FUZZY LOGIC AS A METHOD FOR THE APPLICATION OF QUALITATIVE CONCEPTS IN A QUANTITATIVE SYSTEM FRAMEWORK

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1. INTRODUCTION

The central aim of the ongoing research program [1] is to develop a methodology for sustainable coastal-zone management in the tropics. The project is based on a multidisciplinary cooperation in the fields of economics, geography, anthropology, fisheries science, oceanography, and marine biology. A System Dynamics approach is followed for the management research in order to deal with the dynamic nature of the coastal-zone processes and cross-sectoral linkages. The integrated system model will serve to evaluate and rank different management strategies. The disciplinary models are based on quantitative as well as qualitative concepts. The integration of the latter in a quantitative system framework forms a particular problem related to integrated system modeling. In this paper we will show how fuzzy logic may be applied to include qualitative concepts in a quantitative simulation model .

Coral reefs are assumed to play an essential role in the abundance and diversity of associated fish species. Data have been collected on the structural complexity of the coral reef, the relative coverage with living coral, and the number and species diversity of the associated species of reef fish [2]. By means of example we will consider the combined influence of reef complexity and live coral coverage on the diversity of reef fish. Qualitative knowledge on the relationship studied is stored explicitly in the form of the fuzzy membership functions and the qualitative inference rules. The outcomes are compared with the results obtained with a multivariate linear regression analysis. Rather than to obtain the best possible description of the data the intention of this paper is to show how qualitative concepts can be incorporated in simulation models.

2. METHODOLOGY

The reef complexity is measured by underwater observations along line transects. Depending on the degree of complexity a numerical value within the range of 1.0 to 17.0 is assigned to the different life forms observed, such as sand, branching coral, sponges, and algae [2] . Sampling is based on 100 m. transects. The live coral coverage (LCC) is defined as the ratio of line intercept to the total length of the transect. Simultaneously, the total number of fish and the number of fish categories are estimated. The data set analyzed here comprises 47 sample values for the reef complexity, the live coral coverage, and the total number of fish present .

Prior to analysis the data are transformed to a normal distribution according to the linear mapping $x_i \rightarrow \left(x_i - \mu\right) / \sigma$, where and are the sample average and standard deviation respectively. The membership function parameters are determined using the ANFIS routine provided by the Matlab package [3], which combines a Sugeno type fuzzy inference system with an adaptive neural backpropagation learning algorithm [4]. For the reef complexity we use a Gaussian type membership function $\mu(x) = \exp(-(x-c)^2 / 2\sigma^2)$, for the LCC we use a trapezoidal membership function: $\mu(x,a,b) = \max[\min(\frac{x-a}{b-a},1,\frac{d-x}{d-c}),0]$. Consistent with linear Sugeno inference the crisp output value for variable y is calculated directly as the linear combination of the fuzzy values of the two numerical input variables x1 and x2:

*IF (x1 = "value 1") AND (x2 = "value 2") THEN (y = p*x1 + q*x2 + r)*

First the antecedent degree of membership ${}_r$ is calculated for each rule *r*, then the numerical output value is computed as the weighted sum over the rule antecedents [5]:

$$y_{Sugeno} = \sum_r \mu_r \times (px_1 + qx_2 + r) \Big/ \sum_r \mu_r$$

By means of example the qualitative inference rules are defined as:

1. IF (LCC = poor) OR (complexity = low) THEN (number fish = low)

2. IF (LCC = fair) AND (complexity = normal) THEN (number fish = medium)

3. IF (LCC = good) AND (complexity = high) THEN (number fish = high)

In principle nine inference rules are possible. Thus, each of the two input variables and the single output variable can have three fuzzy values. The logical AND operation is performed according to the product rule $\mu_{AND} = \mu_1 \times \mu_2$. The OR operation is performed according to the probabilistic rule [5] $\mu_{OR} = \mu_1 + \mu_2 - \mu_1 \times \mu_2$. In total 27 parameters are used by the ANFIS routine. For comparison a multiple linear regression analysis (MLR) was performed, using the reef complexity and live coral coverage as independents.

