The Danube Delta Biosphere Reserve: a Case Study for Qualitative Modeling of Sustainable Development

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Abstract

We present progress towards developing a qualitative reasoning model of sustainable development issues in the Danube Delta Biosphere Reserve (DDBR), Romania, following a standardized methodology for conceptual description of QR case studies. Using the QR ontology, we have organized our expert knowledge about negative effects of water pollution on aquatic biota (especially on fish) and human health (those people living in and around the DDBR). We present essential background about the model system, organization of this knowledge into knowledge structures that will drive our QR model, and define causal dependencies that will be implemented in the QR modeling workbench, Garp3. The new methodology was very helpful in structuring the model-building effort. This structure will aid the task of comparing and re-combining QR case studies of sustainability issues in the future.

Introduction

To meet the objectives of the European Union's Strategy for Sustainable Development (SSD) that call for increasing participation in the process of making decisions that affect sustainable development (SD), stakeholders, decision makers, and citizens must gain a better understanding the factors that affect SD (European Commission 2001). SD is broadly defined as "a real increase in well-being and standard of life for the average person that can be maintained over the long-term without degrading the environment or compromising the ability of future generations to meet their own needs" (Brundtland and the World Commission on Environment and Development 1987, Cunningham and Cunningham 2005).

Part of the NaturNet-Redime project involves developing qualitative reasoning (QR) models of five case studies that explore different SD issues and scenarios, in order to support these objectives of the SSD. The goal is to represent SD problems (Nuttle and Salles 2005) from different systems and perspectives and build an online curriculum about SD that focuses on user interaction with QR models.

Both to support the model building effort as well as to facilitate integration of the different models, Bredeweg et al (2005; this volume) developed a "structured approach to qualitative modeling. Researchers from three case studies, the Danube Delta Biosphere Reserve (DDBR, this paper), Riacho Fundo (Salles and Rios Caldas, this volume), and River Mesta (Uzunov et al., this volume) have been following this methodology (Nuttle et al. 2006) and the other two case studies (one in England, the other in Austria) are forthcoming.

The goal of this paper is to describe progress in following the methodology for the DDBR, including a description of the model system, model goals, and model specifications. We also provide a critique on the effectiveness of the methodology framework for supporting development of QR models by novice QR model builders and discuss conclusions and perspectives for future work.

Model System

The DDBR, located at the mouth of the Danube River before it reaches the Black Sea, has been designated as a World Heritage Site and Wetland of International Importance since 1990 (according to The Convention on Wetlands, signed in Ramsar, Iran, in 1971).

The DDBR's status as a biosphere reserve dictates that all social and economic actions must fall in line with biodiversity conservation and protection measures. Thus, the most appropriate concept of sustainable development for DDBR can be expressed by development through biodiversity, where all flora and fauna are conserved both to meet obligations of international conventions, but also to serve as natural resources for social and economic development of the region.

Stakeholder Issues

Scientists from DDNI met with local stakeholders to determine threats to conserve and develop these resources within the DDBR.

There have been identified the following threats:

- Decline in biodiversity (Otel and Ciocarlan 2000) over the last several decades
- Contamination of water and fish from pollutants
- Concern about contamination in humans
- Reduction of fish diversity and abundance.

