Integrating Natural and Social Science Knowledge in a Decision Support System for Coastal Zone Management

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Abstract: Decision-makers and scientists in the field of coastal-zone management show a growing interest for integrated system models in which ecological, economic and physical processes can be combined. RaMCo (Rapid Assessment Module for Coastal zone management) is a prototype decision-support system designed for the coastal zone of Southwest Sulawesi, Indonesia. The model runs on a PC and can be used to study the long-term impacts of different management measures, such as the construction of a storage lake or investments in tourism. Different scenarios for demographic, economic, and hydrological conditions can be introduced. The model is based on a multidisciplinary research program in economics, geography, cultural anthropology, fisheries science, oceanography, marine biology, and systems science. The central aim was to provide decision makers with a theoretical framework for the comparison of different management strategies and examine the problems and potential solutions for the simultaneous application of natural and social science concepts. The paper discusses a number of problems encountered when social science concepts are to be integrated in a quantitative systems framework and the way these were dealt with in the design of RaMCo.

Keywords: Decision support systems; Coastal zone management; Integrated assessment; Systems analysis; Indonesia

1. INTRODUCTION

The aim of WOTRO (Netherlands Foundation for the Advancement of Tropical Research) research program W.01.60 was to develop a scientific methodology to support coastal zone management in the tropics. The coastal zone of Southwest Sulawesi (Indonesia) was selected as the study area. The region comprises a mainland shore and a 40 km broad shelf, in which a multitude of coral reefs can be found. Four ecological coral zones parallel to the coast have been identified. The outer shelf reefs are most exposed to storm-generated waves, whereas the reefs on the inner shelf are predominantly influenced by land-based processes. The main city in the region, Ujung Pandang, has a fast-growing population consisting of over one million inhabitants. Fisheries and reef exploitation are the main source of income on the islands of the Spermonde archipelago. Along the coast brackish-water shrimp ponds are used to cultivate fish, prawns and seaweed. The river delta is dominated by irrigated rice fields. Upstream the soil is used for dry-field agriculture based on crops such as corn, sweet potatoes and cassava. The city of Ujung Pandang provides the main source of non-rural employment in the region and exerts a major attractive force on the working population of the rural areas.

During the project the RaMCo model [Uljee et al., 1996] was developed to assess the impacts of land- and sea-based human activities on the marine environment. The model served as a tool for the comparison of management strategies, and discussion among scientists and decision makers. A problem-based approach starting with the local authorities of the planning board Bappeda was followed for the design. Typically, a simulation run describes the development of the coastal-zone system over a period of 25 years with time steps of a month. Spatial changes in, for example, land use and the condition of marine ecosystems are shown on a grid of 400 m. Model users can study the short- and long-term consequences of actions such as the construction of a storage lake or investments in industry under different hydrological, demographic, and economic scenarios. The model is available on the internet at *http://www.riks.nl.*

Due to the integrated nature of RaMCo natural and social science concepts had to be combined in a joint framework of analysis. From the beginning of the design three interrelated problems became apparent: the existence of multiple scales of processes and process models, the interface of qualitative and quantitative concepts, and the uncertainty inherent to human behavior. Two case examples taken from the model, urbanization and marine fisheries, will illustrate how these were dealt with.

2. FRAMEWORK OF ANALYSIS

The relationship between management objectives, measures and scenarios is shown in Figure 1, which gives a conceptual description of the RaMCo system.

