., primary and secondary productivity) (Edwards, 2002). However, Impacts may be identified and quantified without any positive or negative connotation, signalling simply a change in the environmental parameters compared to their values before the intervention of a new factor (e.g., impacts of peri-urban populations of butterflies on reõsidential populations of butterflies). In more rare cases, Impacts may also signal a "positive" effect (e.g., impacts of climate changes on biomass growth).

The socio-economic sciences, by contrast, tend to employ the term Impacts with focus on effects on the human systems, associated with changes in environmental functions, such as resources provision, water and air quality, soil fertility, physical and mental health, social cohesion (Bowen and Riley, 2003; Gobin et al., 2004). This notion of environmental function (or environmental service[4]) expresses the perception in human societies that certain categories of the environment are able to accomplish services that contribute to human well-being (this concept used in biosciences too, for analyzing the consequences of Pressures on the environment, e.g. Björklund et al., 1999; Edwards, 2002; Lobo et al., 2005).

According to EEA, Impacts are consequences of changes in the State of the environment for the environmental functions (Gabrielsen and Bosch, 2003; EEA, 2005a). In this respect, even if effects of human activities on the State of the environment are related and occur in a sequence, it is nevertheless only the "last step" of this sequence (which "directly reflect changes in environmental use functions by humans") that should be considered an Impact (Gabrielsen and Bosch, 2003, pp. 8).

There are several classifications proposed for environmental functions. The best known distinguishes four categories: Supporting (e.g., nutrient cycling, soil formation, primary production); Provisioning (e.g., food, freshwater, wood and fiber); Regulating (e.g., climate regulation, disease regulation, water purification) and Cultural (e.g., aesthetic, spiritual, educational, recreational) (MEA, 2003).

The classification called 5S' (Noël and O'Connor, 1998) has the benefit of replacing Regulating functions with Life Support and adding a new category, Site, which covers the missing spatial dimension of functions of biodiversity in the MEA classification. The five classes are:

- *S*ource: provision of resources for human activity, such as energy, water, forestry products, food, pollination.
- *S*ink: neutralization and recycling of wastes from human activities, such as the role of soil or plants as sink for CO_2 or the provision of air quality through gaseous wastes recycling and dilution.
- Life *S*upport: maintenance of a "balanced" nature, adequate for both human and non-human life, through processes like the control of the hydrologic cycle by forests or the maintenance of species diversity which has not an immediate significance for human beings but which assure the resilience of the ecosystem.
- *S*ite: physical place for human activities and habitation.
- *S*cenery: the meaning and significance attributed to the environment as an object of sensory awareness: spiritual value of nature, related to social and cultural contexts, ethical convictions and aesthetic appreciation and interest as an object of knowledge.

Indicators of Impacts elaborated in different reports seem to confuse changes in State and changes in environmental functions. Recent EEA reports highlight the diversity of "objects" affected by Impacts: land use, the availability of natural resources, the absorption of discharges, the ecosystems health/stability and amenities, the diversity, viability and distribution of species, the climate stability, the viability of sectors of economy and society, the human health or international socio-political issues, the cultural richness, the employment and the viability of local communities, future generations (EEA, 2005a,b).

The difficulty to define and quantify Impacts stems partly from the complexity of needed measurements of changes in ecosystems and the incomplete knowledge on them (EEA, 2005a). But it is also clear that different disciplines are dealing with different aspects of Impacts, and are addressing different things with this same concept. Biosciences are typically concerned with genes, species and ecosystems, whereas social sciences are concerned with social and economic systems and humanities with individual well-being. It is clear that it is neither possible nor needed to change the vocabulary previously used, but a common terminology that serves as some kind of "bridge" is desirable. In Section 3.3 below, based on discussion of underlying conceptual differences and similarities between 'changes of State' and 'changes in the environmental functions', a number of methodological suggestions will be made for clarifying usages of this term.

2.5. Responses

Responses have to do with decision making. Depending on the decisional pattern and scale considered relevant, two main groups of

[4] The Millennium Ecosystem Assessment refers to "ecosystem services" (MEA, 2003). In the present paper, we use the term of "environmental function"/ "environmental service", which we consider more adequate for the study of biodiversity: it is not only the ecosystem that is providing goods and services to human beings, but also the species (ex: role of honeybees in pollination) and the genetic level (ex: genetic richness for biotechnologies or breeding); and there is also the "physical" environment, associated with all living forms.

definitions of Responses may be identified. One associates Responses uniquely to policy action; the other identifies Responses from different levels of the society, represented both by groups and by individuals, from the government, private or non-governmental sectors.

Responses may seek to control Driving Forces or Pressures (prevention, mitigation), to maintain or restore the State of the environment, to help to accommodate to Impacts (adaptation) or even deliberate "do nothing" strategies (Smeets and Weterings, 1999; Gabrielsen and Bosch, 2003; Perrings, 2005). Responses have also been framed as "negative" Driving Forces, since they aim, for instance, at redirecting prevailing trends in consumption and production patterns (Smeets and Weterings, 1999).

