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USING BIOENERGETIC MODELS TO ESTIMATE ENVIRONMENTAL CONDITIONS IN ANCHIALINE CAVES

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Ways of deducing information on physicochemical characteristics of anchialine caves from measurements of sedentary biota are investigated. First, photographs of *Ficopomatus enigmaticus* from two different anchialine caves are used to draw qualitative conclusions on water circulation patterns and organic loads of the two caves. Next, the ability of bioenergetic models to quantify average conditions in anchialine caves from information on abundance, distribution, morphological characteristcs, and individual growth rates of *F. enigmaticus* is discussed, and a development of a bioenergetic model is suggested.

Key words: dynamic energy budget, biomarkers

INTRODUCTION

Long-term average conditions and their trends in anchialine caves are often difficult to characterize. Traditional characterization involves spot-measurements of physicochemical parameters and census of the biota. Spot measurements are sporadic, susceptible to short-term fluctuations, and their timing biased towards more pleasant weather. Arriving at long-term trends from such measurements requires frequent visits to often inaccessible locations. Long-term monitoring equipment (e.g. temperature and depth sensors) can improve our understanding of physical parameters, variability, and help estimate water exchange, but needs to be re-installed over the course of multiple years. Data on the abundance and distribution of the biota is collected, but rarely – if ever – used to deduce long-term physicochemical conditions of caves.

Censuses of the biota could, however, be combined with basic bioenergetic considerations to help estimate long-term conditions and average organic matter fluxes in a cave. Sedentary organisms, such as *Ficopomatus enigmaticus*, are especially well-suited for this purpose. We illustrate the concepts using the examples of two recently characterized anchialine caves: Vidrovača cave and Jama pod Orljakom cave. Both caves are located in the Krka River estuary. Vidrovača cave is 45 m long and 8 m deep, and has an entrance directly connected with estuary water. Jama pod Orljakom is 23 m deep and 90 m long with two pools 3.5 and 7 m deep. Jama pod Orljakom has connection with the estuarine waters only through karstificated limestones.

METHODS

Growth of organisms depends on environmental conditions; a good bioenergetic model of growth can, therefore, be used to back-calculate environmental conditions

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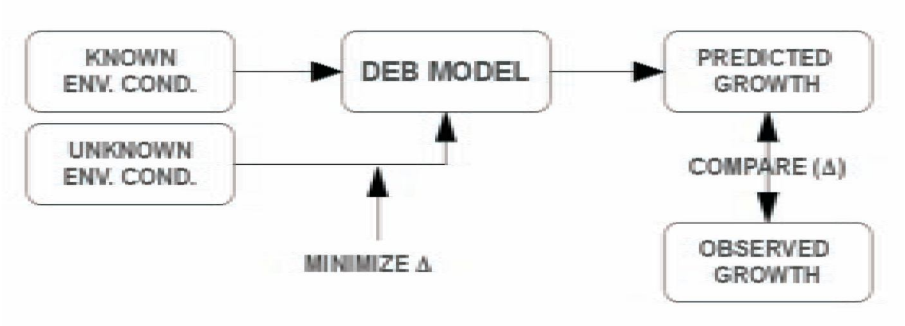

Fig. 1. Using a Dynamic Energy Budget (DEB) model to estimate environmental conditions. DEB predicts size and distribution of organisms from a set of environmental conditions. The predictions can then be compared to observations. Finding such a set, which minimizes the difference, gives an estimate of the unknown conditions. Known conditions are readily assimilated.

