Geoforum 41 (2010) 479–488

Contents lists available at ScienceDirect

Geoforum

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

Structuring problems in sustainability science: The multi-level DPSIR framework

Barry Ness *, Stefan Anderberg, Lennart Olsson

Lund University Centre for Sustainability Studies (LUCSUS), P.O. Box 170, 221 00 Lund, Sweden

ARTICLE INFO

Article history:
Received 19 June 2008
Received in revised form 3 June 2009

Keywords:
Sustainability science
Scale
Hierarchies
Multi-level
Baltic Sea
Eutrophication
DPSIR
Hägerstrand

ABSTRACT

Sustainability science needs approaches that allow for the integration of knowledge across disciplines and scales. This paper suggests an approach to conceptualize problems of unsustainability by embedding the Drivers–Pressure–State–Impact–Response (DPSIR) scheme within a multi-level institutional framework represented by Hägerstrand's system of nested domains. The proposed taxonomy helps to decipher and to better understand key casual chains and societal responses at the appropriate spatial levels for particular sustainability problem areas. To illustrate the scheme more concretely the example of recent problem-solving efforts for Baltic Sea eutrophication driven by Swedish agriculture is examined. The discussion focuses on how the scheme fulfills the four research strategy requirements within the field of sustainability science and how the scheme is distinct from alternative approaches.

1. Introduction

Efforts in recent years to promote and operationalize the emerging field of sustainability science have intensified (*cf.* Kates et al., 2001; Komiyama and Takauchi, 2006; Boulanger and Bréchet, 2005; Gallopín et al., 2001). Work has concentrated significantly in the areas of capacity building, research trajectory establishment, research and training mainstreaming, and bridging the clefts between research and decision-making (Cash et al., 2003; Clark and Dickson, 2003a,b). To help foster the ensuing generation of sustainability scientists, energy is also now devoted to program development and educational resources.[1] Development of the methodological *toolbox* to assist in the understanding of socio-ecological systems (SESs), and the problem-solving rifts posed by the current system of academic specialization has also been an important focus (Clark, 2002; Gallopín et al., 2001; Komiyama and Takauchi, 2006; Ravetz, 2004; Young et al., 2006b). Moving beyond the current scientific barriers to a more operational understanding of SESs – including the multitude of perspectives, cross-scale dynamics, host of non-linear interactions and the irreducible uncertainty of systems – is considered one of the largest challenges for the field today (Boulanger and Bréchet, 2005; Folke and Gunderson, 2006; Gallopín et al., 2001; Martens, 2006). In order to meet these challenges, Kates and colleagues (2001) name four research strategies that would need to differ from conventional scientific activities. These areas include: (i) covering the range of spatial scales between diverse phenomena, (ii) accounting for temporal inertias and urgency of processes, (iii) dealing with functional complexity resulting from multiple stresses, and (iv) the recognition of a wide range of outlooks equating to usable knowledge in both science and society.

Before problem-solving efforts can be undertaken, an adequate overview of the problem(s), associated driving forces, and resulting effects at a variety of levels must be developed. Numerous conceptualization methods and frameworks have been developed that can be applied under the broad area of sustainability assessment (*cf.* Ness et al., 2007; Bammer, 2005; Parris and Kates, 2003b). These approaches include e.g. causal loop diagramming (Richardson, 1991; Richardson and Pugh, 1981; Roberts et al., 1983), the *soft systems* methodology (Checkland, 1991), flow diagrams and mental mapping (Klijn, 2004), the institutional analysis and development (IAD) framework (Ostrom, 2005; Andersson and Ostrom, 2008) and policy analysis frameworks (White, 1979; Roe, 1997; O'Laughlin, 2004).

Issues of scale and the dynamics associated with scale have become more important with a better understanding of global processes and sustainability issues.[2] By scale, we mean the parts of a system that can be broken down by the spatial, temporal, quantitative, jurisdictional, analytical or network levels (Cash et al., 2006;

* Corresponding author.
E-mail address: barry.ness@lucsus.lu.se (B. Ness).

[1] From the San Servolo Workshop on the Grand Challenges of Sustainability Science. October 20–22, 2006 and the Forum: Science and Innovation for Sustainable Development (2008).

[2] For a more detailed discussion of scale, and how scale is interpreted and used by the social and natural sciences see Gibson et al. (2000).

0016-7185/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geoforum.2009.12.005

Gibson et al., 2000; Adger et al., 2006; Young, 2006). There is an increasing acknowledgement that many problems have causes and solutions that span multiple levels. There is often however an admission of ignorance or unwillingness to address particular levels and/or cross-scale interactions (Cash et al., 2006). It is therefore important that these interactions be explored – especially deeper insights into the often diffuse governance linkages – in order to gain a better understanding of problem areas.

The aim of this article is to contribute to the discussion of the epistemological basis of sustainability science research – adding to previous work in this area (*cf*. Swart et al., 2004; Turner et al., 2003; Waggoner and Ausubel, 2002; Young et al., 2006a,b; Ostrom, 2009; Schröter et al., 2005). We present how the merging of two established schemes, the Drivers–Pressure–State–Impact–Response (DPSIR) model and Hägerstrand's system of nested spatial domains, can contribute to the understanding and assessment of complex unsustainability issues. Taken together, the schemes offer one way to structure the larger multi-level relationships of problems while carrying out a more detailed analysis via the exploration of specific causal chains at each of the levels – focusing on important aspects such as key driving forces, actor-level impacts and what problem-solving attempts are taking place. The approach may also be able to act as a basis and/or contribute to other study approaches including quantitative spatial dynamics, scenario- or transition-focused studies (*cf*. Geels and Kemp, 2000; van der Brugge et al., 2005; Swart et al., 2004).

The article begins with a brief overview of the two approaches. It then describes how one approach can be embedded in the other. To exemplify the framework more concretely, the paper takes the path of analyzing the multi-level dynamics of a specific problem associated with a particular sector, in this case recent efforts to control contributions from Swedish agriculture for Baltic Sea eutrophication. The subsequent section discusses lessons from the example, how this methodology fulfills important criteria in sustainability science and how the framework relates to other approaches.

2. DPSIR framework

The DPSIR framework is a functional analysis scheme for structuring the cause-effect relationships in connection with environmental and natural resource management problems (EEA Report, 1999; Bowen and Riley, 2003; Giupponi, 2002, 2007). DPSIR stands for Driving forces–Pressure–State–Impact–Response, and it is associated with the European Environment Agency (EEA). The scheme is a tool for the integration of economic, social and natural system information into a framework in order to provide a basis for a more detailed analysis (Bidone and Lacerda, 2004). The main aim of DPSIR is to identify policy options and to evaluate the efficiency of responses (EEA Report, 1999). The scheme helps to structure information and makes it possible to identify important relations as well as to develop an overview and understanding of a problem. The EEA approach has evolved from more simplistic frameworks for environmental issues such as the Pressure–State–Response (P–S–R) scheme launched by the Organization for Economic Cooperation and Development in the 1980s and the United Nations Commission on Sustainable Development's Drivers–Pressure–Response (D–P–R) framework (OECD, 1994).

