# Role of scientists in social-ecological systems governance for sustainability

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**Abstract**

Social-ecological systems' dynamics challenge institutions and their functions. For a social-ecological system to be sustainable, a balanced interdependence of societal and ecological systems is vital. Given the diversity of social-ecological system contexts, different institutional functions are required for social-ecological system's sustainability. In our paper, we perform a theoretical analysis, mapping four context images of social-ecological systems to four different institutional functions and deriving the associated roles of scientists. We show that institutions are needed to balance, to protect, to respond and to mitigate depending on the context images. We determine that the differentiated roles required of scientists to support social-ecological system sustainability vary from advocate, to mediator, messenger and forecaster.

## 1. Introduction

A balanced interaction between the social and ecological subsystems is a critical factor for the social-ecological system's (SES) sustainability. In this paper, we call attention to different functions that are required from institutions in order to sustain a balanced interdependence of SES under different systemic and contextual conditions. Institutions are seen as essential means for governing SES. Institutional capacity in dealing with SES dynamics is a subject of research (Berkes and Folke, 1998; Rammel et.al, 2007, p.14; Lebel et.al, 2006). Berkes and Folke (1998, p.354) raised the issue of institutional function when regarding SES and Lebel et.al. (2006) argue that the way institutions are structured plays an important role in the management of environmental resources when noting that "polycentric and multilayered institutions appear to be important to building or enabling the capacity to build resilience".

Institutions and institutional functions are realized by individuals that operate and reform them. Amongst these actors, scientists play an important role: they can be the communication channel to both the society and to the institutions for sustaining the socio-ecological system. Our research addresses the question: *What is the role of scientists in contributing to socio-ecological systems' sustainability under different contexts of socio-ecological interactions?* Our analysis commences by deducing the different functions that institutions need to fulfill for sustaining a balanced SES interdependence and identifying the differentiated role of scientists in every context condition.

## 2. Methodology

Our analysis unfolds in three steps:

**Step 1-Mapping SES context images:** We examine how interdependencies of the SES change under four context images. We ground our analysis in governance theories of SES and examples of SES' responses for every image. In our analysis we will concentrate on two characteristics for describing SES interdependencies: (a) the social practices of indigenous communities, that is the societal response to the ecosystem (these can vary from malpractices to good practices), and (b) the state of the ecosystem dynamics. The ecosystem is considered to be subject to continuous change, hence ecosystem dynamics are always present. The scale of the ecosystem dynamics varies from active ecosystem dynamics where the ecosystem undergoes drastic changes to latent ecosystem dynamics where the ecosystem experiences changes that comply with the revitalizing cycle of the ecosystem. When examining the interdependencies of a SES, ecosystem services flow from the ecosystem to the society, while from the society to the ecosystem there are different flows depending on the context conditions. The state of the ecosystem concerns a systemic condition whereas the SES interdependencies and dynamics constitute the context for the institutions established to sustain SES.

**Step 2-Deducing institutional functions:** For every context-image, an effective (desirable) institutional function is deduced from theories and research findings on SES governance. In our view, there different institutional arrangements can be established to fulfill the specified institutional function. We argue that a unique relationship between institutional arrangements and institutional functions does not exist. For example, establishment of quota systems may be used in fisheries so as to ensure protection of the ecosystem as an institutional function in one country (in one context); whereas quotas can be used so as to promote adaptation to SES dynamics in another country (different context). By focusing on institutional functions, the identification of effective or desirable outcomes of institutional operation becomes central to the analysis, supporting a new system's view of how institutional arrangements are established. Indeed, the understanding of institutional functions and their implications for the institutional architecture in which they are embedded are essential when change or introduction of new institutions is suggested (Imperial, 1999, p.454).

