The Response component in DPSIR and the SES dynamical stability

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Abstract

DPSIR implies a dynamical model of Socio-Ecological System (SES) including a negative feedback loop. Within such model, all the five components of DPSIR can be located on the basis of the actually collected data flows, even if the pattern of their mutual interactions appears to be somewhere different from what is usually postulated. Also the role played by each component can be reconsidered. Specifically, the Response component refers to the actions carried out by the humans in order to safeguard the State component in a range of values acceptable for both the protection of the natural ecosystem and the improvement of the well-being of the human society. Design and implementation of Response should take into account the dynamical properties of SES as a whole, as far as those dynamical properties can be estimated on the basis of the DPSIR data flows. In such a way, it could be minimized the risk of implementing actions that affect the system stability.

1. Introduction

The intertwined relation of the mankind with the other living species and with the chemical-physical properties of Earth has been described by the term “Socio-Ecological System” or SES (Gallopin, 1991). For such system, it has been observed the presence of thresholds, namely of specific configurations acting as a divide between different system states. Some of the possible states are stable, i.e. an increasing perturbation is somehow absorbed by the SES; some other ones are not stable and the SES irreversibly modifies its behaviour. A linkage between thresholds and stability (as well as the various dynamical properties of the system) has been noted; the implications of such linkage have been examined with reference to real systems and, in particular, to spatial planning and management processes (McAlpine/Wotton, 2009). Thresholds for natural systems have been reviewed by Groofman et al. (2006).

In order to further such analysis, it appears to be convenient to refine some methodological tools, aiming to a possible quantitative description based on real data. As far as the global data surveys of environmental data are concerned, it has to be noted that many data sets about the European environment are routinely collected adopting the DPSIR framework by every Member State of the EU as well as by other cooperating States, on the basis of multi-lateral legal agreements and under the coordination of EEA. Therefore, such data sets are consistent in spatial and temporal terms and may provide a useful basis for the above mentioned methodological refinement.

2. DPSIR from a system point of view

It has been shown that the DPSIR framework implies a specific system model of the environment described by transfer functions and based upon feedback loops, where the ecosystem and the related protection activities interacts with the human society in terms both of cooperation and of competition (Caponigro/Iannucci 2010). Exploiting well consolidated tools of the systems theory, other aspects of such
DPSIR-related model have been highlighted, mainly in reference to the sustainable availability of ecosystem services necessary for the well-being of the humans (Iannucci et al. 2011).

The five DPSIR components (i.e. Driver, Pressure, State, Impact, Response) are defined by the EEA Glossary (available at [http://glossary.eea.europa.eu/](http://glossary.eea.europa.eu/)), with the noteworthy exception of Impact whose definition can be found in Gabrielsen and Bosch (2003). On the basis of such definitions, the model implied by the DPSIR framework is shown in fig. 1 (from Caponigro/Iannucci 2010).

![Figure 1](image.png)

Figure 1
Block diagram of the system implied by DPSIR

The links refer to the data flows actually collected in the framework of DPSIR or to their known transforms. The trasference of each block (i.e. the transfer function mapping the input to the output) can be estimated relying upon consolidated systems theory (Box/Jenkins 1976), as far as the data flows meet some basic requirements. Specifically, Impact is the difference between the “target” (i.e. the expected measures) and the actually recorded “measures” of the ecosystem. Namely, the vector of the expected measures formally stores the baseline that we are using to monitor the well-being of the ecosystem; if the actual measures don’t match such baseline, the ecosystem is somehow endangered and a corrective human-implemented action is required (i.e. the Response component is activated).

The actual measures are provided by the State of the ecosystem, through the branch where a feedback block is positioned. When the State data are brought back to the comparison with the above-mentioned baseline, the feedback block can operate assuming alternative (but not mutually exclusive) ways:

- It produces the actual measures via a simple proportional operation; the State data are multiplied by a factor that, without loss of generality, can also be equal to 1; this implies that the baseline vector only includes (part of) the variables adopted to describe the State of the ecosystem (e.g. number and distribution of the species; concentration of NOx);
- It produces the actual measures transforming the State data into equivalent albeit different data (as when the measured chemical-physical properties are translated into risks for the human health): this is the case where the feedback block exhibits a fully-fledged transfer function.
In both cases the global dynamical behavior of the ecosystem is affected. It is easy to understand that the measurement, inter alia, translates continuous processes into sampled discrete data series (where the sampling modifies the frequency patterns) and, moreover, that the comparison of such data series with the baseline is usually postponed in time (thus introducing some time delays in activating the Response).

3. **Stability and resilience**

In literature, there is a consensus (even if with some distinctions) about the fact that SES is an open, dynamical, non-linear, back-coupled, complex, adaptive system (Berkes et al. 2003). Usually, such definition is condensed in the shorter form of SES as a complex adaptive system (Norberg/Cumming 2008), focusing upon two points:

- SES is conform to the abstract notion of complex system (Hall/Fagen 1956): “A system is a set of objects together with relationships between the objects and between their attributes”;
- Moreover, SES is able to modify the above mentioned relationships in order to cope with external forces; a capability of learning and reasoning is inherent to such process of self-organization (Simon 1976).

It appears to be of interest to note that the system implied by DPSIR (as modelled in the fig. 1 above) meets the notion of SES as above defined. It should be noted that:

- On one hand, the model derived from DPSIR describes a system that complies to the definition of Hall and Fagen and, moreover, is evidently open, dynamical and back-coupled;
- On the other hand, such model is based upon the block transferences that reflect the relationships between incoming and outgoing data flows; when such data flows are modified, the relevant transference can accordingly evolve, providing the necessary adaptive behaviour;
- Finally, the non-linearity (inherent to any real system) can be substantially dealt by the above mentioned adaptive feature and by suitably limiting the domain of analysis (so that, where necessary, the non-linear system can be approximated by a linear representation).