A DPSIR scheme can be described best through an example, in this case for nutrient losses for Swedish agriculture that contribute to eutrophication for waters in and around the country (Fig. 1). *Driving forces* refer to the independent, external causes (or forces) that underlie movement toward or away from desired targets (Chorley and Kennedy, 1971; Parris and Kates, 2003a). The driving forces can be situated in both SES domains. One key driver in the example is the quest for yield maximization in agriculture. *Pressures* represent the consequence of the driving force. They can be positive or negative, although most conceptualizations focus on only the negative, e.g., emissions to air, wastewater discharges, and municipal solid waste generation. The pressure in our example is the excessive use of fertilizers on croplands, which result in nutrient losses to water and ammonia emissions to air from livestock production. The pressures in turn affect the *state* of the environment. State variables describe the condition, or observable changes in the system following the pressure. In the case of Baltic Sea eutrophication from agriculture, the state is eutrophic waters and aquatic dead zones triggered in part by agricultural nutrient run-off that is most apparent in summer months in the many water bodies in and around Southern Sweden. The resulting *impacts* are often stated in terms of measurable damages to the environment or human health; examples of impacts are decreases in fishing-related revenues due to the aquatic state changes or sickness from bathing in eutrophic waters. *Responses* are the defined societal (decision-making) measures to correct the problems of the previous phases. As a societal feedback, responses can be directed toward any of the first four stages. They often take the form of policy and/or planning actions. Responses can be either adaptive or mitigative. Examples of responses are taxes, fees, regulations, or design for the environment measures (Bowen and Riley, 2003; EEA Report, 1999). Policy responses for Swedish eutrophication problems have generally not been directed at problem driving forces, but rather to the subsequent stages in the form of more immediate, point-source measures such as locally-initiated river bending and/or wetland creation projects, or in the form of the establishment of spongy national or regional environmental priority goals. Such responses have led to inadequate problem-solving results.

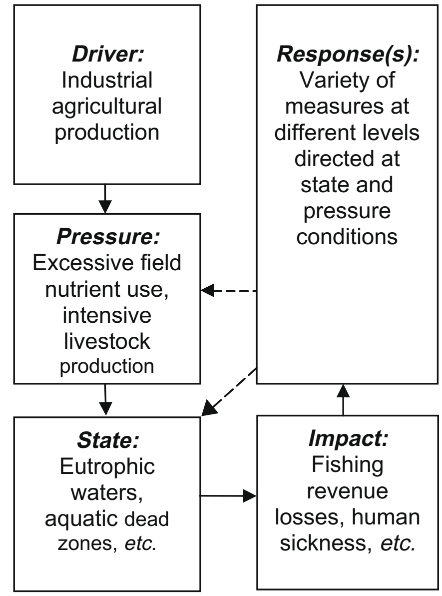

Fig. 1. A generic DPSIR scheme for Swedish anthropogenic eutrophication from agriculture. The scheme shows the *driver* of industrial agricultural production creates the *pressure* of excess field nutrient use and animal production. This pressure causes field nutrient run-off from and large ammonia (to air) releases that lead to the state of aquatic dead zones and large eutrophic areas in the Baltic Sea. The human system impact of *impact* diminished fishing revenues, sickness to swimmers, among numerous others. Responses generally have been mitigative measures to decrease state and pressure conditions.

Critique toward the DPSIR approach and its predecessors is often directed at the mechanistic oversimplification of the scheme, scheme linearity, and the difficulty in handling parameters that

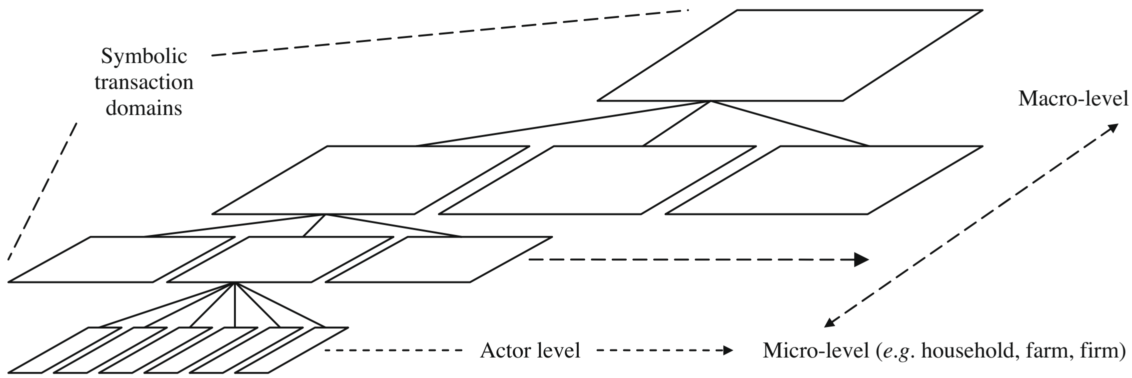

Fig. 2. Conventional nested spatial domain conceptualization as proposed by Hägerstrand. The figure shows how the symbolic transaction domains are situated and operate under each level above them. The actors at the lowest level are then left with a set of freedoms to carry out their daily activities.

may act as both a response and driving force (Klijn, 2004). Another challenge of the DPSIR framework is that it has been developed and used for displaying environmental impacts caused by socio-economic driving forces. Socio-economic system effects in the form of cases or deaths from HIV/AIDS or malaria have seldom been included in such analyses – thusly not reflecting the complete range of sustainability challenges. Finally, there is the problem of the scheme's ability to encompass the multi-dimensional and multi-level relationships of problems. Most unsustainability issues are characterized by very complex scale dynamics of space and time exacerbated by multiple anthropogenic and natural driving forces (Kates et al., 2001). These issues include, e.g., global climate change, eutrophication and biotic diversity.

3. Hägerstrand's system of nested domains

Hägerstrand (2001), along with others (*c.f.* Chave and Levin, 2001; Gibson et al., 2000; Turner et al., 1990; Wilbanks and Kates, 1999), argue that the management of the biosphere must be based on a more comprehensive and hierarchical understanding of how macro and micro aspects are connected. This more specifically translates to how larger-scale decision-making works, or fails to work, with individual actions occurring on the landscape (Kahn, 1966). By hierarchical, Hägerstrand implies the socio-spatial authority structure in human systems (Simon, 1973). He explores how actions on the landscape can be partitioned into mosaics of spatial domains, e.g., social institutions, where each group of actors at each level possess their own set of rights, responsibilities and expertise, which are often limited to predetermined jurisdictional reaches (what he calls *functional specialization*). In its most basic form, the system is structured in hierarchical orders (Fig. 2) where domains are in general held together by the domains acting above them, e.g., local governments working under a provincial government, provincial governments under the national government, etc.[3] Higher order domains do not operate directly on the landscape but are responsible for the rule-making and control (called *symbolic transactions*) within their respective spatial boundaries. These symbolic transactions have however, most often only an indirect effect on the physical actions in the landscape through setting legal limits or creating incentives.