The definition used by EEA focuses on two dimensions: the agents involved and types of measures that can constitute Responses: "Response indicators refer to Responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment." (Gabrielsen and Bosch, 2003, pp. 8). For application on biodiversity, "Responses are the measures taken to address drivers, pressures, state or impacts. They include measures to protect and conserve biodiversity (in situ and ex situ), and include, for example, measures to promote the equitable sharing of the monetary or non-monetary gains arising from the utilisation of genetic resources." (EEA, 2007, p. 13).

Most of the indicators developed for Responses concern political actions of protection, mitigation, conservation or promotion (Gabrielsen and Bosch, 2003, EEA, 2006b; OECD, 2003). Other indicators refer to Responses as being a mixed result of both effective top–down political action and bottom–up social awareness (e.g., waste recycling rates, community-based initiatives such as eco-communities).

We have noted, earlier, the inclusion of political processes, regulatory frameworks and policies among Driving Forces. So it can be ambiguous or difficult to draw a line between Responses and Driving Forces. For example, some policies may not (or not adequately) consider biodiversity concerns, and therefore they may be considered Driving Forces of Pressures on biodiversity (e.g. by stimulating intensive agricultural practices). Some policies may target the management of Impacts on biodiversity, and in this respect they can be considered a Response (e.g., policies for biodiversity conservation). Most of the time the users of the DPSIR do not make the difference between these two patterns, and only the role of policies as Responses is retained (Bowen and Riley, 2003).

In conclusion, depending of the objectives of the research, very different descriptions of systems and of the inter-relationships between the environmental and the human systems can be developed. The DPSIR scheme can be "turned" (analysing either the impacts of the socio-economic system on the environment, or vice versa). Thus the same phenomenon may, depending on the angle of attack, legitimately be characterised as a Driving Force, Pressure, State or Response (Mysiak et al., 2005). For instance, 'energy consumption' has been considered a State indicator (IAEA and IEA, 2001), a Driving Force (EEA, 2006b), and a Pressure (EUROSTAT, 2001); and 'biological invasions' have been dealt with as Driving Forces, Pressures, State and Impact indicators. Users employ the DPSIR according to the state of knowledge in the field, the data available, the scale of the study, their own disciplinary background, and analysis purposes. This creates ambiguity and low comparability between descriptions and indicators issued from different studies.

The qualities of the DPSIR scheme in terms of flexibility, general applicability, organisation of the information and as framework for communication between scientists and politicians, are thus counterbalanced by the fact that the applicability in very diverse situations renders the definitions of its components very generic and sometimes even incoherent. The DPSIR model is essentially a discursive framework which, in view of its ambiguities, cannot be used as an analytical guide to describe complex issues marked by uncertainty, time and space scale indeterminacies and social interactions. We suggest, however, that the concepts can be very useful if embedded within a more rigorously specified systems framework.

3. Methodology and definitions proposed

Our method juxtaposes two frameworks for the organisation of the environmental information: the DPSIR and the tetrahedron of sustainability. The purpose is to ameliorate the communication value of the first by integrating it with the analytical power of the second. This has been undertaken to obtain a specification of the DPSIR framework focussed on biodiversity loss. Although we believe that the approach is quite robust, the applicability to other domains is not discussed here.

For integrated analyses of sustainability challenges, societal options can be framed in a comparative scenario context for the exploration of the "ecological–economic space of opportunities" for society into the future. This means to explore, within the limits of what might be feasible, a range of alternative evolutions that, on various societal grounds, might be judged as more or less desirable, or undesirable.

In this regard, the tetrahedral model has been developed for the analysis of sustainability issues, highlighting the interdependency between economic, social, environmental and political dimensions. It may be construed as the articulation of two complementary axes that together, portray "the problem of social choice":

- The first axis, feasibility is the "edge" composed of the interdependent ecological and economic spheres. This is the realm of systems science and integrated economy–environment modelling.
- The second axis, desirability is the "edge" composed by the interference of the political and social spheres. This signifies the governance problem of institutional arrangements for coordination of the actors in society with their disparate interests and preoccupations.

The advantage of this framing is that it highlights the fundamental complementarity of, on the one hand, systems analyses with natural sciences foundations and, on the other hand, social sciences and humanities for the characterisation of what is good, just and acceptable (including for whom and why) (O'Connor, 2007).

3.1. Sustainability: the "four spheres" and their interfaces

Systems approaches to sustainability, since the 1970s (e.g., Passet, 1979), have sought to highlight the interdependence of three fundamentally different 'spheres' of organisation — the economic, social and environmental spheres. This is a neutral but asymmetric interdependence: the economic is embedded within the social, and both are embedded within the biosphere. There was a natural environment before there was human society and its institutions, and such societal institutions are older and wider than the market which is considered today par excellence as the organisational feature of the economic sphere. There is no denying that the economic sphere of commodity production, exchange and consumption is increasing in importance. Nevertheless, the economic sphere, often the principal focus of development policy discourses and indicators, depends for its viability on the vitality and sustainability of the social and environmental spheres.

Ensuring a respect for conditions of natural and social system viability, upon which long-run economic activity depends, appears as a key precept for sustainability policy (Spangenberg et al., 2002; Spangenberg, 2005).