3. RESULTS

The ANFIS routine resulted in $\chi^2_{tot}/ N_{data} \approx 1.7 \times 10^2$ whereas the MLR resulted in $\chi^2_{tot}/ N_{data} \approx 3.8 \times 10^2$. For further comparison the residual values for both methods are shown in Figure 1. The membership functions obtained for the input variables with the ANFIS routine are shown in Figure 2.

4. DISCUSSION

As expected for highly correlated input variables the ANFIS routine performs better than the linear regression analysis. On the other hand only three parameters are used for the linear regression, compared to the 27 parameters for ANFIS. The main advantage of the fuzzy approach however, is that the qualitative model concepts are explicitly available in the form of

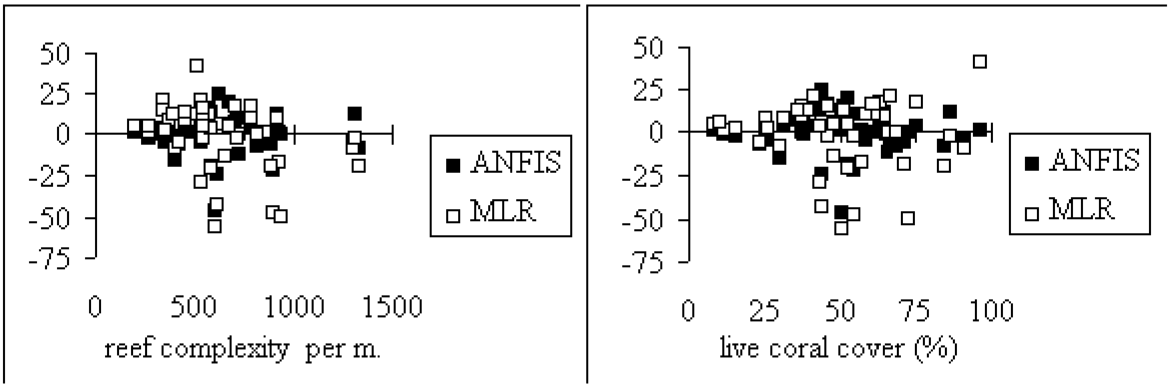

Figure 1. Residual plots for ANFIS and MLR predictions of reef complexity and live coral cover.

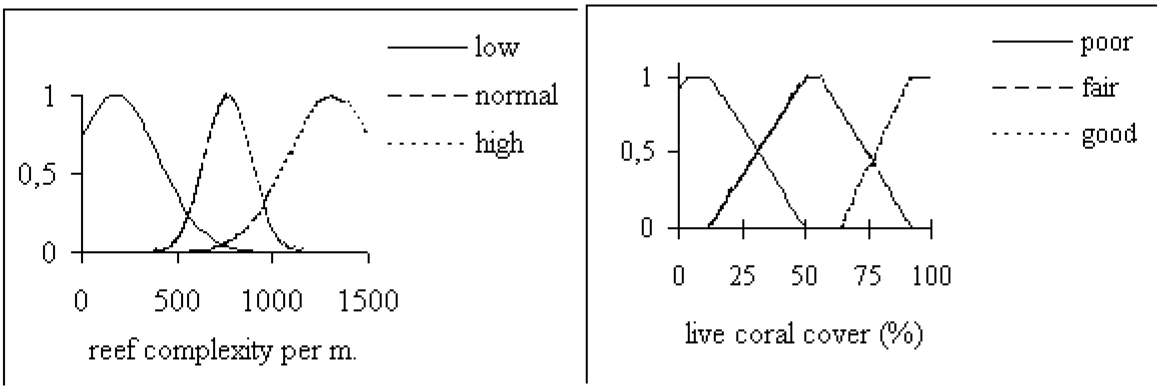

Figure 2. Membership functions obtained with ANFIS for the reef complexity and live coral cover.

the inference rules and membership functions. As pointed out by Tessem and Davidsen [6] fuzzy set theory may prove to be a useful alternative for conventional methods to incorporate qualitative concepts in simulation models, such as the table functions now provided by simulation tools. Conditions in favor of the applying fuzzy logic are: qualitative expert knowledge, dependency of input variables, non-linearity of relationships, and the absence of mathematical models.

5. REFERENCES

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