Hägerstrand's conceptualization allows one to visualize how the symbolic transaction domains at each of the upper-levels influence the actors below, and how the assortment of regulations, policies, subsidies, and information are ultimately translated on the ground. The result is a multitude of small actions in the landscape (micro-level) all being guided by the technological and legal freedoms and limits defined in domain levels above (meso- and macro-levels) – or what Hägerstrand labels, *territorial competencies* (Hägerstrand and Lohm, 1990). The approach is also a way to show goal divergences between the upper symbolic transactions levels and actions taking place at the base. It is when these small actions go unchecked that we receive the large-scale problems of the day (Hägerstrand, 2001).

The approach though is not only static and top-down; Hägerstrand also explores the different ways actors at the bottom can work to influence the system working above it. He shows that groups of actors can join forces to form, e.g., trade unions, cooperatives, idealistic organizations centered on particular causes or issues to influence decisions taken at the upper-levels. The result is an interpretation of a dynamic set of interactions between the upper, administrative, rule-making levels and the action level constraints and opportunities taking place directly in the landscape.

This conceptualization is the institutional part of Hägerstrand's broader *process landscape* approach, which is a development of the *time-geographical perspective* for the study of SES interactions (*cf.* Anderberg, 1999; Hägerstrand, 1992; Lenntorp, 1999). Although the scheme has all-encompassing ambitions, it places inadequate focus on what is taking place within each level, or provides little or no explicit attention on such things as natural climatic, geological or geographic constraints that exist in the landscape, e.g., soil conditions, access to water.

4. Merging the two approaches

Although Hägerstand's approach allows for incorporating the multi-level perspective of particular problems, it lacks a systematic framework for structuring causal relationships at each level. What is required is to maintain focus on the applicable structure while simultaneously delving deeper into the nature of the causalities at the various levels. For this purpose the DPSIR scheme can be reintroduced at each symbolic transaction level. The DPSIR scheme acts as a comprehensive representation of focused areas, allowing decision-makers to step-wise trace fundamental problem drivers through actual impacts at the landscape level, and explore where appropriate responses can be directed. DPSIR by itself however does not allow the viewer to easily identify the multitude of levels that influence the situation and/or where inconsistencies (or *disconnects*) may lie between the levels.

Deciphering issues of unsustainability in the sector can be carried out by structuring individual problem situations. This involves reaching an agreement on the actual problems associated with the sector, and at which scale levels the problems and associated driving forces are located. It is often suggested that this is performed in a participative manner in order to obtain a multitude of perspec-

[3] Young (2006) presents a detailed discussion on hierarchical inconsistencies.

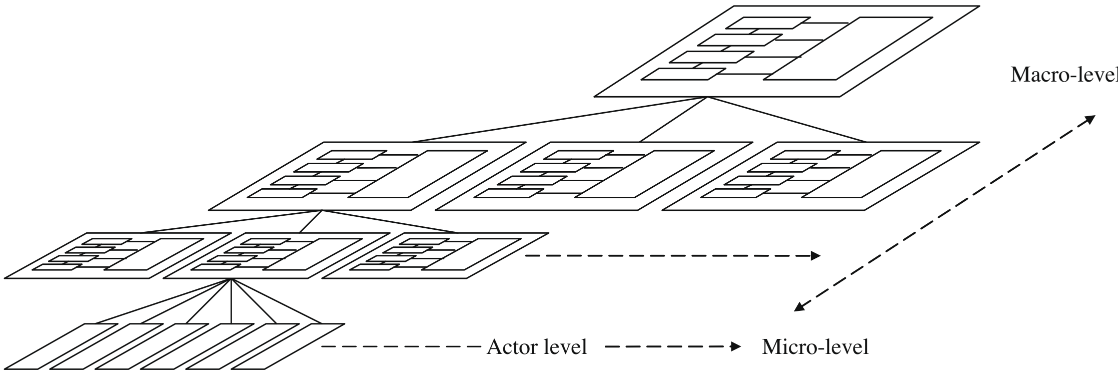

Fig. 3. Conceptualization of the merging of DPSIR scheme(s) into the system of nested spatial domains. The taxonomy allows for a focus on both actor constraints and the problem's causal linkages at each level.

tives (Clark and Dickson, 2003a; O'Riordan et al., 1999; Renn, 2004; Kasemir et al., 2003). The creation of DPSIR schemes for each of the problem situations, the driving forces, effects and response(s), for reaching a common overview and understanding of the problem may be essential. Combining DPSIR with Hägerstrand's system of spatial domains can provide both the macro- and microscopic insights needed in better understanding problems of unsustainability (Fig. 3).

5. Structuring the problem of Baltic Sea eutrophication from Swedish agriculture

5.1. Background

Baltic Sea eutrophication is a sustainability challenge consisting of complex biogeochemical processes in a changing socio-political environment. Since the mid-19th century there has been a fourfold increase of nitrogen inputs into the Sea and an eightfold increase in phosphorus, which has created oxygen depleted waters and ever-increasing algae blooms (Boesch et al., 2006). Contributing to problem-solving challenges, the nutrient loading is driven by scores of point and non-point sources from land and air. Nutrient releases from agriculture (e.g., field nutrient run-off to waterways, ammonia air releases from livestock) are amongst the most significant contributors. For a more thorough description of general Baltic Sea sustainability challenges and problem-solving efforts, including eutrophication, see *cf.* HELCOM (2009) and Joas et al. (2008). Despite the long term trends, Swedish efforts to curb nutrient influxes into the Baltic Sea have shown signs of success in recent years, especially from agricultural sources (Boesch et al., 2006; HELCOM, 2009). But how can the problem structure and subsequent successes be understood in a multi-level perspective; furthermore what is inhibiting the realization of additional pressure decreases that may result in improved state conditions?

5.2. Multi-level structure for Baltic Sea eutrophication

Fig. 4 suggests a scheme for problem-solving efforts for Baltic Sea eutrophication caused by Swedish agriculture. The solid lines connecting the levels represent enforceable legislative responses (e.g., national legislation and EU Directives); the dashed lines represent the softer, non-enforceable measures (e.g., national goals and voluntary programs). The figure is predominantly a conventional top-down administrative arrangement consisting of the EU level, Swedish national, regional and local governmental institutions and the finally the action (i.e. farmer) level.[4] There are however important differences beyond the conventional structure. The figure shows that policy efforts are becoming increasingly efficient through not always adhering to the step-wise, top-down pattern. Measures can instead skip levels and move from for example upper- or mid-levels (e.g., state or county) direct to the action level, thereby reducing the possibility of disconnects from occurring. There has also been the emergence of a variety of non-state actors (left side of figure) that assist measures to more effectively reach the actor-level or act as an alternative governance mechanism. These actors, consisting of the farmer's union, environmental interest groups, etc., play vital roles in not only in creating and carrying out measures, but also operate as an important feedback mechanism as to which direction future policy actions should take. The entire institutional structure is a dynamic mix of attempts directed at Swedish agricultural production in controlling nutrient run-off and ammonia releases. But is this adequate to understand the problem dynamics – especially to gain insights as to where additional interventions should be directed?

