Predictive modeling of biodiversity – a case study of a second order Carpathian River

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Introduction

Biodiversity is important to quantify the degree of internal regulation (homeostasis) and the carrying capacity of lotic ecosystems. Mathematical models can be used to reveal biodiversity-biotope relations and to predict the evolution of these systems.

We present a case study of the Cibin River, a second order tributary of the Danube in Transylvania, in the centre of Romania. Cibin River originates in the glacial lakes of the Cindrel Mountains (1920 m a.s.l.) in the Carpathians, has a length of 82 km and a catchment of 2210 km^2 (Posea et al. 1982). The river features various biotopes and is subject to many human impacts such as hydro-technical works, pollution sources, overexcavation of river bed gravel, and exploitation of riparian land (Curtean-Bănăduc & Bănăduc 2001). Scientific data exist since 1851 (Curtean-Bănăduc 2005).

Methods

During 1999–2004, quantitative samples of benthic macro-invertebrates were taken monthly, in the period March–November, at nine stations. In addition, biotope characteristics were evaluated (slope, substrate type, mean water flow, and physico-chemical parameters: temperature, pH, mineralization of organic matter (RF), total hardness (TH), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD-Mn), Cl^-, SO_4^{2-}, NO_3^-, total N, PO_4^{3-}, total P, Pb, Zn, Cu, Cd, and Mn). The sampling stations were chosen according to the valley morphology, the confluence of main tributaries, and type and degree of human impacts.

At each station, numerous samplings at different sites and substrates were carried out to cover the diversity of habitats. A total number of 1404 quantitative samples were analyzed.

Correlation and regression analysis were used to show the variation in diversity of benthic macro-invertebrates (expressed through biodiversity indices of Margalef – MA, Menhinick – ME, Simpson – SIM, Shannon-Wiener – H and equitability – €) related to the variation in biotope indicators.

Results and discussion

In Cibin River, 107 macro-invertebrate species belonging to 67 genera, 39 families, 16 orders, 10 classes and 6 phyla were identified. Caddis flies (Trichoptera), stoneflies (Plecoptera), mayflies (Ephemeroptera) and dragonflies (Odonata) were more abundant in the mountainous river sector, where the water has a high flow velocity, stony substrates predominate, and pollution is insignificant. Midges (Chironomidae) and worms (Oligochaeta) showed higher species numbers in the middle and lower course of the river, where the slope and flow velocity are low and the trophic supply (water richer in organic substances) is favorable for these organisms.

Macro-invertebrate diversity is highest in the mountainous sector of the river, where human impact is insignificant, and decreases downstream in parallel with increasing human impact. The minimum is found downstream of the input by the effluent of Sibiu's waste water treatment plant *(Figure 1).* In the mountainous section stenovalent rheophilic and oxyphilic species prevail, but the number of individuals of each species is low due to low trophic supply and relatively unstable physical environment (high water velocity, frequent floods). In the middle and lower river sections, the structure of benthic macro-invertebrate communities is determined by the type and degree of pollution. However, these communities are characterized by a stability (structural constancy) which is higher than that found in the mountains (Curtean-Bănăduc 2004).

The comparison of our data with historical records (Bielz 1851, 1867; Mayr 1853; Kis 1971; Plattner 1963; Schneider 1973; Botoşăneanu & Schneider 1978) showed that in Cibin River 19 macro-invertebrate species have disappeared and 13 species have a reduced distribution along the river. The majority of these stenovalent species has low resistance to environmental changes induced by human impact. These temporal dynamics reflect the degradation of natural river habitats by hydro-technical works (Gura Râului Dam, river