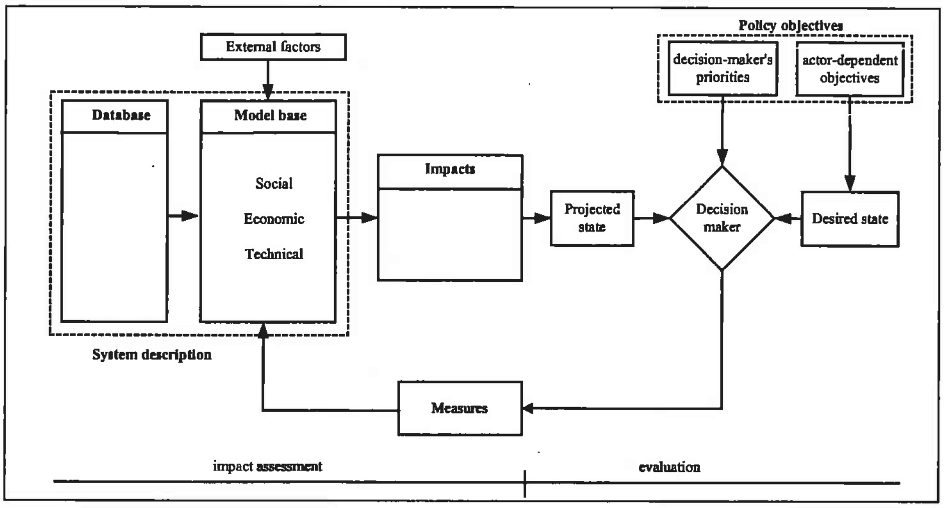

Figure 1. Framework for policy analysis [Wind, 1988].

In the initial phase of the design the decision was made to distinguish between the tasks of natural and social sciences by giving the former the responsibility of describing the impacts on the environment, while the underlying causes were examined by the social scientists.

The RaMCo model is organized around a system dynamics model with quantitative submodels for economic, ecological and physical processes. Scenarios account for uncertain social and natural factors that drive the system (Figure 2). For the hydrological conditions, market prices, and the population growth rate these scenarios are quantitative. Processes which are too difficult to describe in mathematical terms are included as qualitative scenarios. In RaMCo two case examples, urbanization and marine fishing effort, have been worked out. The problem of how to incorporate these qualitative scenarios in a quantitative simulation model will be further discussed in section 3.

The user of the model can influence the system by measures at different levels, combined with a selection of scenarios. During a simulation run the spatial and temporal dynamics of ecological state variables (for example the condition of coral reefs and fish stocks), economic state variables (for example the production value of different agricultural and non-agricultural sectors) and resource state variables (for example the per capita water and rice supply) are presented to the model users. It is emphasized that these results are quantitative but should not be regarded as a prediction of the future state of the coastal-zone system, and are only to be interpreted as qualitative indications to "what-if?" questions.

Although the framework of Figure 2 was useful to deal with the predictability problem inherent to social processes and the integration of qualitative and quantitative model concepts it is not a solution to the third problem mentioned, that of scale differences. In general social scientists distinguish between the micro-scale patterns and macro-scale patterns. Examples of micro-scale patterns are the decisions taken by individual fishermen or shopkeepers. These have to be consistent with the macro-scale patterns used in RaMCo. Usually concepts and data are collected at this micro-scale level while secondary data such as statistics are used to gain understanding of the macro-scale dynamics. In the project the results at the micro-scale research were used to validate the concepts that had been formulated for the macro-scale dynamics of urbanization and marine fisheries.