5.3. Trans-national level

There are two institutions involved in Baltic Sea eutrophication efforts at the trans-national level. One important public institution engaged is the EU. In recent years the EU has come to play an important *framer* of policies in this realm due to now eight of the nine Baltic Sea border countries being EU member states. Fig. 5 shows the DPSIR for this level. Driven significantly by industrialized (agricultural) activities and the general increased awareness of environmental issues, amongst other drivers, the EU has responded to the state of polluted waters throughout the Union by enacting numerous enforceable policies and directives and other *softer* policy measures. Many of the actions (e.g., Common Agricultural Policy measures) have generally concentrated on problem drivers and pressures; there have however been measures addressing state conditions as well. Two directives with the closest links to the Baltic Sea eutrophication challenge are the 1991 Nitrates Directive, and the more recent, Water Framework Directive (WFD). Both attempts take a more comprehensive view to water resources management, replacing prior and more fragmented approaches. The Nitrates Directive, among other measures, has called on EU member nations to identify areas vulnerable to nitrogen pollution and to create *plans of action* for addressing agricultural sources (EC, 1991). The WFD's focus on eutrophication has the aims, among others, of creating a *good* (ecological and chemical) *status* of EU waters through the establishment of a single management system. The work is carried out in three cycles based not on EU member county boundaries, but rather on river basin management plans and river districts, where significant emphasis is on pricing mechanisms and public participation throughout the process (EC, 2000).

[4] The roles of interest organizations were not considered in the framework despite that they can influence the system.

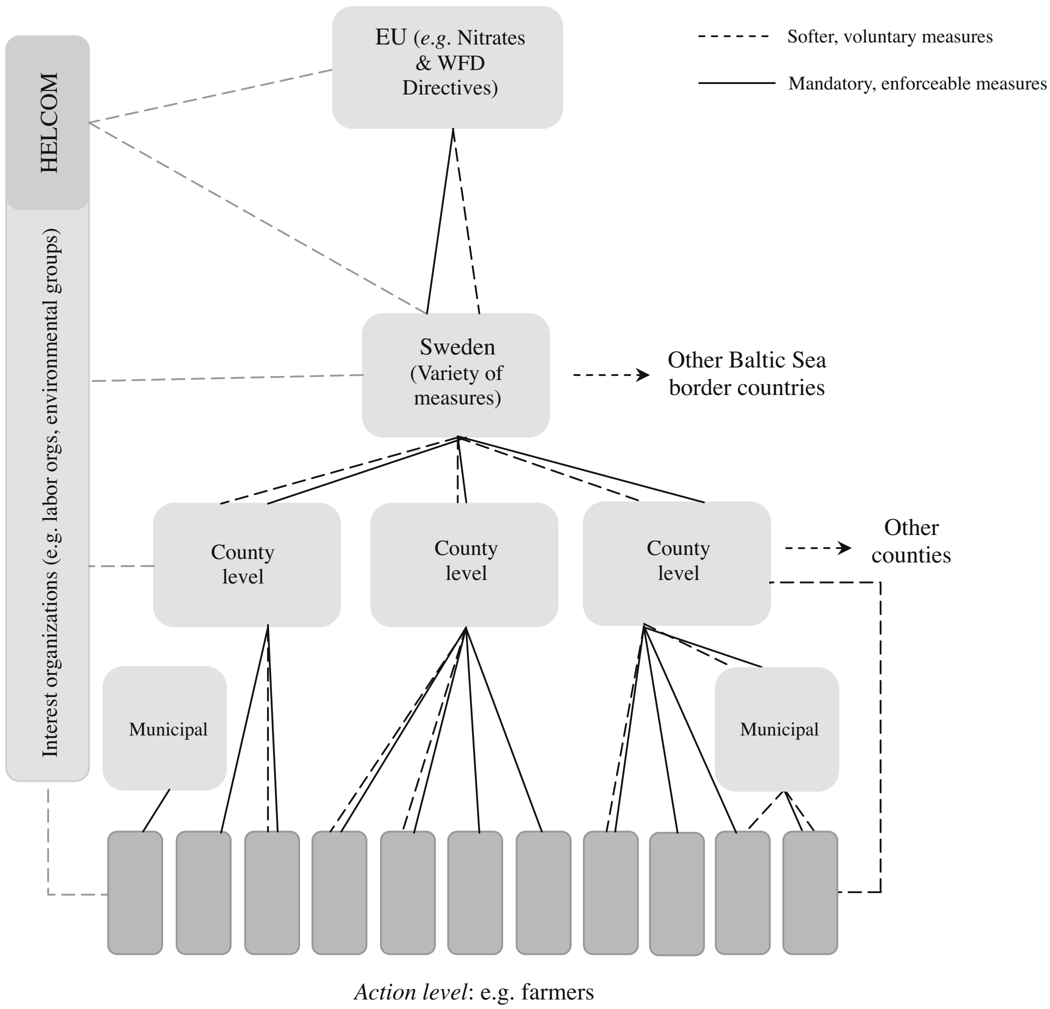

Fig. 4. Multilevel structure for Baltic Sea eutrophication from Swedish agricultural sources. The figure shows the actors of the EU and HELCOM at the trans-national level with Swedish national below. Under the Swedish national level are the county and municipal levels that are generally responsible for carrying out and enforcing upper-level decisions. At the action level are the farmers whose goal it is to generate revenues all while abiding by the variety of harder and softer measures from above. The figure shows that there are action level disconnects where some voluntary measures are not undertaken by farmers. The figure also shows (outside lines to right and left) that levels are sometimes bypassed and move from national and county levels direct to the action level.

Although the WFD approach allows for a better focus on the region-specific differences in eutrophication and nutrient discharges, challenges remain with the national and cross-national implementation of measures that were once based on administrative districts and not entire watersheds.

Concerted multi-national Baltic Sea eutrophication problem-solving attempts existed prior to the EU. Early inter-governmental efforts came with the signing of the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM) in 1974. Today HELCOM represents an institution between the EU and state levels; it also represents one of the actors that are not a part of a traditional command and control system. For a more detailed history of HELCOM, please refer to Kern and Löffelsend (2008). Although the nine country alliance has a focus on the variety of problems plaguing the Baltic Sea, the eutrophication problem is one of its central concerns. Fig. 6 can be used as an example for the variety of these actors that help shape amelioration efforts. The figure shows the DPSIR scheme for HELCOM with a more specific focus on its activities related agricultural sources. It shows similar drivers, pressures, state and impacts as the previous DPSIRs. HELCOM responses, or more accurately *recommendations*, have been directed largely at pressure and state conditions in the form of straight nutrient release percentage reductions for Convention signees. This direction changed however in 2003 when HELCOM altered its approach to a system that more closely resembles the EU-WFD's ecosystem approach. HELCOM's efforts have shifted to the more modest goals of creating good ecological status of the Baltic Sea (Backer and Leppänen, 2008). The revised approach is based on five steps: vision, goals, objectives, indicators and targets (HELCOM, 2006). Although the approach change in recent years has strengthened ties to EU measures, the timeline to establish an agreed-upon approach will take many years – thusly delaying problem-solving efforts further.