**Step 3-Identifying the role of scientists under different contexts of SES interaction:** To understand the systemic and context conditions, knowledge concerning these conditions needs to be exchanged between the actors. The role of scientists in different SES contexts is diverse. Scientists can act as a communication channel to both the society and to the institutions for sustaining the socio-ecological system. A list of definitions of the terms is provided in the Appendix.

## 3. Multiplicity of institutional functions for social-ecological systems governance

Within social-ecological systems governance, institutions are social constructs with the functions of regulating, legitimizing and protecting interests depending on the context conditions. We elaborate on four different social-ecological system contexts and deduce four different institutional functions required to safeguard the system's sustainability.

### 3.1 Institutions for protecting SES dynamics

*Context Image:* The first context image of SES interdependencies maps the situation in which indigenous communities adopt mal-practices when dealing with the ecosystem (e.g exploitation of a natural depleteable resource), and the ecosystem in response is under pressure. The above described context image reflects the tragedy of the commons described by Hardin (1968). (Figure 1, Context Image I)

*Institutional function:* For dealing with the anthropogenic harm towards the ecosystem, institutions are viewed as the means to ***protect*** the ecosystem. The need for protection of the ecosystem from the negative effects of human practices was the driving force for the development of the ecosystem-based management paradigm (Imperial, 1999; Pretty and Ward, 2001). In the early stages, ecosystem thinkers made a distinction between the 'management' and 'engineering' of the ecosystem. According to ecosystem thinkers (Costanza et.al., 1997; Pretty and Ward, 2001), the ecosystem could not be engineered or controlled; rather information from ecologists on the 'capricious' dynamics of the system was necessary for effective non-interventionist management. Ecosystem based management suggests institutions to protect the ecosystem from anthropogenic mal-practices (Imperial, 1999, p.454). In early ecosystem governance writings, the need for centralized institutional arrangements that secure an effective intervention to the problem of the commons is promoted (Hardin, 1968). In ecosystem-based management research and in common-pool resources management writings (Ostrom, 1990), the preference for non-hierarchical institutions and community-based institutions is presented.

*Role of scientists:* When dealing with the anthropogenic harm towards the ecosystem, scientists have the role of the ***advocate***, meaning to advocate and inform the society about the impact of its actions on the ecosystem. Scientists need to look to the past for understanding and pinpointing healthy states of the ecosystem and good practices that are not in use at present so as to establish the protection of the ecosystem in future. The case of the ocean management of the Barents Sea Lofoten, Norway, reported by Knol (2010, p.259) is an example of the advocative role of scientists towards integrative approach for SES governance.

### 3.2 Institutions for mitigating SES dynamics

*Context Image***:** The second context image of SES interdependencies maps the situation in which indigenous communities adopt mal-practices when dealing with the ecosystem and the ecosystem is under pressure due to incipient or manifest extreme dynamics. The above described context image represents the collapse of

ecosystems as described by Diamond (2004; 2005) such as the well-documented case of collapse is the Easter Island community (Figure 1, Context Image II).

More specifically, there are two approaches that elaborate on the collapse of social-ecological systems: the resilience approach and the vulnerability approach. According to the resilience approach, collapse occurs when the SES cannot accommodate the changes (that means that it is pushed beyond its carrying capacity or exceeds its thresholds) and collapse is followed by a reorganization of the social-ecological system (Anderies, Walker and Kinzig, 2006; Walker and Meyers, 2004). Given SES' inherent complexity, collapse is an extreme but intrinsic behavior of such systems when experiencing severe disturbances (Abel et.al., 2006). In contrast to the resilience approach, the vulnerability approach states that the social-ecological system is vulnerable to changes and is influenced by change considering collapsing irreversible (Metzger, Leemans and Schroter, 2005; Parmesan and Yohe, 2003; Manuel-Navarrete, Gomez and Gallopin, 2007). The conceptualization of collapsing from the vulnerability approach, complemented by that of ecological-anthropological studies (Diamond, 2004; 2005), is adopted in our paper. Collapses of SES include the decay or complete destruction of a SES as a result of synergies between systemic and contextual dynamics.