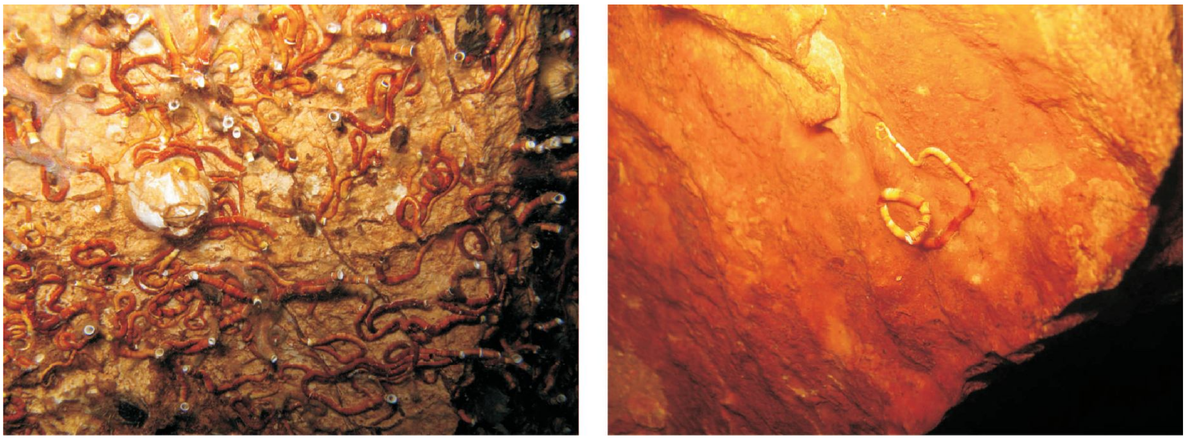

Fig. 2. Pictures of *F. enigmaticus* in Vidrovača (left) and Jama pod Orljakom (right) caves.

from the observed growth. **Traditional bioenergetic methods** mostly rely on mass--balance considerations: biomass present in the caves indicates the level of resources required and, therefore, available to the biota. These methods can satisfactorily estimate energy required for the observed biomass levels, but accounting for specifics of the cave is in-situ data-intensive. Furthermore, results are difficult to compare across systems because growth model parameters are coupled to environmental parameters and are specific to each cave. Newer theory, such as **Dynamic Energy Budget (DEB)** theory (Kooijman, 2010), decouples the environmental model from the growth model, thus decoupling the growth model development from the analysis of environmental factors.

Models based on DEB theory calculate growth and reproduction of organisms as a function of environmental conditions such as water temperature and food, from basic biochemical principles and life history data obtainable from limited, focused experiments. An organism is considered to consist of two major pools: energy reserves and structure. Energy reserves are acquired from the environment and can be metabolized for maintenance (processes required for proper functioning of an organism such as protein turnover, cross-membrane gradients, osmotic pressure regulation), growth, development, and reproduction. Structure – on the other hand – cannot be metabolized and requires energy for maintenance. The rate of growth and final size of the structure highly depends on temperature and available resources. Fig. 1 shows how a DEB model can be used to deduce average conditions in a cave. In the case of *F. enigmaticus*, additional information can be extracted from morphology of their tubes: in high currents, tubes are close to the rock, while in low currents they grow away from it (BIANCHI & MORRI, 2001).

RESULTS AND DISCUSSION

Even without the DEB model, some information can be deduced. In Vidrovača cave, *F. enigmaticus* is very dense at the entrance to the cave (Fig. 2), density and worm size falling as the distance from the entrance increases. High biomass densities signify high organic matter loads, and the directional density profile signifies a point source of organic matter. Tubes are close to the rock and pointing in the same direction, signifying relatively high current flow. In Jama pod Orljakom cave, *F. enigmaticus* is scarce and randomly distributed. The scarcity indicates low organic matter availability, while the distribution indicates that the source of organic matter is diffuse. The tube is perpendicular to the rock, indicating low water currents.

The above analysis is qualitative; a DEB model can be used to quantify such analysis and provide further detail using data obtainable from photographs such as organism density and size (e.g. tube length and maximum diameter). The final size of an organism in DEB depends on available organic matter; the observed maximum size of *F. enigmaticus* at some location directly gives *average organic matter flux* at that location, from which water exchange can be estimated. Looking at gradients of organic matter, current strength can be estimated from known filtration ability of *F. enigmaticus* (independently of the estimate from the tube morphology).

CONCLUSION

Theoretical approaches can be used to extract more information from in-situ data; some are presented here, but additional ones are possible. Characterization of the water exchange in Vidrovača cave currently underway will both help develop and validate the approaches presented here. Developing a DEB model of *F. enigmaticus* is a difficult task that requires detailed knowledge of the organism. Apart from additional data necessary to parameterize a DEB model of *F. enigmaticus*, a better understanding of filtration mechanisms and rates, body scaling of the worm (the relationship between filtering area and tube length), and energy dedicated to reproduction has to be attained.

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