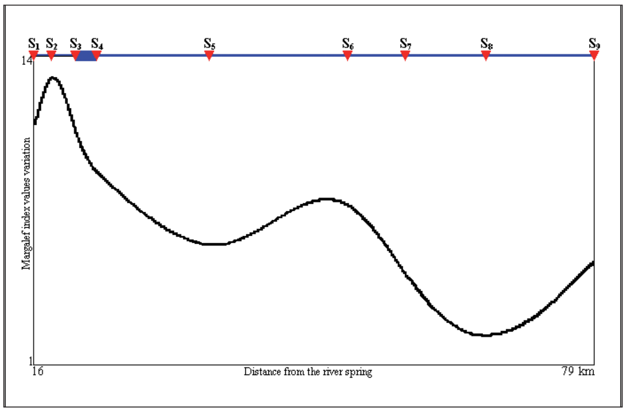

Figure 1. Variations of the Margalef-index MA along Cibin River (S_1 – S_9 sampling stations). Interpolation between stations by cubic function. High values of MA express high diversity. Macro-invertebrate diversity is highest in the mountainous sector of the river (S_1 – S_3), where human impact is insignificant, and decreases downstream in parallel with increasing human impact. The minimum is found downstream of the input by the effluent of Sibiu's waste water treatment plant (S_8)

canalization, marshes and floodplain drainage, cutting off meanders, river bank reshaping and embanking, tributary deviations, etc.), and pollution.

Regression analysis showed significant statistical relations between the diversity of benthic macro-invertebrates and the following biotope parameters: slope, dissolved oxygen, biochemical oxygen demand, organic matter, total hardness, chloride and sulphate concentration, and degree of mineralization. Some examples are given below (in the equations r^2 signifies the determination coefficient, S.D. is the standard deviation and q the level of significance):

$\ln(MA) = 2.523 – 0.053 \ln(BOD_5) \ln(DO) \ln(COD\text{-}Mn)$;
$r^2=0.799$; S.D.±0.247; $q<0.001$

$\ln(H) = 1.526 - 0.029 \ln(BOD_5) \ln(COD\text{-}Mn) \ln(DO)$;
$r^2=0.897$; S.D.±0.09; $q<0.001$

$\ln(SIM)=-2.712 + 0.056 \ln(BOD_5) \ln(COD\text{-}Mn) \ln(DO)$;
$r^2=0.788$; S.D.±0.269; $q<0.001$

$\ln(ME)=0.639 – 0.150 \ln(TH) \ln(RF)$;
$r^2=0.795$; S.D.±0.391; $q<0.005$

Conclusions

The predictive potential of regression analysis can be used by changing the independent variables (e.g., parameters of habitat quality) in various scenarios of river management. The output of such models is a prognostic variation in biodiversity (as a measure of homeostasis) of benthic macroinvertebrates with a known range of error. Hence, the model may deliver a set of modifications of some biotope parameters that can be used to establish a sound programme for sustainable river basin management. It must be stressed that such statistical and empirical models can hardly be transposed from one system to another and cannot be generalized without a sound calibration. These methods are time and resource-consuming, involving a highly skilled team of professionals.

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The use of models in flood risk management of the Lower Danube

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Introduction

Long-term strategic planning to achieve the objectives of the Water Framework Directive and the effective implementation of flood prevention, protection and mitigation need a sound scientific basis. The complexity of natural hydrological processes determines the principles, methods and analysis used for their study.

For example, establishing and reassessing the flood defence lines of settlements in the Lower Danube Plain and developing an integrated analysis of the hydromorphological, ecological, and economic conditions means to map, in a first step, the hydro-geomorphological units such as floodplains and agricultural polders.

Mapping has been neglected in the last 25 years. Therefore, a digital terrain model (DTM) was created which can design the defense strategy against flooding and base spatial planning (Kraus & Pfeifer 1998). With the DTM, floodplain dynamics and land use can be correlated, and indicators and indices of landscape can be characterized. Maps make the results clearly visible to the public, stakeholders and politicians.

Methods of mapping and modeling

Since the area of the Lower Danube Plain is crowded with channels and dams, the DTM needs at least nine topographical points to model a dam in three dimensions (2 pts for its base, 4 pts for the berm, 3 pts for its top). Hence, four points per square meter with a precision in altitude of ±5 cm are necessary when considering a dam with a base-width of 20 m. LIDAR (Light Detection and Ranging) is the only method that can ensure these requirements. The light detection is based on echo/laser pulse backscattering, i.e., measures the time used by the beam from leaving the sender in a round-trip plane to reaching the targeted scanned object, e.g., the land surface with hills, trees, houses, etc. We used a laser scanner with an accuracy of 5 cm (Riegl LMS-Q560) located on a plane (Partenavia P3) with two engines (Ly-