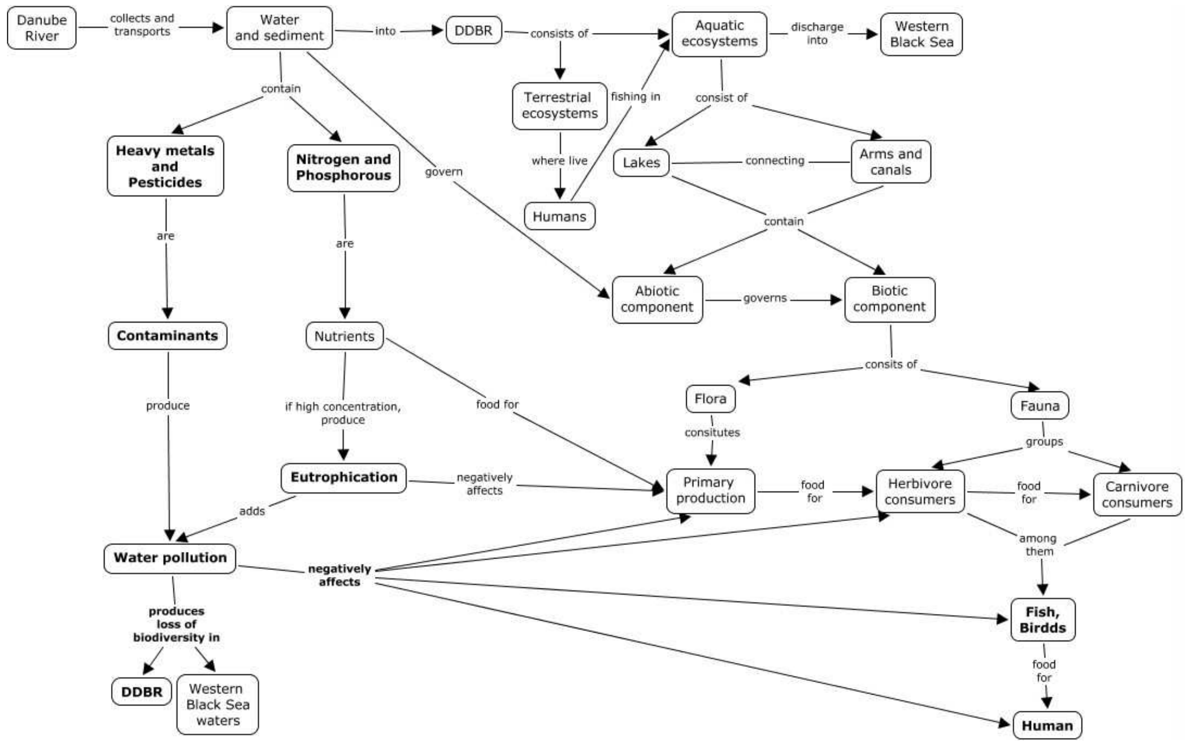

Figure 1. Concept map for Danube Delta Biosphere Reserve water pollution – the negative effect on DDBR biodiversity and human health.

Contaminants come in basically two forms: heavy nutrient loads from agricultural fertilizers and heavy metals from industry. In both cases, most of the pollutants originate from far upstream in the vast Danube River catchment. Heavy nutrient loads lead to algal blooms, which can result in toxic by-products form algae as well as depletion of oxygen in the water when algae die and are degraded by bacteria (Oosterberg et al. 2000). This can cause die-offs in fish. Heavy metals in the DDBR waters threaten human populations in two ways, first from direct consumption because many people drink untreated water directly form DDBR waterways, and second from consumption of fish which bioaccumulate heavy metals (Otchere 2003; Wachs 2000) in their muscle tissues.

Main Model Goals

Contamination by pollutants is at the root of most of DDBR's threats to SD. Furthermore, in order to understand indirect as well as direct effects of pollutants on humans, their effects on other ecosystem components, like fish, must also be understood. Thus, the DDBR model will describe the aquatic ecosystems behavior governed by water pollution rate and the ways it propagates to aquatic organisms and to humans living in or around DDBR. The main goal of the DDBR model is:

To create a knowledge structure that captures connections between water pollution in the Danube River catchments basin and health of human population living in and around the DDBR.

The model will be used to explain and educate DDBR and environment agency representatives, decision makers, and stakeholders about the working of processes within the Danube River and their influence on these processes. The model will furthermore be used for argumentation purposes to convince decision makers what kind of actions they should take in order to improve (or stop) the Danube River water pollution process, thereby improving the quality of life within DDBR.