*Institutional function:* For dealing with the anthropogenic harm towards the ecosystem which is starting to or is already manifesting extreme dynamics, institutions are viewed as the means to ***mitigate*** the ecosystem. Starting from this context image, environmental management as a SES governance approach proposes mitigation measures for sustaining a balanced SES interdependence. Technology and consequently, technological means (e.g. effluent treatment technology, dikes) lie at the core of the environmental management approach, specifically approaches such as end-of-pipe management.

*Role of scientists:* When dealing with the anthropogenic harm towards the ecosystem and incipient or manifest extreme ecosystem dynamics, scientists have the role of ***forecaster*** (in Turnhout et. al, 2008, p.230 is referred as 'signaller'). Scientists have to communicate the urgency of the situation, put in perspective what happens in the SES as they search for rescue measures. Scientists in this context need to initiate action to rescue the SES hence have to adopt an active role to "shake" society with the scientific forecasts. The case of the fynbos watersheds in Western Cape Province, South Africa reported by Gutrich et. al, (2005, p.200) is an example of the forecaster role of scientists.

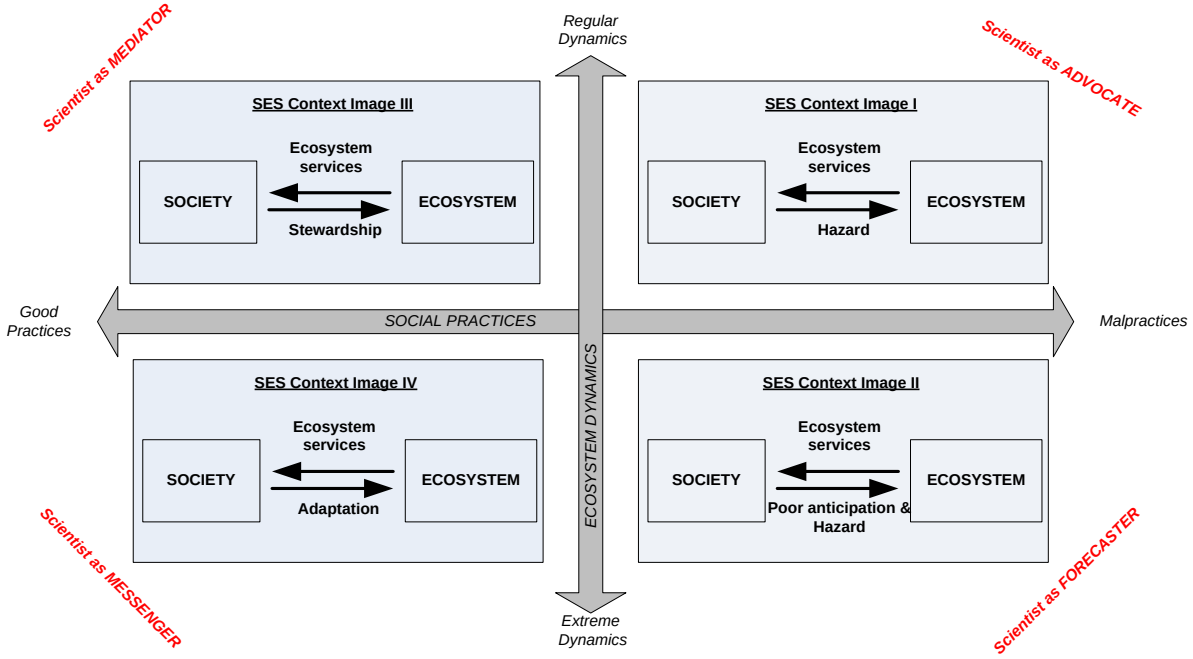


**Figure 1: Social-Ecological System's Context Images and the Role of Scientists.**

### 3.3 Institutions for balancing SES dynamics

*Context Image:* The third context image of SES interdependencies maps the situation in which local communities have good practices when dealing with the ecosystem and the ecosystem experiences regular dynamics. When local communities are seen to employ sustainable practices, the local community is considered to acquire the memory of the system (Scott, 1998). In this context, the local community steward the ecosystem and is directly responsible for its sustainability (Ostrom, 1990; Carlsson and Berkes, 2005; Kofinas, 2009) (Figure 1, Context Image III).