Governance for sustainability therefore centres not only on the enhancement of economic performance but, more particularly, on the regulation of the economic sphere in relation to the two other spheres in order to assure the simultaneous respect for quality/performance goals pertaining to each of the three spheres and the respect for one sphere in relation to another (O'Connor, 2007).

For analytical purposes, it is convenient to highlight as complementary: (1) descriptions centred on the internal functioning of each sphere having a degree of autonomy relative to the other spheres; and (2) descriptions of the interlinkages and interactions between spheres.

In terms of systems analysis, each "sphere" or organisational dimension represents a class of nested complex, non-linear, evolving systems. Most environmental problems cannot be characterised through linear causal chains, supposedly acting in one single system. In reality, many issues involve "cumulative causation" with the interference of all four dimensions. Phenomena that characterise the dynamics of environmental issues have multiple causes and represent the cause for many different other phenomena, having ecological, economic, social and political dimensions in the same time. The effects of several causes can be synergic or antagonistic, and causes and effects can interact ones with each others. For many environmental problems, it is difficult or even impossible to distinguish the contribution of each cause to an effect, or even to consider the multiple effects of one cause. Therefore, restriction to a pair-wise analysis of interfaces is artificial in a fundamental sense (i.e., the economic and political are inseparable from the social, and the economic cannot exist without the environmental), but is useful as a didactic approach (see also Spangenberg, 2002), allowing management focus on mutually reinforcing processes.

The pair-wise interface aspects can be characterised through investigation of the "demands" and "supply" of each sphere relative to the others. Analyses in functional terms may focus on the roles, services or behaviour that is expected of, or sought by one sphere from each of the other spheres, in order to permit its "system viability" (Spangenberg, 2005; O'Connor, 2007). In the tabular exposition below (adapted from O'Connor, 2007), we present some of the distinctive features of the 4 spheres and the 6 interfaces (see Table 1).

In the terms of DPSIR, the economic sphere sends Pressures towards the environment, whose changes, in reaction, can affect the environment itself and then also the social and the economic spheres, through Impacts. The Impacts are modifying the environmental functions of which different groups in the society may benefit, and therefore may generate conflicts of access.

The different arguments for one or another solution to these conflicts are expressed in the political sphere which is responsible for giving Responses to contradictory demands (coming from the social and the economic spheres).

The movement from the political sphere towards the environmental sphere consists of the "supply" of public policy aiming to influence the functioning of environmental systems. Environmental management may seek, for example, to regulate the conditions of access to "natural capital" as a factor of production of economic goods and services, to ensure the long-term maintenance of environmental functions; or in any other way to promote a "respect for" environment.

In searching a meaning for the movement in the opposite sense, from the environmental sphere towards the political sphere, we note

Table 1
The tetrahedral model for sustainability studies (O'Connor, 2007, adapted).

Component	Elements of characterisation
The 3 spheres	The "three spheres"...
Economic	Economic self-organisation,e.g.,markets, performance imperatives such as efficiency, growth governing production, transport and consumption activities.
Social	Social self-organisation, notably forms of collective identity and the frameworks of meaning (symbols, culture) and of relationships (networks, memberships) through which people situate themselves in human communities and within the biophysical world. The basis for ideologies and life-styles.
Environmental	Environmental self-organisation, e.g.,the dynamic structures of physical and biological activity including atmosphere and ocean circulation, water and nutrient cycles, living organisms from the microorganisms up to the scale of the Biosphere.
The 4th sphere	... and the institutional arrangements for their governance... Gaining and managing power
Political	The distribution of power and the governance dimension is constituted through the emergence of conventions and procedures for the regulation of each of the other three spheres in relation to the others, in order to assure the simultaneous respect for quality/performance goals pertaining to *all of them*. This is the sphere of arbitrage amongst diverse principles and claims of interest, achieved de facto or by design through force and institutional arrangements, ranging from town and county councils through national government structures to internationalagencies of the United Nations.
Policy domains	The three domains of governance/regulation
Political ⇔ economic	Pol to econ: supply of "economic policy" or "governance" of the economic domain, demand of compliance, information and resources (taxes) Econ to pol: demands (with accompanying arguments and principles) made on government by economic actors concerning "the economy" and with regard to the social and environmental spheres (e.g.., property rights, free market, favour innovation, assure infrastructure). Supply of, e.g., taxes or electoral support.
Political ⇔ environmental	Pol to env: supply of "environmental policy" for assuring the permanence of the ecological welfare base through maintenance of environmental functionsand the "respect for" environment. Env to pol: Non-human nature voices its demands only indirectly in political fora, through actors such as NGOs. Supply of time, participation and personal investment (NGOs). Well "taken care" of, the environment is, indirectly, supplier of social stability.
Political ⇔ social	Pol to soci: supply of "social policy" which may seek to mobilise society for the needs of the economic and/or to promote and ensure respect for specified forms of community. Demand of legitimacy and public confidence. Soci to pol: demands made on government concerning civil society or the community and with regard to economic and environmental spheres (e.g.,equity in the distribution of environmental "goods and bads", participatory political system, social security system, gender equity, good working conditions). Supply of, e.g., "human capital", cultural framing.
Systems interfaces	Characterisation of the interfaces of the 3 spheres
Environmental ⇔ economic	The economic sphere seeks the "services" of "natural capital"to economic welfare as a factor of production; this engenders "Pressures" and "Impacts" on environmental functioning and services, including feedback effects on economy and community.
Economic ⇔ social	The economic sphere seeks the "services" of "human" and "social capital" to economic welfare; this may signify, on the one hand, opportunities for employment, revenues, goods and services but, on the other hand, exploitation and perturbation of existing community forms. For the demands of "social responsibility", the economic is a means and not an end, and the question is whether "opportunities" provided by the economic are nourishing or perturbing the affirmed values and forms of community. This is also the domain of "environmental justice" conflicts causedby unequal access to resources and unequal burdens of pollution.
Social ⇔ environmental	This is the domain of the "meanings of nature" or the spectrum of "environmental functions" identified by/for a society (i.e. nature as a cosmology, perceived qualityof landscape). This material-symbolic space of meanings permits members of society to articulate "risks" and to affirm values (e.g. biodiversity conservation, reverence for nature, rights and duties of the current generation to consume "natural capital" relative to rights/duties of respect towards future generations).