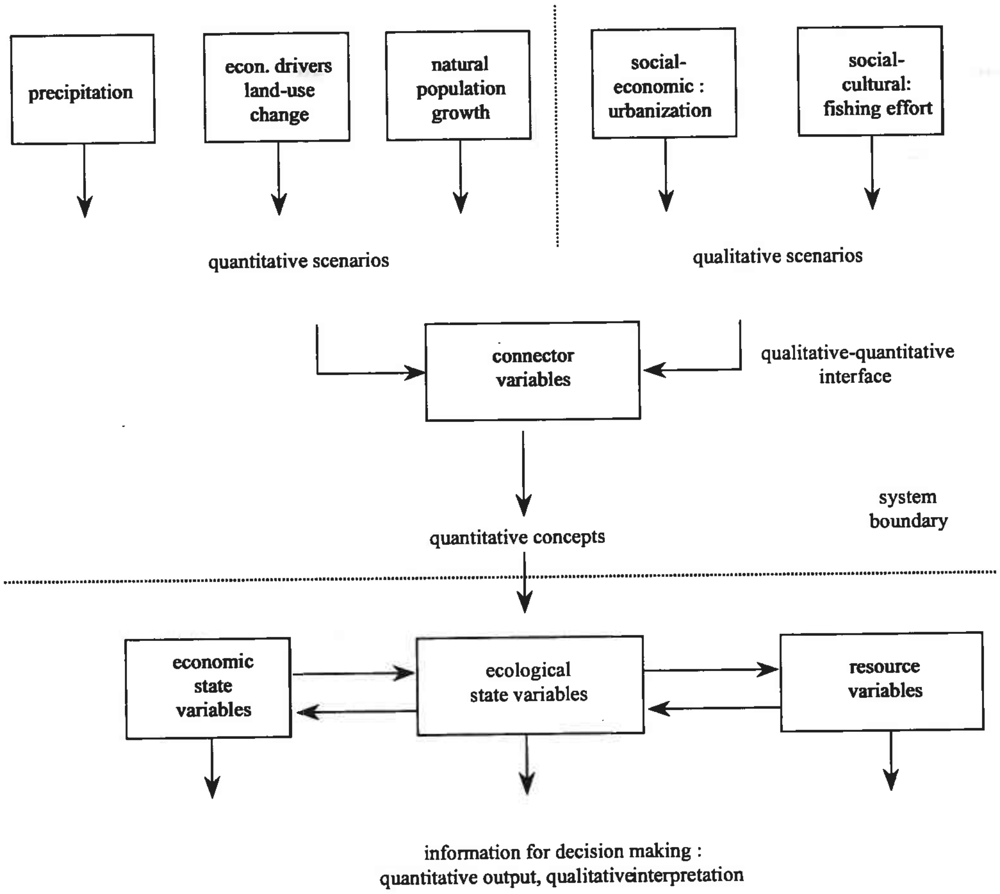

Figure 2. The scenario-driven approach of RaMCo with qualitative-quantitative interface.

3. INTEGRATION OF SOCIAL PROCESSES

Several problems are encountered when one attempts to formulate mathematical models for social processes. The driving variables can be hard or impossible to identify, difficult to measure even on a qualitative scale, and the limitation of variables required in most practical system designs can be unacceptable in view of the observed complexity. To overcome the objections made by the social scientists two techniques were applied in the design of RaMCo. In the case of urbanization fuzzy sets were used [de Kok et al., 2000] to translate three qualitative scenarios for the urbanization of Ujung Pandang into a quantitative value for the migration rate (Figure 3). The scenarios differ in the macro-economic conditions that prevail, and the way the urban authorities intervene in the urbanization process, for example by prohibiting informal sector activities and the destruction of slum areas. Each scenario describes how these social-economic and institutional factors influence the future migration rate. An interesting result was the trend breach observed for one of the scenarios.

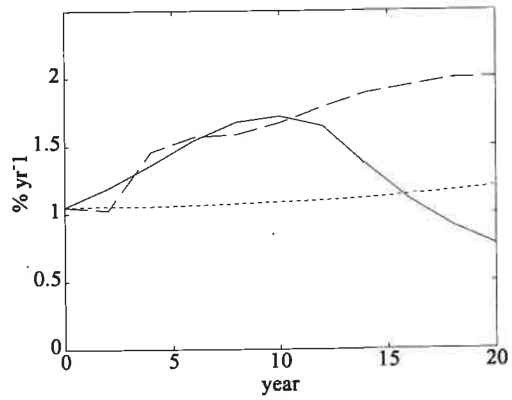

Figure 3. Migration scenarios for Ujung Pandang in RaMCO: urban biased (solid), sustainable (dotted), and increasing urban-rural inequality (dashed).