5.4. National level

Despite the trans-national level attempts, many of the important Baltic Sea eutrophication problem-solving policy measures stem from national governmental institutions in Sweden. They have been in response to trans-national level priorities as well as autonomous initiatives. Fig. 7 shows a similar DPSI chain as the prior ones. But it also shows Swedish responses consisting of a host of more focused soft and hard measures also addressing pressure and state conditions. The instruments have been of four types: legislation, financial support, information campaigns and extension services, and research and development (Jordbruksverket, 2006).

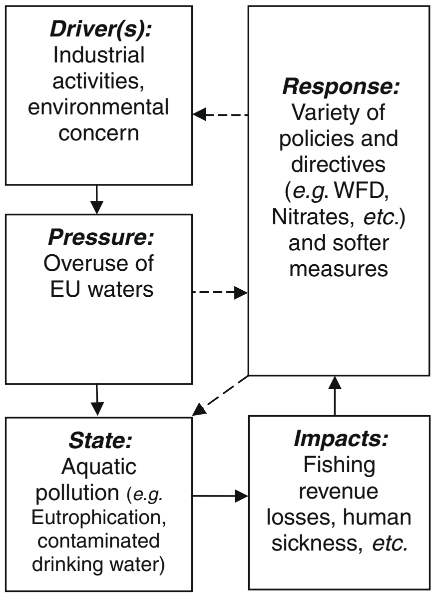

Fig. 5. The problem of water quality and a sampling of responses at the EU level. The DPSIR shows that EU responses have been in the form of broad policy measures that address drivers, pressures and state conditions, and might not always account for the specific nature of eutrophication of the Baltic Sea.

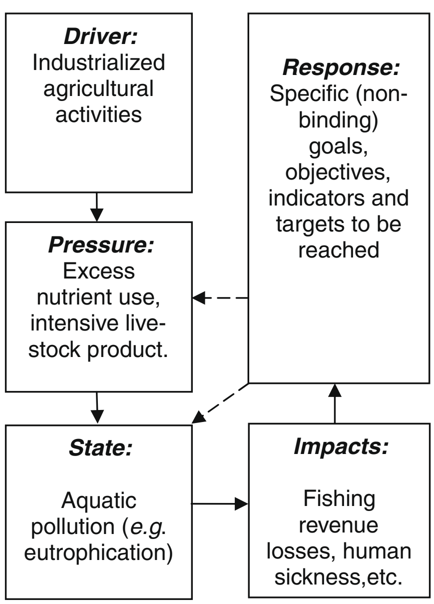

Fig. 6. The problem of Baltic Sea eutrophication and responses by HELCOM. The scheme shows that responses have historically been in the form of general *recommendations* that although address both pressure and state conditions, are not enforceable and therefore carry minimal political teeth.

Legislative efforts include general restrictions focusing on among other areas as slurry storage capacity requirements, mineral and organic fertilizer spread date restrictions. The regulations set a general basis for what, how and when activities in agriculture can be carried out. Addressing problem pressures have also centered on efforts to reduce excessive nutrient field use through financial instruments of special taxes on nutrients. There has furthermore been financial support available for the use of nutrient *catch crops* in winter months, buffer strip establishment between waterways and arable lands, and money for the establishment of

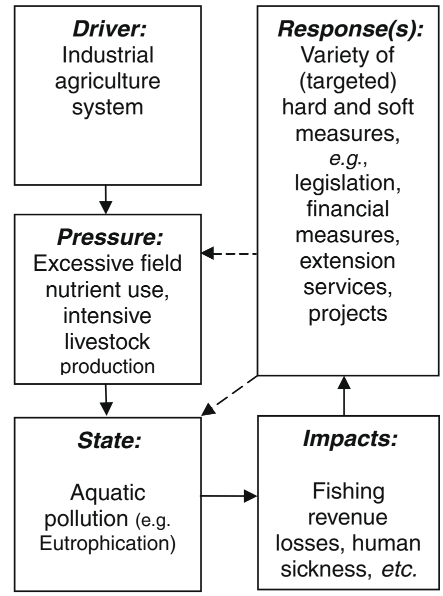

Fig. 7. The problem of water quality and a sampling of responses at the Swedish national level. The DPSIR shows that there have been a variety of hard and soft responses that have generally addressed both pressure and state conditions.

wetlands and ponds (Jordbruksverket, 2006). The establishment of 16 environmental quality objectives (EQOs) has also helped to prioritize and steer national and regional policy efforts. The seventh EQO is zero eutrophication that has set percentage reduction targets to be reached by 2010 for nitrogen, phosphorus and ammonia (SEPA, 2008). To operationalize the above measures, information and outreach services have been strengthened as well as a strengthening of research and development, including cropping and technical development projects as well as environmental monitoring activities.

5.5. County and local levels

County and municipal governments also play key roles in the system. These actors play an instrumental role in linking upper-levels with actors on the landscape. Their role in general is not to devise new measures, but to enforce and better tailor existing policies. Because of their direct experience with the action level, they furthermore can act as an important mechanism to create more targeted and effectual national and trans-national legislation. The DPSIR scheme for these levels (Fig. 8) shows that the responses focus on state conditions through e.g., legislative enforcement and monitoring activities, farm permit issuing, wetland creation projects, or even impact-focused responses such as emergency response services.

5.6. Hybrid approaches

Baltic Sea eutrophication problem has also seen the emergence of alternative governance approaches in recent years. An example of this effort in lessening nutrient flows from agriculture is the *Focus on Nutrients Project* (no DPSIR provided). It represents a hybrid approach between state and non-state actors, or more precisely between county governments, the Swedish Board of Agriculture (i.e. national level) and the Federation of Swedish Farmers (non-state actor). Emphasis is placed on linking the latest research with actual actions on the landscape. The voluntary project aims at ways to reduce nutrient outflows through individual farmer consultations by trained extension service officers. Focus is placed on individual

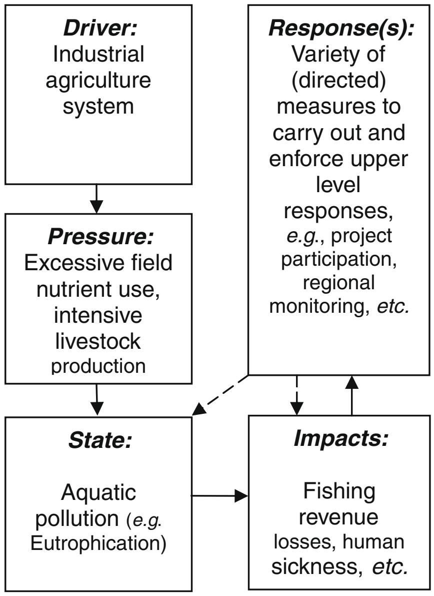

Fig. 8. Driver of eutrophication and a sampling of responses at the county and local levels. The DPSIR shows that the fundamental DPSI stages are the same as the Swedish national level, but the nature of the responses change from creating measures to decrease nutrient outputs to more focused efforts action level to carry out and enforce upper-level responses.

farm-tailored actions such as wetland planning, plant nutrient balances, field fertilization (e.g., manure spreading) and field strategies (e.g., catch crop planting) to reduce nutrient outflows. So far there have been roughly 6000 Swedish farmers that have partaken in the program (Greppa Näringen, 2005).