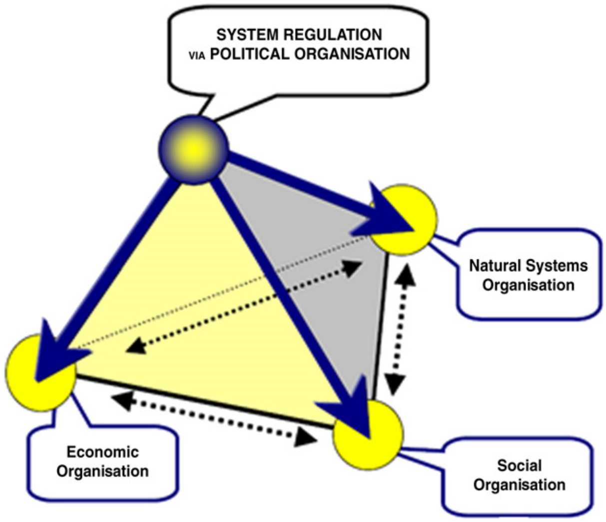

Fig. 3. The tetrahedron for sustainability studies (O'Connor, 2007).

that non-human nature does not voice demands directly in political forums. Rather the changes in the environmental sphere cause Impacts on the economic and social systems which, once their origin in the environmental system has been recognized, lead to Responses in the political system. In effect, it is "represented" through actors' voices (notably NGOs) who bring claims and justifications "on behalf of the environment".

The Impacts of environmental changes on the economic sphere may concern the loss of profit or opportunities for profit. The significance of such changes in opportunity is a matter of social perception, norms and prevailing attitudes; and, indeed, such changes when perceived can contribute to changes in attitudes and norms in society. This contributes to a "cumulative causation". Confronted lay the demands of the social and the political dimensions, the economy may answer, for instance, through adaptation strategies, trying to restructure its internal functioning and its patterns of interaction with the other spheres, in order to find modalities of existing in new contexts (e.g., changes in products and processes patterns, international agreements or fair trade chains). Or, it might voice demands to the other spheres to adapt to economic developments (e.g., globalisation, restructuring of the social or the political system, cf. O'Connor, 1994).

The following sections illustrate the application of this 'four spheres' methodology for defining and using the DPSIR categories adequately for the analysis of risks for biodiversity.

Table 2
The four spheres and their interfaces (reproduced from O'Connor, 2007).

	Social	Economic	Environmental	Political
Social	Forms of collective identity and community: the social sphere			
Economic	Opportunities & impacts: "the economy versus the community"	Performance, products and output: the economic sphere		
Environmental	Living with(in) nature: meanings, values & risks: sustaining what and for whom?	Environmental functions: pressures on & services of the environment	Energy, matter, natural cycles & biodiversity: the environmental sphere	
Political	Social policy: (capacity of communities; citizen/public participation)	Economic policy: (shaping the rules and limits of markets)	Environmental policy: (regulation of what counts as an environmental value)	Coordination, power and governance: the political sphere

Table 3
Methodological cross-cuttings between DPSIR representation of environmental issues and the tetrahedral framework for sustainability analysis.

	Social	Economic	Environmental	Political
Social	Driving Force			
Economic	Driving Force	Driving Force		
Environmental	Impacts	Pressures	State	
Political	Response	Response	Response	Driving force

3.2. DPSIR definitions in the "four spheres" framework

The framework of analytical appraisal developed in the present paper can be synthetically represented by considering interfaces between each pair of the four dimensions (Fig. 3), using a simple 4×4 matrix array (Table 2). The diagonal cells evoke performance concepts and criteria that relate principally to a single dimension; the off diagonal cells signal performance concepts and criteria arising as "interferences" of two dimensions.

The purpose of this section is to offer a methodological specification, based on solid, clear and easy-to-use methodological background, for each of the DPSIR categories. To each of the cross-cuttings between the four 'spheres' of sustainability, we associate one category of the DPSIR framework, leading to the attribution shown in Table 3.