*Institutional function:* Where local communities steward the ecosystem, institutions need to ***balance*** the interdependence between society and ecosystem to safeguard its sustainability. Adaptive co-management researchers have worked on deducing institutional arrangements from empirical cases where ecosystem stewardship occurred and management practices for settling ecosystem stewardship were realized (Carlsson and Berkes, 2005; Olsson, Folke and Hahn, 2004; Olsson, Folke and Berkes, 2004; Chapin, Kofinas and Folke, 2009; Folke, Chapin and Olsson, 2009). Adaptive co-management is an approach "based on well-accepted ecological principles and adjusts practices to fit local conditions" (Kofinas, 2009, p.78) and proposes an active involvement of local communities for sustainable governance. The importance of local communities and local knowledge for ecosystems' sustainability is addressed by social science (Scott, 1998) and policy science scholars (Healey, 2006; Hajer, 2003; Hajer and Wagenaar, 2003).

*Role of scientists:* When dealing with the stewardship of the ecosystem, scientists have the role of the ***mediator.*** Scientists can act as society's interpretive arm, to inform society about the ecosystem dynamics and health and as the interpreters of societal visions. Scientists in this context need to assess the present situation within the context of a reflexive view on planning (Voss et.al, 2009). The case of water usage between sugarcane and diversified production in Hawaii reported by Gutrich et.al., (2005, p.205) is an example of the mediator role of scientists.

### 3.4 Institutions for responding to SES dynamics

*Context Image:* The fourth context image of SES interdependencies maps the situation in which local communities have good practices when dealing with the ecosystem and the ecosystem experiences extreme dynamics. In this context, local communities (need to) alter their practices continuously so as to adapt to the extreme ecosystem dynamics. An example of extreme ecosystem dynamics is the desertification of semi-arid South European regions (e.g. Spain, Eastern regions of Crete, Greece). (Figure 1, Context Image IV)

*Institutional function*: Where local communities adapt or strive to adapt to extreme ecosystem dynamics, institutions need to ***respond*** to the interdependence between society and ecosystem to safeguard sustainability. Adaptive co-management as a SES governance approach provides the ground for institutional arrangements that enable adaptation and response to extreme ecosystem dynamics (Kofinas, 2009). Complementary to adaptive co-management, adaptive management addresses participative processes and an active role of policy practitioners and scientists in aiding the adaptation to SES dynamics (Hamouda et.al., 2004, p.5032). The adaptive co-management "combines the dynamic learning characteristic of adaptive management with the linkage characteristic of collaborative management" (Galaz et.al., 2008, p.161) that makes it a community-based collaborative version of the adaptive management approach; where the inclusion of all interested and affected actors is at the core (Frantzeskaki et.al., 2010).

*Role of scientists:* In this context, scientists have to take the role of the ***messenger.*** Scientists have to be society's change messengers that forewarn society and erect signposts indicative of the dynamics of the ecosystem. Scientists in this context need to look forward and prepare society to continuously respond and adapt to changing conditions. The scientists in this context adopt a cooperative standpoint when signposting the changing conditions hence act as messengers. The cases reported by Steel et.al, (2005, p.5) contemplate that scientists in this context act as messengers "changing the way scientists and lay people view the natural world".