6. Discussion

6.1. Case study

The multi-level framework in Fig. 4 focuses on the broad institutional structure of problem-solving efforts for Swedish agriculture. The figure showed the combination of traditional policy approaches in conjunction with a more fluid system of voluntary measures (programs, projects, etc.). The DPSIR schemes for each level have highlighted more specific societal problem-solving responses for Baltic Sea eutrophication with a focus on Swedish agricultural sources. Although Sweden could be viewed as having some successes in its efforts in addressing point and non-point agricultural sources, there are still disconnects between the upper symbolic transactions levels and the action (i.e. farmer) level that inhibit further progress. The dotted lines in the figure show that many voluntary measures that originate at the upper-levels do not reach the farm level. Although farmers must adhere to the myriad basic national laws on agricultural practices, the laws only pertain to general practices, and therefore only encompass a certain percentage of farm nutrient outflows. Other important voluntary and more tailored reduction programs exist, but due to financial constraints or outright farmer disinterest in participation, the projects and programs do not reach their potential in reducing overall flows from agriculture. Such efforts must be strengthened if additional nutrient decreases are to be realized.

The example has focused on nutrient inputs leading to Baltic Sea eutrophication stemming from Swedish agricultural practices; of course Sweden is only one of the nine Baltic Sea border nations and agricultural sources are not the only contributor to the problem. Sweden has made important strides in addressing its nutrient flows recent decades. In order for more ambitious goals to be established and realized, increased efforts must not only concentrate on the national level down to the action level, but they should also work upward into more effective trans-national governance schemes. An approach that has emerged in recent years is the increased pressure from Swedish county and national levels in further pressuring other Baltic Sea border countries to better address nutrient discharge levels. The approach has not only occurred through HELCOM and the EU, but also on a country-by-country basis.

Because of the international reach of the problem, trans-national institutions must be the framer and motivator of Baltic Sea eutrophication problem-solving efforts. With Sweden and Finland joining in 1995 and Estonia, Latvia, Lithuania and Poland in 2004, the EU has emerged as *the* institution for the Baltic Sea with measures through a variety of both hard and soft policy measures. Furthermore, EU efforts have also become more effective in recent times due to successes in better addressing regional differences of problem areas. The WFD for example has employed the watershed approach where problem-solving efforts are tailored to the specific nature of defined drainage basins. Efforts by HELCOM on the other hand have been redirected to better match EU problem-solving measures (e.g., the ecosystem approach), but measures are still dominated by recommendations that are not enforceable, creating the risk of HELCOM of becoming superfluous. Continued and strengthened efforts between the EU and HELCOM are needed for adopting targeted and enforceable policies that address the unique regional characteristics and work hand-in-hand with regional socio-economic development.

6.2. Approach

How does the suggested scheme fit within the methodological rubric of sustainability science, and does it fulfill the four research strategies criteria propounded by Kates et al. (2001)? Equally important, what makes the approach distinctive from other approaches? First, *does the taxonomy address a range of spatial scales inherent in problems of unsustainability?* Hägerstrand's methodological contribution allows the analyst to determine the spatial reach of the particular problem *and* to gain an understanding of the unique institutional arrangements of each problem area. Numerous other conceptualization or policy analysis frameworks are spatially implicit (*cf.* Checkland, 1991; White, 1979; O'Laughlin, 2004) – focusing only on causal connections and not at the levels they are occurring. Although these approaches do a sufficient job at allowing the analyst to e.g., structure problems, detect where policy inequities may occur or weigh the costs and benefits of a particular policy decision, they pay little or no direct attention to the institutional reach of the problem or to detect the territorial *incompetencies* between the various levels. Causal loop diagramming, for example, focuses on the causal relationships between the applicable variables; however problems structured in this manner leave no explicit inference to the level the interactions are occurring. As the example has demonstrated, it is often not within each level, but rather between the various domain levels that decision-making voids or other exterior counter-measures exist. The framework assists in making these relationships more explicit.

Combined with the DPSIR scheme, the analyst can furthermore decipher the causal relationships at each of the levels and illustrate what responses are directed at the problems or where additional actions might be aimed. As with Hägerstrand's taxonomy, the IAD framework, for example, allows one to detect the structure of the institutional arrangements influencing the actor-level, but the IAD framework places less emphasis on examining the causal chains of each specific problem area (Andersson, 2006) often missing the key driving forces, or what specifically has been done at the different levels to respond to the problem.

Second, *does the scheme account for temporal inertias and process urgencies?* Recognition of a problem, how it impacts SESs and the responses via the DPSIR system have both direct and indirect connections to inertias and urgencies. The magnitude and swiftness of actual responses are implicitly part of the taxonomy. The DPSIR framework is unique because response(s) can be analyzed or specifically determined based on which DPSI stage it is focused. Ideally, and as the example has helped to demonstrate, it is suggested that a "response portfolio" be used which directs responses back to a range of stages (see Fig. 9). *Quick fix* responses should generally be directed to problem impacts or states and addresses urgencies (e.g., the use of breathing filters in Asia to address poor outdoor air quality); they should not be viewed as solutions in themselves. They may help in solution urgency terms, but do little to address the fundamental drivers of the problem. Lasting responses are slower moving – often taking years or decades to initiate; they are aimed closer to problem drivers. An example of such a policy might be national landscape planning policies to ward-off forest clear-cutting practices that drive air quality problems, or even international measures that quell the demand for the products, which drive the forest product demand or palm oil plantation creation in the first place.

Third, *is the scheme capable of handling functional complexity brought on by such things as multiple stresses?* One feature of the proposed scheme is to act as a mode to disentangle the complexity inherent in problems of unsustainability. It attempts to create a system to manage complexity through breaking problems down into a handful of elementary components via the DPSIR scheme at different, but appropriate, levels. As mentioned, a limitation does exist with DPSIR's ability to encompass, for example, multiple drivers or stresses in a single, efficient scheme – meaning things can become cumbersome and messy. But the problem does not reside in the limitation of the scheme, rather it lies in the multitude of causal interactions inherent in the problems themselves. If a scheme is to contribute to the more effective structuring and understanding of a problem area, a requisite level of detail must be reached – corresponding to multiple DPSIR models connected by the spatial limitations in which they are nested. For simplicity, the Swedish eutrophication example focused on nutrient run-off from agricultural sources, it is, in reality, only one contributor to the problem. If a more accurate picture of the situation was to be performed, the additional problem contributors (e.g., nutrient loading from wastewater treatment, etc.) and nutrient leaching profiles for individual crops in the larger rotation system would also have to be examined.

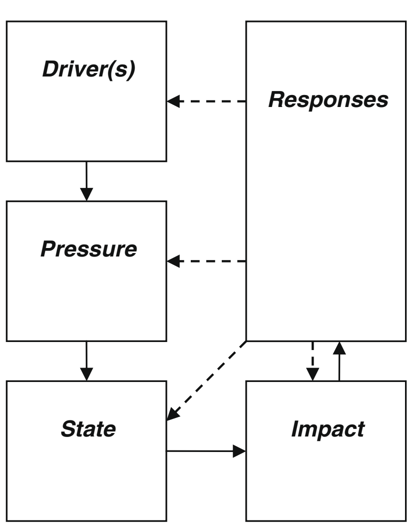

Fig. 9. "Response portfolio" where a variety of responses are directed back to the different DPSI phases.