This process of attribution obviously involves some strong simplifications. These are motivated for *didactic* clarity, keeping in mind the overall "cumulative causation" dynamics of coevolution. For example, we have attributed "Impacts" to the interface "social–environmental", referring to the impacts of environmental change on society. We might also have situated "Impacts" on the "economic–environmental" interface, but we have chosen to privilege "Pressures" at this interface. Obviously, the changes in biodiversity leading to the loss of environmental services with economic value (e.g., biologic resources) have an effect directly on the economic system (the "economic–environmental" interface). As well, some changes in the viability of vegetal or animal populations may affect life support functions (the "environment–environment" interface). All these changes will be called "Impacts" when they will be socially perceived as being "negative" in some way or another. For this reason, we consider that placing Impacts on the "environmental–social" interface allows us to include in this category both effects of environmental changes on the social sphere and on the economic and environmental sphere.

3.3. DPSIR for ALARM analyses

Turn now to the use that we propose for DPSIR in the ALARM[5] project analysis. An increasing number of case studies show the potential of biological invasions, climate change, loss of pollinators and environmental chemicals to cause adverse effects on biodiversity. However, knowledge on how they act in concert at European scale is poor. Contributing to this body of knowledge, the ALARM project addresses such aspects of combined impacts and their consequences, by developing risk analysis at large scale. Risk analysis is defined in ALARM as "a multi-stage process that includes the identification/characterization of a hazard or risk factor, assessment of the likelihood of occurrence, evaluation of impacts associated with that hazard, evaluation of mitigation measures (risk management), and communication of risks" (OIE, 2000, in ALARM consortium, 2003).

[5] The ALARM project (Assessing LArge scale environmental Risks for biodiversity with tested Methods) started in February 2004. ALARM (GOCE-CT-2003-506675) is an Integrated Project, funded by European Commission within the 6th Framework Programme. ALARM, one of the largest Biodiversity research projects, is co-ordinated by the UFZ, Helmholtz-Centre for Environmental Research in Germany. It combines the expertise of 250 scientists from 68 partners in 35 countries (Settele et al., 2005, 2007).

In the context of this project, we have developed formulations adapted to biodiversity risk of Driving Forces, Pressures, State, Impacts and Responses as will be presented below. We reviewed the uses and definitions found in literature for each of the D–P–S–I–R categories (see Section 2 above), in reference to the four key factors of change exploited in the ALARM project, that is: biological invasions, climate change, loss of pollinators and environmental chemicals. Common points and differences between these definitions and usages were assessed, and interpreted in light of the research already undertaken by each of the four teams of socio-economists working in ALARM, each focusing on one of the four risk domains. On this basis, the DPSIR definitions offered by the EEA (2005a,b, 2007) have been rephrased, in order to obtain a common denominator for the four risk categories.

The definitions given in the following sub-sections have been empirically tested for applicability on different aspects of biodiversity loss, further specifying the definitions given here for each domain of application. We therefore affirm that the definitions described below are robust for biodiversity loss description with the DPSIR scheme (see the following papers in this issue).

3.3.1. Pressures (economic–environmental)

The following definition of Pressures, emerging from the exercise described above, results from the adaptation of the EEA definition to the above systems considerations (Gabrielsen and Bosch, 2003):

Pressures are consequences of human activities (i.e. release of chemicals, physical and biological agents, extraction and use of resources, patterns of land use, creation of invasion corridors) which have the potential to cause or contribute to adverse effects (Impacts).

The potential of a Pressure (in the DPSIR language) to cause a change in the State[6] of biodiversity is also called *hazard* (in risk analysis language). For instance, introduced species (Pressure) may present characteristics (e.g., high adaptability) which have the potential to produce ecosystem disturbance (changes of State), which indirectly may lead to income losses (which will be socially framed as Impacts).

The states of awareness and knowledge have major influence on the ability to recognize "what a Pressure is" and for declaring an anthropogenic factor as such. Pressures include proven causes of changes in State, the plausible ones and those hidden behind a "veil of ignorance". In politics, the Pressures addressed are those for which, based on the best available knowledge, arguments can be brought for saying that they might produce Impacts. For characterising the relationship between Pressures and changes of State, the risk assessment process (as described above) follows four sequential steps: identification of Pressures that determine the potential to negatively affect people or the biodiversity (hazard identification, Pressures characterisation), evaluate their potential consequence(s) (hazard characterisation, Impact potential), assess their likelihood of occurrence (exposure assessment, Impact probability) and finally calculate the risk (risk characterisation, Impact risk, obtained by multiplying Impact potential with Impact probability).