Fuzzy sets still require quantitative estimates for variables, and a limitation of variables for practical reasons. Therefore, the cultural anthropologists considered this method less suitable to describe the complexity of marine fisheries along the coast. In this case a qualitative model or cognitive map [Kosko, 1986] was used to describe the influence of key determinants on the connector variable, the fishing effort (Figure 4). The aim was to describe possible shifts between small-scale, traditional fisheries (category A-C) and large-scale intensive fisheries (category D) with powered vessels and crews of 5-10 fishermen.

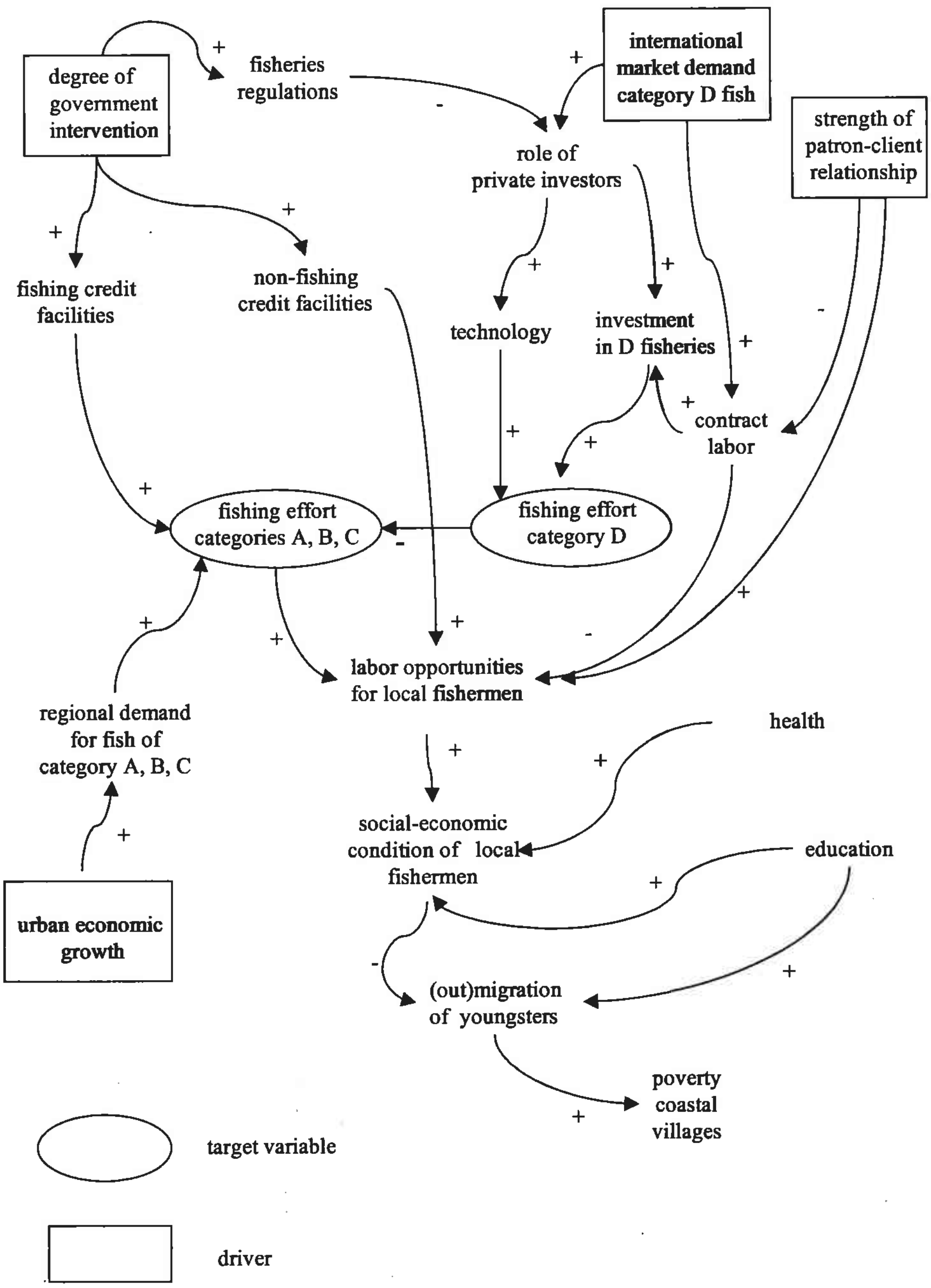

Figure 4. Cognitive map for marine fisheries in Southwest Sulawesi.