DDBR Concept Map

We begin with a concept map that helps identify, clarify, and focus our knowledge about the system of interest (Figure 1). The model for the DDBR case study should capture the most relevant problems mentioned by the stakeholders, as reflected in the model goals. Hence, the concept map stresses effects of water pollution process on the aquatic biological components and human health for people living inside or around the DDBR.

System Selection and Structural Model

The full structural model of the DDBR is shown in Figure 2. It depicts a broader perspective on the entities and relations between them in the DDBR. The subsets of entities that are relevant to the model goal specified above are shown in **bold** in Figure 2. The main system entities to be included in QR are thus model ***Water***, ***Fish***, and ***Human***. They can be related to each other by the following configurations:

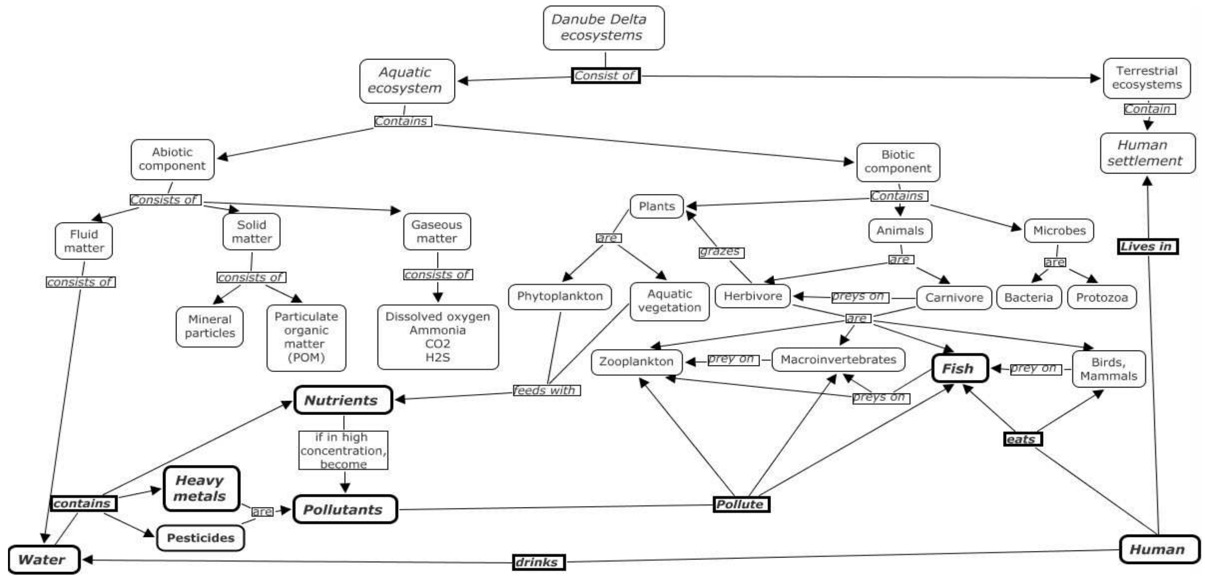

Figure 2. Structural model of the Danube Delta Biosphere Reserve aquatic ecosystems (Note: The structural entity hierarchy related directly to water pollution is represented in **bold**).

- Fish ***lives in*** Water;
- Human ***eats*** Fish
- Human ***drinks*** Water
- Human ***catches*** Fish.

Global Behavior

There are seven main processes influencing behavior of humans and each aquatic organism group within the DDBR:

- water flow
- water eutrophycation
- phytoplankton bloom (overgrowth of algae)
- bottom sediment resuspension
- water pollution
- fish growth
- human disease incidence

In total, 12 processes are active in the DDBR aquatic environment that influences the abundance of each organism group. Changes in these abundances propagate to other quantities that affect other organism groups. These causal dependencies (Influence: I+/I- or Proportionality: P+/P-) for the aquatic system of the DDBR are presented in Figure 3.