3.3.2. State (environmental)

There is actually no agreed definition of the State of biodiversity. The reference definition of the Convention on Biological Diversity[7] is hardly operational, mainly because the measure of the "quantity" of biodiversity will always be patchy and incomplete (Gabrielsen and Bosch, 2003; Spangenberg, 2007). In the EEA definition (see Section 2.3), the term "quality" (Gabrielsen and Bosch, 2003) supposes a comparative judgment with a given threshold considered sustainable. However, as we have shown above (see Section 2.2), due to limitations of knowledge and inherent indeterminacy, thresholds practicable at European scale are based both on scientific processes and on criteria of what is judged to be valuable by the society[8] and/or political priorities relevant for communication towards the public (e.g., responsibility to protect species or areas considered vulnerable) (Rogers and Greenaway, 2005). In these cases, for understanding the evolution of biodiversity in time, comparison is made either with measurements previously done or with estimated ones.

The State of biodiversity is the quantity of biological features (measured within species, between species and between ecosystems), of physical and chemical features of ecosystems, and/or of environmental functions, vulnerable to (a) Pressure(s), in a certain area.

One cannot measure all the biodiversity. Furthermore, because of the complexity of natural systems, there is not a single "measurement unit" capable of characterising the whole system. Species diversity is only a way to measure, but a range of yardsticks that may be chosen to address different systems characteristics (bioindicator species, ecosystem resilience[9], and so on).

3.3.3. Impacts (environmental–social)

In line with the EEA, we use the concept of environmental function for defining Impacts (EEA, 2005a,b):

Impacts are changes in the environmental functions, affecting (negatively) the social, economic and environmental dimensions, and which are caused by changes in the State of the biodiversity.

The main criticism of the term environmental function concerns its anthropocentric view on ecosystems. The concept would be incomplete if its usage neglected the changes in the ecosystem that are not immediately and directly linked to human "uses" of nature. In order to avoid such misunderstanding, this paper explicitly extends the concept of environmental function to have a larger meaning than the one of "use", by distinguishing two categories of environmental functions: "*functions OF*" (the environment) and "*functions FOR*" (humans). The "functions OF" are the basic processes and cycles in the internal functioning of ecosystems, which are responsible for sustaining their evolution and resilience. The "functions FOR" are those which provide human welfare (Noël and O'Connor, 1998; Ekins et al., 2003).

Once the structure of an ecosystem is modified as a consequence of a Pressure, its functioning is also changing; therefore changes of State may determine undesirable changes in the environmental functions "OF" the ecosystem. As the "functions OF" the environment are the basis for the "functions FOR" humans, the change in the functioning of the ecosystem affects the environmental functions "FOR" the socio-economic system (as represented in Fig. 4).

As a form of life, humans are inevitably related to the maintenance of the biosphere ensuring the biophysical conditions that make human life on earth possible. These are represented by "regulating" and "supporting" functions (MEA, 2003), or by "life support" functions (5S'). Moreover, both material and less tangible environmental benefits are included among the environmental functions. The source, sink and site functions ("FOR"), though undoubtedly essential, are only a partial indication of humans' dependence upon nature. The "cultural" (or "scenery") class expresses the cultural/spiritual/informational dimension of nature: fulfilling personal needs (freedom, self-development, recreation, psycho-physical health, moral attitude) and collective needs (social contacts, norms and values, symbols, ideals, cultural identity). The responsibility for protecting living beings which have no direct utility for humans is an ethical conviction, which is not

[6] As defined in this paper, Section 3.3.2.

[7] "The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity, 2003).

[8] Often, the content and the acceptability of these criteria are disputed between different groups in the society (industrial lobbies, NGOs, governments, scientists...). These aspects are discussed in other papers in this issue and are not the object here.

[9] Metaphorically, vulnerability is another "metric" for choosing the "biodiversity to measure". Vulnerability in this context is understood to be the susceptibility of biodiversity to be affected (for a detailed discussion on the relationship between vulnerability terminology and the DPSIR framework, see Maxim and Spangenberg, 2007).