## 4. Implications for Social-Ecological Systems' Sustainability

*Shifting SES contexts:* Institutions as social constructs (Giddens, 1984; Young et.al., 2008, p.43) are subject to change in response to changes in social demands and interests. The mapping of different SES context images

reveals the diversity of SES interdependencies and how SES co-construct both their contexts and the institutions that regulate them. The diversity of SES images, however, reveals the different context states that a SES can exhibit. For instance, in a SES where mal-practices are in place, but the institutions effectively mitigate them and knowledge transfer occurs, the social practices may change towards good practices on the basis of (social) learning. The operation of institutions along with social mechanisms -such as social learning- can result in a shift between SES context images. In the case where there is a shift to the left in figure 1, we consider institutions to perform effectively. Institutions, however, cannot totally control social practices. Such an ineffective operation of institutions is examined by institutional research as part of institutional failures experienced when complex problems are addressed (Scott, 1998; Eggertson, 2005, pp.41-42). When institutions either fail to operate effectively or do not fit with the SES dynamics, the problem of fit or institutional misfit (Young et.al., 2008; Folke et.al., 2009, p.111), SES' sustainability is threatened and a shift towards collapse may occur. Institutions therefore need to anticipate the complexity of SES and of SES dynamics. Accordingly, administrators need to bear in mind that for SES sustainability, institutions need to adapt to context conditions and allow for the shifts in practices to follow a SES context shift (Young, 2008, p.135).

*Adaptive governance is not a cure all:* Adaptive management and adaptive co-management as the management approaches linked to the adaptive governance paradigm, propose participatory processes and learning by doing for adapting to SES dynamics (Berkes and Folke, 1998; Olsson, Folke and Berkes, 2004; Frantzeskaki et.al., 2010). Adaptive governance as the meta-level approach responds to SES context conditions in which ecosystem dynamics are not manifestly extreme and local communities can either contribute with their knowledge to the policy process (community-based management cases) or learn from policy practitioners and scientists how to alter their practices (adaptive co-management cases mainly). In the context where ecosystem dynamics are extreme and local communities employ mal-practices, effective intervention calls for an engineering approach to mitigate severe impacts to the ecosystem; thus environmental management practices are preferred to adaptive governance in this case. Adaptive governance approaches can be adopted in parallel or at a later stage when mitigation has been achieved, as a means to involve social actors actively and to enable social learning.

*The multi-faceted role of scientists*: We focus on the role of scientists in different SES contexts and not in the various interfaces (e.g. the science-policy, the science-stakeholders or the science-management interface). Our analysis reveals that the role of scientists can vary from advocate of the ecosystem when it needs to be protected, to forewarning of the disasters to come when the effects of the ecosystem need to be mitigated, to mediator when the social and ecological systems are in balance and messenger when society needs to respond and adapt to the ongoing changes in the ecosystem. The theoretical verification that multiplicity of institutional functions and of roles of scientists is considered exist comprises a key finding of our analysis.

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**Appendix -** Definitions of the terms used in our analysis listed in an alphabetic order.

**Formal Institutions** – Systems of rules that guide, regulate, and legitimize actions and activities in a defined area of interest or sector e.g. drinking water or health sectors (Vatn, 2009, p.2207).

**Governance** – The process of steering towards a desirable outcome or state in the forms of formal processes of decision making (governing processes) and informal processes of societal dynamics (participatory, deliberative and/or emergent processes of societal drive).

**Institutional function** – The aggregate action that a formal institution is established and expected to perform. It can also be seen as the outcome of the operation of institutions.

**Institutional arrangement** – A specific type of formal arrangement (regulated by an administrative organization) such as a quota system, a market, a taxation scheme, a legislation, a law, and more.

**Local community** – The citizens of a region or loci that are part of the social subsystem excluding policy makers, policy practitioners, administrators and scientists.
**Policy administrator or administrator** – The officer employed in a public (state) institutional organization and legally vested with the task to facilitate or monitor the operation of the institutional function for a specific sector (and maybe for a specific issue or connected issues).
**Policy practitioner** – The street-level administrators who are assigned to implement the policies (put policies into practice).