From these causal relations, the ones related ***strictly to water pollution process*** and its direct / indirect effect both on aquatic biotic components and on humans, are selected in constructing the DDBR QR model.

Detailed System Structure

The purpose of this section is to transform the graphical and textual descriptions described above into the more explicit terminology of the Garp3 QR modeling workbench. This includes organizing the ideas just described into scenarios, model fragments, agents, assumptions, etc., to facilitate their implementation in Garp3. Description of all model components can be found in the complete model documentation (see acknowledgements).

Scenarios

Scenarios present initial situations, including the configuration of the system of interest and starting values for quantities. We specify three scenarios to describe the ways DDBR aquatic ecosystem *Water pollution rate* propagates and induces direct changes on *Fish population* behavior and both direct and indirect changes on *Human* behavior:

1. *Water pollution rate* direct impacts on *Fish* behavior and *Human health*. This scenario pertains both to the configuration Fish *lives in* Water and Human *drinks* Water (refers to those people who take water directly from the DDBR canals/lakes).
2. *Water pollution rate* indirect impact on *Human health*. This scenario pertains to the configuration Human *eats* Fish.
3. *Water pollution rate* indirect impact on *Human social behavior*. This scenario pertains to the configuration Human *catches* Fish (as for most DDBR people fishing is their main job).

Model Fragments

Model fragments emphasize the causality conditions which have been generating loss of DDBR biodiversity, decline of some flora and fauna species, modification of community structure, risk to human health, etc, to delimit those objectives for sustainable use of natural resources.