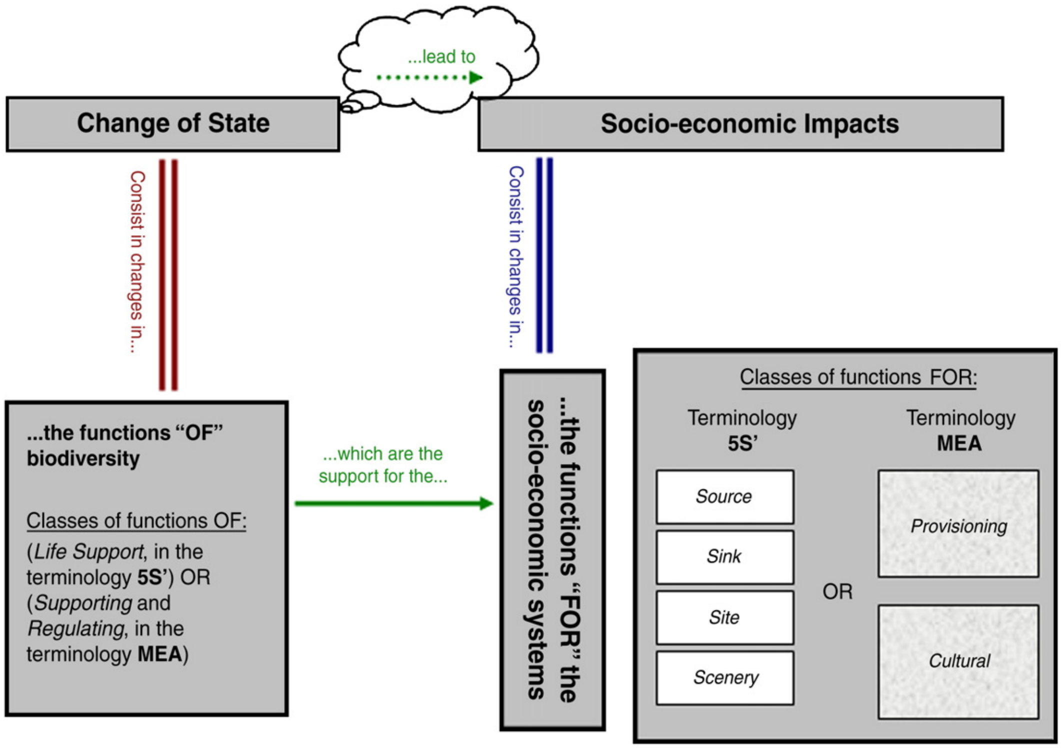

Fig. 4. 'Changes of' and 'Impacts on' the environmental functions of biodiversity.

less a need for many people. These last functions "FOR" have, obviously, no specific utilitarian content for the functioning of the economic sphere.

Both classifications of environmental functions (5S' and MEA) were used by socio-economic analysts in the ALARM project. Therefore, both were represented in Fig. 4, for describing the signification that we give to the concept of Impact.

3.3.4. Response (political–social; political–economic; political–environmental)

Given that the main purpose for using DPSIR is to organise information in order to communicate to policy-makers, we define a Response as a policy action, initiated by institutions or groups (politicians, managers, consensus groups, etc.) which is directly or indirectly triggered by [the societal perception of] Impacts and which attempts to prevent, eliminate, compensate, reduce or adapt to them and their consequences.

The social perception of the existence of relevant Impacts is one of the main reasons for developing political Responses. Policy actions can have both positive and negative effects on the environment or certain elements thereof; therefore in our model they can be considered either a Response or a Driving Force (Table 2).

Essentially, a preventive policy will aim at the reduction of Pressures and therefore will address in the first place Driving Forces (e.g., changing behaviour or production patterns, mitigation) (Spangenberg, 2007). A curative policy (end-of-pipe) will only try to diminish the Impacts by adaptation, either through running technical solutions such as restoration, cleaning and global monitoring of the environment in regard to quality norms (action on State), or through protection of the Impacted social groups (Mysiak et al., 2005). In some cases, deliberate "wait and see" strategies are also a Response.

3.3.5. Driving Forces (social; economic; political; social–economic)

One main purpose of this paper is to offer a redefinition (even a deconstruction) of the concept of Driving Force, in order to account for both causal relationships and non-linear dynamics of complex evolving human and natural systems, while still allowing a differentiation between criteria of performance of each of them and of their interactions.

Driving Forces belong to the "whole" context (social, economic, political) that defines an environmental problem. It may be an element belonging to one of the four systems described by the tetrahedron (Section 3.1) or to the relationships between them which is having a role of influence on the structure, the functioning or on the patterns of interaction between them for the given case (e.g., institutional arrangements, economic trends, social values, consumption patterns). Thus Driving Forces are features that contribute to the dynamics of their change beyond the Impact–Response mechanisms, a "residual category" triggering Pressures:

Driving Forces are changes in the social, economic and institutional systems (and/or their relationships) which are triggering, directly and indirectly, Pressures on biodiversity.

The internal functioning of the political sphere (Policy × Policy, in Table 3), with its patterns of decision making (e.g., technocratic, participative…) and its structure (e.g., responsibilities of different ministries, relationships between different administrative scales, patterns of control of the efficiency of regulations), can represent in itself a driver for environmental pressures. For example, if one country has a political system informally functioning on the basis of corruption, the control of Pressures on biodiversity tends to become ineffective, although formal environmental, economic or social policies exist (Pellegrini and Gerlagh, 2006).

Natural factors (e.g., volcanoes, natural emissions of chemicals) are not included here among Driving Forces but they are covered by the definition of State as dynamic, not static. Of course, natural and anthropogenic factors are interrelated, but the drivers of main risks for biodiversity are human-made. The socio-economic dynamics itself generates risks for society and the economy and nature degradation is the carrier for feed-backs of human action on humans (Beck, 1986). Therefore, the Driving Forces are pointing to the elements determinant for the current "crisis of control" (O'Connor, 1994b). Once acknowledged, their management could allow to the society to better imperfectly control itself through governance (Spangenberg, 2007).

4. Discussion and conclusions

In order to develop methods for the assessment of large-scale environmental risks for biodiversity, socio-economic research focuses on its relationships with society and economy.

In ALARM, they are analysed in relation to four factors of change in biodiversity: biological invasions, climate change, loss of pollinators and environmental chemicals. The purpose of the socio-economic cross-cutting analysis is the construction of a decisional support useful for the management of biodiversity issues at European scale (Settele et al., 2005).