**References**


Abel, N., Cumming, D.H.M., Anderies, J.M., (2006), Collapse and reorganization in social-ecological systems: Questions, some ideas and policy implications, Ecology and Society, Vol.11, No.1, (www.ecologyandsociety.org/vol11/iss1/art17).

Anderies, J.M., Walker, B.H., Kinzig, A.P., (2006), Fifteen weddings and a funeral: Case studies and resilience-based management, Ecology and Society, Vol.11, No.1 (www.ecologyandsociety.org/vol11/iss1/art21).

Berkes, F., and Folke, C. (1998), Linking social and ecological systems, Management practices and social mechanisms for building resilience, Cambridge University Press.

Brock, W.A., and Carpenter, S.R., (2007), Panaceas and diversification of environmental policy, Proceedings of the National Academy of Science of the United States of America, Vol.104, No.39, pp.15206-15211.

Carlsson, L., and F.Berkes, (2005), Co-management: concepts and methodological implications, Journal of Environmental Management, Vol.75, pp.65-76

Chapin, F.S. III, Kofinas, G.P., Folke, C., (Eds), (2009), Principles of ecosystem stewardship, Resilience-based natural resource management in a changing world, Springer.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Naeem, S., Limburg, K., Paruelo, J., O'Neill, R.V., Raskin, R., Sutton, P., van den Belt, M., (1997), The value of the world's ecosystem services and natural capital. Nature, 387, pp.253–260.

Diamond, J.M., (2004), Lessons from environmental collapses of past societies, Fourth annual John H. Chafee Memorial Lecture on Science and the Environment, January 29, 2004, National Council for Science and the Environment.

Diamond, J., (2005), Collapse, How societies choose to fail or survive, Penguin Books.

Eggertsson, T., (2005), Imperfect institutions, Possibilities and limits of reform, University of Michigan Press, US.

Folke, C., Chapin, F.S. III., Olsson, P., (2009), Transformations in ecosystem stewardship, as Chapter 5, pp.103-125, in Chapin, F.S. III, Kofinas, G.P., and Folke, C., (Eds), Principles of ecosystem stewardship, Resilience-based natural resource management in a changing world, Springer.

Frantzeskaki, N., Slinger, J.H., Vreugdenhil, H., and van Daalen, E., (2010), Social-ecological systems governance: from paradigm to management approach, Nature and Culture, Vol.5, No.1, Spring 2010, pp.84–98.

Galaz, V., Olsson, P., Hahn, T., Folke, C., Svedin, U., (2008), The problem of fit among biophysical systems, environmental and resource regimes, and broader governance systems: Insights and emerging challenges, Chapter 5, pp.147-186, in Young, O.R.,King, L.A., and Schroeder, H., (Eds), Institutions and environmental change, Principal findings, applications and research frontiers, The MIT Press.

Giddens, A., (1984), The constitution of society, Polity Press

Gutrich, J., et al., (2005), Science in the public process of ecosystem management: lessons from Hawaii, Southeast Asia, Africa and the US Mainland, Journal of environmental management, Vol.76, pp.197-209.

Hamouda, L., Hipel, K.W., Kilgour, D.M., The, J.L., (2004), Adaptive management of salmon aquaculture in British Columbia, IEEE International Conference on Systems, Man and Cybernetics, 10-13 October 2004, The Hague, The Netherlands, pp.5031-5037.

Hardin, G. (1968), The tragedy of the commons, Science, 162, No. 3859, pp.1243-1248.

Hajer, M.A., (2003), Policy without polity? Policy analysis and the institutional void, Policy Sciences, Vol.36, pp.175-195.

Hajer, M.A., and H. Wagenaar, (Eds) (2003), Deliberative policy analysis, Understanding governance in the network society, Cambridge University Press.