The causal influences of the cognitive map are represented by a matrix F_{ij} operating on the state variables S_i each time step t:

$$S_i(t+1) = \sum_{ij} F_{ij} S_j(t) \qquad (1)$$

where i and j refer to the system variables with interaction F_{ij}. Finally, the results are mapped onto the domain for the fishing effort. Figure 5 shows the results for three scenarios. The drop in the effort for the intensification scenario is a consequence of a shift from traditional, small-scale fisheries to large-scale fisheries using powered vessels. The values of Figure 5 are used

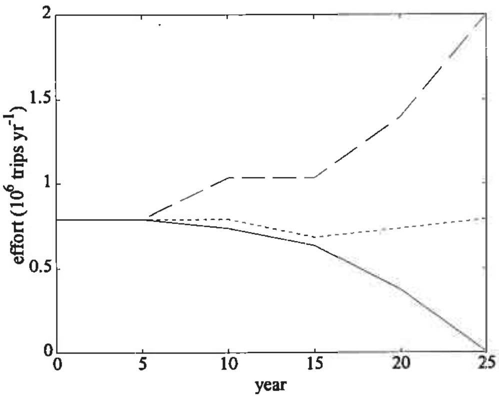

Figure 5. Long-term development of effort in small-scale fisheries for three scenarios: intensification (solid), intermediate (dotted), and extensification (dashed).

in a statistical model for the relationship between catch and effort. Changes in the catch-per-unit-effort can then be used to identify potential overfishing in the future under a given management strategy.

4. DISCUSSION

The experience gained with the design of RaMCo is that social science concepts can be applied in decision-support systems provided one allows sufficiently for qualitative and descriptive models as well. Several techniques are available to integrate these with quantitative models in the system, and this is not a fundamental obstacle for the design.

At the moment the validation of the integrated RaMCo system phase is in a stage of preparation. The behavior of the integrated system will be validated in two ways. Test data for recent changes in the state of the coastal zone will be collected and compared with the model results where possible. An example is the validation of the land-use model using remote sensing data.

Obviously the model allows for many combinations of measures and scenarios that will never occur in reality. To validate the behavior of RaMCo under these hypothetical conditions the designers and social scientists will formulate a number of qualitative test hypotheses. This raises the fundamental question to what extent one can validate an integrated system model. In principle this validation can only take place at the level of submodels. After its conclusion the behavior of the system as a whole can be examined to identify critical aspects such as thresholds, and unstable dynamics.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

de Kok, J.L., M. Titus, and H.G. Wind, Application of fuzzy sets and cognitive maps to incorporate social science scenarios in integrated assessment models, A case study of urbanization in Ujung Pandang, Indonesia, *Integrated Assessment,* 1(3), 177-188, 2000.

Kosko, B., Fuzzy Cognitive Maps, *International Journal of Man-Machine Studies*, 24: 65-75, 1986.

Uljee I., G. Engelen and R. White, RamCo Demo Guide, Workdocument CZM-C 96.08, Coastal Zone Management Centre, National Institute for Coastal and Marine Management, P.O. Box 20907, 2500 EX The Hague, the Netherlands, 1996.

Wind, H.G., Civieltechnisch management, Een samenspel tussen bedrijfskunde, bestuurskunde, en civiele techniek, Inaugural Lecture, University of Twente, Enschede, The Netherlands (in Dutch), 1988.