Based on the definitions elaborated earlier, we have identified climate change, environmental chemicals and biological invasions as Pressures. On the other hand, loss of pollinators expresses a change of State (defined in relation to the Impact on the environmental function of pollination). In this issue, individual papers address these four factors, using the methodological framework presented in this paper, in order to integrate them into a comprehensive description as a basis for choosing Response strategies.

As general appreciation of the method proposed in the present paper, we argue that what the DPSIR framework loses in simplicity by crossing it with the tetrahedral framework, it gains in clarity, completeness and adequacy for pragmatic uses. The combination, however, does not result in a standard one-size-fits-all definition, but is rather a precise specification; it can be done in a different, substantially equivalent fashion in case a different basic question is asked and/or better results are expected. It is the method which is generic, not its applications.

The DPSIR framework has been criticized for not being able to handle appropriately the relationships between complex environmental and socio-economic systems (Berger and Hodge, 1998; Svarstad et al., 2007). We have shown that former uses of the DPSIR mainly refer to relationships between economy and the environment, but they rarely take into consideration social or political aspects. However, we have also shown that these can have important influence, even though indirect, on risks for biodiversity. For example, the role of Driving Forces played by inefficient or inadequate policies, or by the existence of inappropriate institutions or practices for implementing them, is usually ignored by the DPSIR. The literature study highlighted a lack of conceptually well-grounded basis for integrating in the DPSIR social and political aspects with measurements of interactions between the economy and the environment.

By further making the difference between two levels of use, namely for communication and for analytical purposes, we have shown that DPSIR is not adequate for this latter. The way in which a conceptual framework is deployed has a major importance for how it contributes (or not) to the description and/or analysis of a problem. For example, a deliberative process (or other technique for involving stakeholders in the process of research) may be used for “filling in” each of the categories of the “tetrahedral DPSIR”, process in which researchers and stakeholders interact in the even production of the knowledge for policy (Kloprogge and van der Sluijs, 2006).

For dealing with these aspects, this paper builds on methodological developments proposed by O'Connor (2007) for complex system analysis. This offers the advantage of a clear representation of relationships between economy, society and the environment relevant for sustainability studies. Furthermore, it proposes a reference characterisation of sustainability, naming the coevolution of economic, social and environmental systems respecting simultaneously the quality/performance goals pertaining to each of the four spheres (O'Connor, 2007). By highlighting a fourth category of organisation, which is the political sphere, the model allows differentiation of aspects referring to relationships between economy, society and environment which are relevant for the governance of biodiversity.

The tetrahedral framework enlarges the question of choice about “what should be done” from policy to the societal level, evidencing the tensions existing between different criteria of choice. By this, it points towards different levels of the “human sphere” at which decisions are taken and between which sometimes conflicts may arise. Well-informed political decision desirous of legitimacy and efficiency must be aware of these aspects.

The tetrahedral DPSIR framework goes beyond linear causality by allowing descriptions of different levels of interaction — both inside and between systems. The linear causality is, as we have shown, lacking of adequacy for complex environmental problems such as risks for biodiversity (see Introduction). The model we are proposing allows the differentiation of “causal chains” which can be cumulative. For example, all Driving Forces trigger Pressures on biodiversity, but causal interactions also exist among Driving Forces themselves (some Driving Forces can trigger others, as for example political ineffectiveness can trigger social mechanisms unfavourable for effective risk management; also, cultural perceptions of “nature” may trigger management practices which are unfavourable to preserving biological richness). The present paper addresses cumulative causation by specifying the systems and the interfaces between these systems to which Driving Forces can belong (Table 1). Bringing system analysis into the DPSIR model contributes at structuring information of different natures (economic, social…) needed for describing causal chains. In return, the causal relationship brought by the DPSIR framework contributes to clarification of links inside and between the four spheres with a given focus on diminishing risks for biodiversity and a better understanding of possibilities of action.

It should be noted that the concept of Driving Force itself hypothesises the existence of a social and/or political objective of reducing risks for biodiversity. The relevancy of this objective for Europe (the scale of study in ALARM) is taken here for granted. Discussion about different forms of understanding of the concept of risk for biodiversity or about pathways for reducing it is beyond the purpose of this paper.

Finally, reframing the DPSIR model clarifies the contribution of different scientific disciplines involved in research for biodiversity. Biosciences are mainly dealing with identifying and measuring Pressures, State and changes in the State of biodiversity. Social sciences are contributing to the understanding of Driving Forces, of socio-economic Impacts and of Responses. Of course, this “distribution of tasks” is simplified for practical purposes. For example, some aspects of the quality of the scientific information issuing from biosciences may be linked with socio-economic context of their production or/and use. However, having this conceptual framework as background helps at focusing on the points of interaction between biosciences and social sciences, where common work is needed. In ALARM, the common vocabulary and conceptual background developed in this paper supports the coherence among the analyses undertaken by different teams and disciplines.

In conclusion, this new manner of framing the DPSIR answers to the two main gaps identified at the beginning of this paper, namely the lack of clarity of “what should each D, P, S, I or R category of information contain” (first responsible for the lack of comparability between different studies using DPSIR) and the incompleteness of the integrated analysis intended by the DPSIR regarding the political and the social sphere.

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