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User-driven design of decision support systems for polycentric environmental resources management

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A B S T R A C T

Open and decentralized technologies such as the Internet provide increasing opportunities to create knowledge and deliver computer-based decision support for multiple types of users across scales. However, environmental decision support systems/tools (henceforth EDSS) are often strongly science-driven and assuming single types of decision makers, and hence poorly suited for more decentralized and polycentric decision making contexts. In such contexts, EDSS need to be tailored to meet diverse user requirements to ensure that it provides useful (relevant), usable (intuitive), and exchangeable (institutionally unobstructed) information for decision support for different types of actors. To address these issues, we present a participatory framework for designing EDSS that emphasizes a more complete understanding of the decision making structures and iterative design of the user interface. We illustrate the application of the framework through a case study within the context of water-stressed upstream/downstream communities in Lima, Peru.
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1. Introduction

1.1. *Technological advances for decision support in environmental resources management*

Developments in virtual technologies for data collection, processing, transmission, and visualisation provide an increasing opportunity to create and exchange data, information, and knowledge for decision support in environmental management (Beven et al., 2012). For clarity and consistency this article first establishes the terminological differences: "In computational systems **data** are the coded invariances. In human discourse data are that which is stated, for instance, by informants in an empirical study. **Information** is related to meaning or human intention. In computational systems information is the contents of databases, the web, etc. In human discourse systems information is the meaning of statements as they are intended by the speaker/writer and understood/misunderstood by the listener/reader. **Knowledge** is embodied in humans as the capacity to understand, explain and negotiate concepts, actions and intentions (Zins, 2007)".

The Internet in particular, allows for an unprecedented level of information-integration, providing the possibility to combine new and existing data and technologies (interoperability) and cope with growing resources and number of users (scalability) through the adoption of distributed systems (cloud computing). This evolution facilitates access to existing scientific and official datasets, for instance through standards such as the Open Geospatial

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Consortium's, Sensor Model Language, Sensor Web Enablement and Sensor Observation Service (Vitolo et al., 2015). It has also promoted non-conventional data generation activities, such as crowdsourcing, social networks, online surveys, unofficial data repositories, and citizen-science monitoring (Buytaert et al., 2014; Georgiadou et al., 2011). These sources may provide complementary information resources, particularly for data-scarce areas. Although some of the information may be affected by a higher level of uncertainty, their uptake within decision making processes is well-aligned with the principles of post-normal science (Funtowicz et al., 1992).

The exponential growth of these information sources and related technologies has implications for the way in which they are leveraged by environmental decision support systems (EDSS) to support growing public and private decision-making needs. Here, we define EDSS as computer-aided environmental information systems that support unstructured and semi-structured decision-making in environmental management contexts (McIntosh et al., 2011). The anatomy of these decision support systems typically contains three components: (1) databases, (2) analytical processing algorithms (e.g. environmental models), and (3) a user interface. The latter allows users (i.e. the decision makers) to interact with the information but typically hides the technological complexities.

1.2. Environmental decision support systems in a polycentric governance context

The diversification of information sources and availability implies their democratisation for decision support across multiple governance actors and scales (Buytaert et al., 2016). The idea of information democratisation has gained particular significance as part of debates on re-positioning the role of science in society through transdisciplinary processes of engagement with science and stronger involvement of citizens (Scott and Gibbons, 2001; Nowotny, 2005). However, in reality, EDSS solutions continue to be strongly single-actor oriented and science-driven (first versus second generation “Environmental Virtual Observatories” in (Karpouzoglou et al., 2016a)). As such, they are more closely aligned with monocentric (centralised) and technocratic governance structures that are incompatible with high institutional and geographical diversity (Lankford and Hepworth, 2010). The availability and access to information (Ransbotham, 2015) and environmental decision support for the wider range of actors involved remain impeded by lack of understanding of institutional, cultural, and geographical differences. As a result, there is risk that environmental governance processes can become dominated by the better-educated or politically-connected. Political science scholarship highlights that the chances of a particular policy option being adopted in an environmental governance context may largely be determined by the extent to which powerful actors see that option as meeting their interests and/or values (Underdal, 2010).

This has implications for how we conceive of power relations in the context of monocentric and polycentric governance arrangements. The classic monocentric approach ultimately assumes highly centralised forms of power (often concentrated around the State). However, the polycentric governance model attempts to capture and describe a more distributed model of power which makes more explicit linkages with local actors, everyday resource management practices, informal institutions and indigenous knowledge systems (Pahl-Wostl, 2009; Lankford and Hepworth, 2010; Underdal, 2010; Boelens et al., 2015). A polycentric institutional arrangement has been defined as “a mosaic of nested sub-units” of decision making rather than a fully integrated, hierarchical whole (Lankford and Hepworth, 2010). It recognizes a high degree of heterogeneity over a large geographic domain in the production and consumption of public goods (environmental resources) as well as policy preferences (Ostrom, 2009). Such a model is more supportive of bottom-up approaches to decision making that improves the voice of the public in matters that impact them directly (Arnstein, 1969; International Association for Public Participation, 2002; Irvin and Stansbury, 2004) and can ultimately enhance the ability to cope better with change and uncertainty (Ostrom et al., 1961; Huitema et al., 2009; Huntjens et al., 2012).

The polycentric model has gained significance in adaptive governance scholarship, for example, as part of addressing more explicitly the interaction between actors operating at different levels of governance but who may have different and overlapping spheres of responsibility in terms of policy and management (Folke et al., 2005). Adaptive governance brings emphasis on integrating ecosystem dynamics with management structures, fostering experimentation in policy design as well as anticipating surprise as a tool for learning (Gunderson et al, 1999; Karpouzoglou et al., 2016b). In the discussion of polycentricity and adaptive governance, the links with information management are still less well developed as compared to the understanding of institutional interaction (Lebel et al., 2006; Buytaert et al., 2016). In this article we therefore propose polycentricity as a useful concept for strengthening the understanding of both data and institutional diversity and how this understanding may inform a new approach to EDSS (Table 1).

Table 1
Types of knowledge and areas of knowledge with high potential for decision support, adapted from (International Institute for Environment and Development, 2014).

Type of knowledge	Description	Example	EDSS potential	Target users
Tacit knowledge	Knowledge that the knowledge holder is not aware of and is expressed through experience	Peer-peer exchanges; radio; tv; mobile messaging (text, voice, multimedia)	High potential (but underutilised despite opportunities to address local scale management goals)	Small scale or subsistence farmers, pastoralists, governmental officers, NGO workers
Indigenous, traditional knowledge	Local knowledge unique to a culture or society that is passed down in communities	Oral community histories	Intermediate potential (but difficult to operationalise)	Communities of elders, village councils, community religious and spiritual leaders
Participatory, citizens science knowledge	Knowledge held by citizens based on their daily lives	Citizens perceptions of climate change impacts, citizen monitoring	High potential (some utilisation but orientated towards scientific data harvesting)	Small scale farmers, agro-pastoralists, citizen science volunteers
Project/ programme knowledge	Generated from implementation of a programme or development project	Project briefings; online databases	High potential (some utilisation, easier to codify and integrate?)	Development programme administrators; international donors; NGOs, politicians, bureaucrats
Research knowledge	Acquired through scientific investigation	Empirical data; published literature;	High potential (over utilised but little spread outside scientific communities)	Scientists; scientific knowledge brokers; Policy makers

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