Healey, P., (2006), Collaborative planning, Shaping places in fragmented societies, 2nd Edition, Palgrave MacMillan.

Imperial, M.T., (1999), Institutional analysis and ecosystem-based management: The Institutional analysis and development framework, Environmental management, Vol.24, No.4, pp.449-465.

Knol, M., (2010), Scientific advice in integrated ocean management: The process towards the Barents Sea plan, Marine Policy, Vol.34, pp.252-260.

Kofinas, G.P., (2009), Adaptive co-management in social-ecological governance, as Chapter 4, pp.77-101, in Chapin, F.S. III, Kofinas, G.P., and Folke, C., (Eds), (2009), Principles of ecosystem stewardship, Resilience-based natural resource management in a changing world, Springer.

Lebel, L., J. M. Anderies, B. Campbell, C. Folke, S. Hatfield-Dodds, T. P. Hughes, Wilson, J., (2006), Governance and the capacity to manage resilience in regional social-ecological systems. Ecology and Society, Vol. 11, No.1 (www.ecologyandsociety.org/vol11/iss1/art19/).

Manuel-Navarrete, D., Gomez, J.J., Gallopin, G., (2007), Syndromes of sustainability of development for assessing the vulnerability of coupled human–environmental systems. The case of hydrometeorological disasters in Central America and the Caribbean, Global Environmental Change, Vol.17, pp.207–217.

Metzger, M.J., Leemans, R., Schroter, D., (2005), A multidisciplinary multi-scale framework for assessing vulnerabilities to global change, International Journal of Applied Earth Observation and Geoinformation, Vol.7, pp.253-267.

Olsson, P., Folke, C., Hahn, T., (2004), Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in Southern Sweden, Ecology and Society, Vol.9, No.4, (URL:http://www.ecologyandsociety.org/vol9/iss4/art2)

Olsson, P., Folke, C., Berkes, F., (2004), Adaptive co-management for building resilience in social-ecological systems, Environmental Management, Vol.34, No.1, pp.75-90.

Ostrom, E., (1990), Governing the commons: The evolution of institutions for collective action, Cambridge University Press, New York.

Pretty, J., and Ward, H., (2001), Social capital and the environment, World Development, Vol.29, No.2, pp.209-227.

Rammel, C., Stagl, S., Wilfing, H., (2007), Managing complex adaptive systems – A co-evolutionary perspective on natural resource management, Ecological Economics, Vol.63, pp.9-21.

Scott, J.C., (1998), Seeing like a state – How certain schemes to improve the human condition have failed, Yale University Press.

Steel, B., List, P.,Lach, D., Shindler, B.,(2004), The role of scientists in the enevironmental policy process: a case study from the American Wesr, Environmental science and policy, Vol.7, pp.1-13.

Turnhout, E., Hisschemoller, M., Eijsackers, H., (2008), Science in Wadden Sea policy: from accommodation to advocacy, Environemtnal Science and policy, Vol.11,pp. 227-239.

Vatn, A., (2009), An institutional analysis of methods for environmental appraisal, Ecological Economics, Vol.68, pp.2207-2215.

Voss, J.P., Smith, A., Grin, J., (2009), Designing long-term policy: rethinking transition management, Policy sciences, Vol.42, pp.275-302.

Young, O.R., (2008), Building regimes for socioecological systems: Institutional Diagnostics, as Chapter 4, pp.115-144, in Young, O.R.,King, L.A., and Schroeder, H., (Eds), Institutions and environmental change, Principal findings, applications and research frontiers, The MIT Press.

Young, O.R., King, L.A., Schroeder, H., (Eds) (2008), Institutions and environmental change, Principal findings, applications and research frontiers, The MIT Press.

Walker, B., and Meyers, J.A., (2004), Thresholds in ecological and social-ecological systems: a developing database, Ecology and Society, Vol.9, No.2, (www.ecology andsociety.org/vol9/iss2/art3).