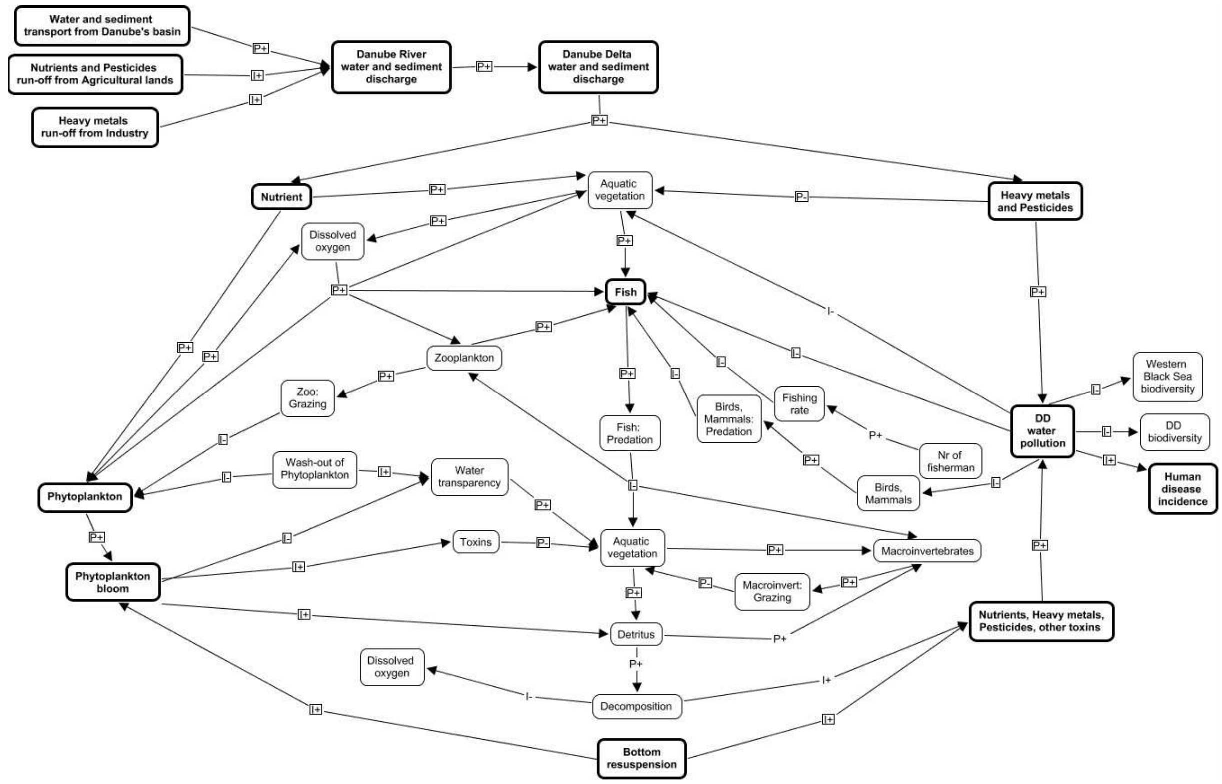

Figure 3. Global Causal model for Danube Delta Biosphere Reserve aquatic ecosystems water pollution.

We describe two types of model fragments: static and process. Later, "agent" model fragments will be added that control such factors as pollution input to the system. Some examples are presented here.

Static model fragments. The static model fragments will describe the *Water*, the *Fish* and *the Human* which along with the associated quantities *Heavy metals* and *Nutrients* constitute the conditions of the model fragments.

As consequences, the quantities for Human: *Disease incidence*; *Life quality*, *Fish*: *Fish population size*, and *Water*: *Water pollution rate* are added.

Process model fragments. The model fragments for the basic processes described refer to Water pollution process, Fish pollution process, Water use by human, Consumption rate of fish by people, Human disease incidence, Human Employment, Human development, presented here. These model fragments specify mainly the consequences of occurrence of the configuration between entities described above (e.g., fish *lives in* water, human *catches* fish).

Critique of Structured Methodology

The structured methodology (Bredeweg et al. 2005) greatly facilitated organization and explication of the large amount of expert knowledge and data available for the DDBR into a form that can be utilized to build a QR model using Garp3 (Bredeweg et al. 2006).

For the most part, the examples of different steps provided in the methodology were very helpful in completing the modeling tasks for the DDBR case study. Nevertheless, the methodology could be improved with more consistent use of examples. Sometimes the examples did not seem to match the actual specifications of what to do. There were two sources of this problem: missing content in the examples and missing content in the methodology itself. Where content was missing in the examples, it was sometimes difficult to figure out how to implement the ideas described in the methodology. This resulted sometimes in unclear representation of ideas and differences between case studies that made their comparison more cumbersome than anticipated.

Finally, evaluation of progress in following the steps in the methodology framework and comparison of the different case studies was sometimes hampered because it was sometimes difficult to make the connection between steps in the process, particularly between the processes (specified in the text under **Global behavior**), causal model (Figure 2) and description of model fragments (Cioaca et al. 2006). We recommend modifications of the methodology to make the connection between earlier and later steps more transparent.

Conclusions

With the help of the "structured approach to qualitative modeling" described by Bredeweg et al (2005, this volume), we have made significant progress in developing a QR model that supports reasoning about SD issues of relevance to stakeholders in the DDBR. Implementation of the specifications described in this paper is currently underway using the QR modeling and simulation workbench, Garp3 (Bredeweg et al. 2006). During the implementation phase, essential issues will become even clearer and important details will be worked out. Such issues include describing behavior under different degrees pollution (examining threshold effects, for example) and feedbacks on how water pollution affects humans (e.g., via health, quality of life) depending on water and fish as their life resources. Implementation will also involve optimizing the model to both capture important and insightful system behavior while at the same time managing non-insightful ambiguity that results from uncertainty in relative magnitudes competing influences on quantities. This optimization will involve use of appropriate quantity spaces and constraints on allowable interpretations (e.g., quantity space correspondences).

Once the model is implemented and functioning to the extent that it satisfies the main model goal, it will be integrated into our online QR curriculum so that end users can use it to investigate SD both within the DDBR and in its broader context. Future submissions will further describe the fully implemented model and its use by stakeholders to learn about SD.

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