Such result doesn’t suggest that the block diagram is able to depict any SES. On the contrary, the block diagram is modelling SES as it is implied by DPSIR with its currently collected DPSIR data flows. This fact has to be properly taken into account in any possible exploitation of information extracted through DPSIR.

SES as a complex adaptive system exhibits four distinct properties: stability, resilience, durability and robustness, in order to maintain its identity and function i.e. its sustainability. Holling (1973) introduced the definition of resilience and Grimm et al. (1992) reviewed the concept of stability for ecosystems. Stability with its relations to resilience and to sustainability has been dealt with by Ludwig et al. (1997); a more extended and updated discussion is available in Cumming (2011).

The definition of such properties is apparently still lacking the desired precision; an effort should be carried out in order to harmonize them also with the concepts of the system theory. However, we basically speak of resilience when a system is able to maintain its identity under external disturbances, of robustness if the system maintains its functions under external disturbances, of stability if the system can find an equilibrium after the end of the forcing effect of the external disturbances, of durability if the system can survive in the time scale of interest.

The resilience appears to be the property most often taken into account when dealing with a SES. From the point of view of DPSIR, i.e. of the stakeholders entrusted with the management of the environment, the stability would appear to be more relevant, as far as it is related to the ability to reach a steady state on the medium/long term, i.e. to the stationary phase of State. However, the resilience should be taken into account at least at the same level, being related to the features of the transient evolution of State on the short term, as pinpointed in the following.
4. **Response as a dynamical component**

DPSIR is meant to provide a reliable basis to design sound policies and to assess the efficacy of such policies in safeguarding SES (specifically nullifying the Impact, i.e. the distance between the desired State and the actual one). Under the sensible hypothesis that the ecosystem (i.e. the block whose transference is indicated as N in fig. 1 above) is not directly modifiable, all the burden of contrasting the disturbances (i.e. the Pressures and possibly the Drivers) to SES is set upon the Response component.

This requires to design a specific Impact-to-Response transference, i.e. the transfer function that can implement a given management approach able, in particular, to reduce the amount of Impact to the lowest possible level (conforming SES to the given baseline, at least asymptotically). The humans should therefore provide Response with dynamical properties matching those of Impact, in a way that the transference C will be globally able to steer SES towards the desired State. In order to do so, Response must be seen as composed of three components, where:

- The first component is proportional to the actual amount of Impact: the more the ecosystem is far from the baseline (i.e. the greater Impact appears to be), the more the corrective action deployed by the humans has to be articulated (accordingly, a broader Response is needed);
- The second component is proportional to the rate of change of Impact: the quicker is this rate, the quicker has to be Response to counter its effects, anticipating them as possible;
- The third component is proportional to the integrated value of Impact over time and measures the amount of past deviation from the adopted baseline: therefore Response has to efface such effects.

To be effective, the design of Response transfer function (the transference C) requires the knowledge of the dynamical properties of the ecosystem (the transference N) as well as those of the feedback block (the transference F). Again, a reliable estimate of such properties could be derived by the DPSIR data flows, specifically those concerning the past time series of Response, of State and of Pressure (the latter, to be seen as external disturbances).

We are also concerned about the evolution of State in time (and/or in space) forced by the Pressures, therefore it is not sufficient to take into account only its expected measures (i.e. its “target”): we have to design the transference C on the basis also of some requirements about the acceptable dynamics of State. It is important not only that State finally remains in the proper domain but also that the transient evolution of State traces a proper path.

For instance, the stakeholders entrusted with the designing of Response might be willing to avoid extended oscillations of State, before reaching the final equilibrium. This can be done including a suitable damping factor into the transference C. Under some hypothesis (useful here to pinpoint the problem, even if not always met in the reality), Fig. 2 provides some typical outputs of a second-order dynamical system: the outputs show a more strong oscillatory trend as the damping factor decreases.

Similarly, they could indicate other features both for the transient and for the stationary phase of State. With reference to a stepwise increase of Pressures (as in Fig.3), the following parameters can be indicated for the transient of State:

- **S**: the admissible overshoot of State upon the expected value;
- **T_{\text{rd}}**: the time delay for S;
- **T_{\text{r}}**: the time delay to get again the half value of the expected value of State;
- **T_{\text{s}}**: the time delay (the so-called t-rise) from 10% to 90% of the expected value of State;
- **T_{\text{a}}**: the time interval to stabilize State in the band of 5% around its expected value.
Moreover, constraints can be applied also with reference to the frequency domain (in terms mainly of amplitude and phase shifting). This could prove even to be of greater interest, due to the fact that SES includes many inherently periodic (daily, seasonal, yearly, etc.) processes and therefore Response has to cope with them.
5. Conclusions

Providing policy makers with high quality, relevant and timely data/information on the environment based on DPSIR model couldn’t be enough to streamline Response component. Dynamical properties of SES should be taken in account to design the actions addressed to keep the State component in a range of values acceptable for the natural ecosystem and the society.

It is counterintuitive that a system with a feedback loop is not always more stable than an open-chain system; this fact has to be taken into account when the Response is generated.

Response translates into a modification of SES dynamical properties; therefore, a not properly designed Response can bring the system out of its resilience/stability state. As a matter of fact, each of the above mentioned Response components (each of them as well as their union) can bring the SES into some instability regions (e.g. the component proportional to the rate can force the SES into an oscillatory mode, where Impact is alternatively positive and negative). Suitable tools (valid for linear models as well as for non-linear ones) are provided by the systems theory and can support the identification of a proper Response, as well as the assessment of the previous measures and the improvement of actual data-flows and decision making processes regarding environmental protection.

Bibliography