Finally, *does the taxonomy recognize multiple perspectives and usable knowledge within science and society?* To incorporate a broader perspective, the authors have advocated that schemes be created in a participatory manner. This cannot only be done via contributions from a multitude of disciplinary perspectives within academia, but also through the inclusion of a relevant but diverse range of perspectives from outside academia. In addition to the inputs gained from participatory approaches, outputs can also be derived from the process. *Societal learning* about complex problems of unsustainability is an important outcome from participatory processes that might not be realized through traditional capacity- and decision-making procedures.

7. Concluding remarks

In the same pages that Hägerstrand uses to introduce the system of nested domains, he also devotes attention to the area of effective knowledge dissemination – also an area of concern in sustainability science. The framework he presents – as well as our elaboration here – places significant emphasis on the policies that can guide actors down more sustainable pathways. But Hägerstrand also argues that "[t]o change a [negative] trend requires a much more all-embracing alteration of behavior than sectoral policies are to bring about" (Hägerstrand, 2001). He declares that widespread knowledge about an issue does not in itself have the power to redirect collective action – suggesting that larger societal transitions are needed. But how are we to overcome the enigmatic relationship between knowledge and behavior in order to create such shifts? To better understand, Hägerstrand again places an emphasis back on the actor-level. He suggests that knowledge – or what he calls "mental pictures" – exists in two distinct types. The first – termed "direct experience" – is the situational and varied knowledge gained through one's daily actions on the landscape. The second type is the knowledge acquired through reports (printed texts, graphs, etc.), where often large-scale and abstract principles are presented. Hägerstrand argues that in order for the knowledge to be more effectively understood, increased efforts must be placed on linking the principles to the daily landscape level experiences (Hägerstrand, 2001). In other words, political decisions are not based solely on increased flows of scientific information nor improved scientific evidence, but rather on the transitions in voter attitudes on particular issues.

This article has suggested an approach that combines the DPSIR scheme with Hägerstrand's system of nested spatial domains. The purpose has been to provide a framework that can lead to the more effective detection and understanding of fundamental relationships of complex problems. The article has provided the short example of Baltic Sea eutrophication from Swedish agriculture to exemplify the approach more concretely.

References

Adger, N.W., Brown, K., Tompkins, E.L., 2006. The political economy of cross-scale networks in resource co-management. Ecology and Society 10. <http://www.ecologyandsociety.org/vol10/iss2/art9/>.

Anderberg, S., 1999. Sustainable Development, Industrial Metabolism and the Process Landscape – Reflections on Regional Material-Flow Studies. Intermediate Technology Publications, London.

Andersson, K., 2006. Understanding decentralized forest governance: an application of the institutional analysis and development framework. Sustainability: Science, Practice and Policy 2. <http://ejournal.nbii.org/>.

Andersson, K.P., Ostrom, E., 2008. Analyzing decentralized resource regimes from a polycentric perspective. Policy Sciences 41, 71–93.

Backer, H., Leppänen, J.-M., 2008. The HELCOM system of a vision, strategic goals and ecological objectives: implementing an ecosystem approach to the management of human activities in the Baltic Sea. Aquatic Conservation: Marine and Freshwater Ecosystems 18, 321–334.

Bammer, G., 2005. Integration and implementation sciences: building a new specialization. Ecology and Society 10. <http://www.ecologyandsociety.org/vol10/iss2/art6>.

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. Regional Environmental Change 4, 5–16.

Boesch, D., Hecky, R., O'Melia, C., Schindler, D., Seitzinger, S., 2006. Eutrophication of Swedish Seas (Final Report 5509). Swedish Environmental Protection Agency, Stockholm.

Boulanger, P.M., Bréchet, T., 2005. Models for policy-making in sustainable development: the state of the art and perspectives for research. Ecological Economics 55, 337–350.

Bowen, R.E., Riley, C., 2003. Socio-economic indicators and integrated coastal management. Ocean and Coastal Management 46, 299–312.

Cash, D.W., Adger, W.N., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., Young, O.R., 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. Ecology and Society 11. <http://www.ecologyandsociety.org/vol11/iss2/art8>.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences of the United States of America 100, 8086–8091.

Chave, J., Levin, S., 2001. Scale and Scaling in Ecological and Economic Systems. Beijer Institute of Ecological Economics, Stockholm.

Checkland, P., 1991. Systems Thinking, Systems Practice. John Wiley and Sons, Chichester, UK.

Chorley, R.J., Kennedy, B.A., 1971. Physical Geography: A Systems Approach. Prentice-Hall, London.

Clark, W.C. (Ed.), 2002. Research Systems for a Transition toward Sustainability. Springer, Heidelberg.

Clark, W.C., Dickson, N.M., 2003a. Research systems for a transition toward sustainability. In: Steffen, W., Jäger, J., Carson, D.J., Bradshaw, C. (Eds.), Global Change Open Science Conference. Springer-Verlag, Amsterdam.

Clark, W.C., Dickson, N.M., 2003b. Science and technology for sustainable development special feature: sustainability science. The emerging research program. Proceedings of the National Academy of Sciences of the United States of America 100, 8059–8061.

EC, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal of the European Union 375, 1–8.

EC, 2000. Council Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Union 327, 1–73.

EEA Report, 1999. Environmental Indicators: Typology and Overview. <http://reports.eea.europa.eu/TEC25/en/tech_25_text.pdf>.

Folke, C., Gunderson, L., 2006. Facing global change through social-ecological research. Ecology and Society 11. <http://www.ecologyandsociety.org/vol11/iss2/art43/>.

Gallopín, G.C., Funtowicz, S., O'Connor, M., Ravetz, J., 2001. Science for the 21st century: from social contract to the scientific core. International Social Science Journal 53, 219–229.

Geels, F., Kemp, R., 2000. Transities Vanuit Sociotechnisch Perspectief (Transitions in a Sociotechnical Perspective). Maastricht, The Netherlands.

Gibson, C.C., Ostrom, E., Ahn, T.K., 2000. The concept of scale and the human dimensions of global change: a survey. Ecological Economics 32, 217–239.

Giupponi, C., 2002. From the DPSIR reporting framework to a system for a dynamic and integrated decision making process. MULINO Conference on European Policy and Tools for Sustainable Water Management, Venice.

Giupponi, C., 2007. Decision support systems for implementing the European Water Framework Directive: The MULINO Approach. Environmental Modelling and Software 22, 248–258.

Greppa Näringen, 2005. Focus on Nutrients – A Project Run Jointly by the Swedish Agricultural Industry, the Swedish County Administrative Boards and the Swedish Board of Agriculture. Swedish Board of Agriculture. <http://www.greppa.nu/>.

HELCOM, 2006. Development of Tools for Assessment of Eutrophication on the Baltic Sea. Baltic Sea Environment Proceedings, BSEP 104. Helsinki Commission, Helsinki.

HELCOM, 2009. Eutrophication in the Baltic Sea – An Integrated Thematic Assessment of the Effects of Nutrient Enrichment and Eutrophication in the Baltic Sea Region: Executive Summary Baltic Sea Environment Proceedings, BSEP 115A. Helsinki Commission, Helsinki.

Hägerstrand, T., 1992. Samhälle och Natur (Society and Nature). Department of Social and Economic Geography, Lund University, Sweden.

Hägerstrand, T., 2001. A look at the political geography of environmental management. In: Buttimer, A. (Ed.), Sustainable Landscapes and Lifeways: Scale and Appropriateness. Cork University Press, Ireland.

Hägerstrand, T., Lohm, U., 1990. Sweden. In: Turner, B.L., II, Clark, W.M., Kates, R.W., Richards, J.F., Mathews, J.T., Beyer, W.B. (Eds.), The Earth Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years. Cambridge University Press, Cambridge, UK.

Joas, M., Jahn, D., Kern, K., 2008. Governance in the Baltic Sea region: balancing states, cities and people. In: Joas, M., Jahn, D., Kern, K. (Eds.), Governing a Common Sea: Environmental Policies in the Baltic Sea Region. Earthscan, London.

Jordbruksverket, 2006. Plan of Action against Plant Nutrient Losses from Agriculture. Swedish Board of Agriculture, Jönköping. <http://www2.sjv.se/webdav/files/SJV/trycksaker/Pdf_ovrigt/ovr125gb.pdf>.

Kahn, A.E., 1966. The tyranny of small decisions: market failures, imperfections, and the limits of economics. Kyklos 19, 23–47.

Kasemir, B., Jäger, J., Jaeger, C.C., Gardner, M.T. (Eds.), 2003. Public Participation in Sustainability Science. A Handbook. Cambridge University Press, Cambridge.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., et al., 2001. Sustainability science. Science 292, 641–642.

Kern, K., Löffelsend, T., 2008. Governance beyond the Nation State: transnationalization and Europeanization of the Baltic Sea region. In: Joas, M., Jahn, D., Kern, K. (Eds.), Governing a Common Sea: Environmental Policies in the Baltic Sera Region. Earthscan, London.

Klijn, J.A. (Ed.), 2004. Driving Forces behind Landscape Transformation in Europe, from a Conceptual Approach to Policy Options. Springer, Dordrecht.

Komiyama, H., Takauchi, K., 2006. Sustainability science: building a new discipline. Sustainability Science 1, 1–6.

Lenntorp, B., 1999. Time geography – at the end of its beginning. GeoJournal 48, 155–158.

Martens, P., 2006. Sustainability: science or fiction? Sustainability: Science, Practice and Policy 2. <http://ejournal.nbii.org/archives/vol2iss1/TOC.html>.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools for sustainability assessment. Ecological Economics 60, 498–509.

O'Laughlin, J., 2004. Policy analysis framework for sustainable development: National Forest case study. Journal of Forestry 102, 34–41.

O'Riordan, T., Burgess, J.S., Szerszynski, B., 1999. Deliberative and Inclusionary Processes: A Report from Two Seminars. CSERGE, Norwich, UK.

OECD, 1994. OECD Core Set of Indicators for Environmental Performance Reviews: A Synthesis Report. Organisation for Economic Co-operation and Development: Environmental Monographs, Paris.

Ostrom, E., 2005. Understanding Institutional Diversity. Princeton University Press, Princeton.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422.

Parris, T.M., Kates, R.W., 2003a. Characterizing a sustainability transition: goals, targets, trends, and driving forces. Proceedings of the National Academy of Sciences of the United States of America 100, 8068–8073.

Parris, T.M., Kates, R.W., 2003b. Characterizing and measuring sustainable development. Annual Review of Environment and Resources 28, 559–586.

Ravetz, J., 2004. The post-normal science of precaution. Futures 36, 347–357.

Renn, O., 2004. Participatory processes for designing environmental policies. Land Use Policy 23, 34–43.

Richardson, G.P., 1991. Feedback Thought in Social Science and Systems Theory. University of Pennsylvania Press, PA.

Richardson, G.P., Pugh III, A.L., 1981. Introduction to System Dynamics Modeling. Productivity Press, Portland.

Roberts, N., Anderssen, D.F., Deal, R.M., Garet, M.S., Shaffer, W.A., 1983. Introduction to Computer Simulation. Productivity Press, Portland.

Roe, E., 1997. Taking Complexity Seriously: Triangulation and Sustainable Development. Kluwer, Boston.

Schröter, D., Polsky, C., Patt, A.G., 2005. Assessing vulnerabilities to the effects of global change: an eight step approach. Mitigation and Adaptation Strategies for Global Change 10, 573–596.

SEPA, 2008. Sweden's Environmental Objectives – Are We Getting There? Swedish Environmental Protection Agency, Stockholm.

Simon, H.A. (Ed.), 1973. The Organization of Complex Systems. George Braziller, New York.

Swart, R.J., Raskin, P., Robinson, J., 2004. The problem of the future: sustainability science and scenario analysis. Global Environmental Change 14, 137–146.

Turner II, B.L., Kasperson, R.E., Meyer, W.B., Dow, K.M., Golding, D., Kasperson, J.X., Mitchell, R.C., Ratick, S.J., 1990. Two types of global environmental change – definitional and spatial-scale issues in their human dimensions. Global Environmental Change 1, 14–22.

Turner II, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., et al., 2003. Science and technology for sustainable development special feature: illustrating the coupled human–environment system for vulnerability analysis: three case studies. Proceedings of the National Academy of Sciences of the United States of America 100, 8074–8079.

van der Brugge, R., Rotmans, J., Loorbach, D., 2005. The transition in Dutch water management. Regional Environmental Change 5, 164–176.

Waggoner, P.E., Ausubel, J.H., 2002. A renovated IPAT identity. Proceedings of the National Academy of Sciences of the United States of America 99, 7860–7865.

White, I.L., 1979. An interdisciplinary approach to applied policy analysis. Technological Forecasting and Social Change 15, 95–106.

Wilbanks, T.J., Kates, R.W., 1999. Global change in local places: how scale matters. Climatic Change 43, 601–628.

Young, O.R., 2006. Vertical interplay among scale: dependent environmental and resource regimes. Ecology and Society 11. <http://www.ecologyandsociety.org/vol11/iss1/art27/>.

Young, O.R., Berkhout, F., Gallopín, G.C., Janssen, M.A., Ostrom, E., Van der Leeuw, S., 2006a. The globalization of socio-ecological systems: an agenda for scientific research. Global Environmental Change 16, 304–316.
Young, O.R., Lambin, E.F., Alcock, F., Haberl, H., Karlsson, S.I., McConnell, W.J., Myint, T., Pahl-Wostl, C., Polsky, C., Ramakrishnan, P.S., Schroeder, H., Scouvart, M., Verburg, P.H., 2006b. A portfolio approach to analyzing complex human-environment interactions: institutions and land change. Ecology and Society 11. <http://www.ecologyandsociety.org/viewissue.php?id=66#Insight>.