FRACTAL ANALYSIS OF THE MOVING BEHAVIOUR OF CAVE BEETLES (COLEOPTERA: CHOLEVIDAE: BATHYSCIINAE

OANA TEODORA MOLDOVAN and CARLOS PAREDES BARTOLOME

The fractal geometry offers the support for the interpretation of the way animals move in the bi - or tridimensional space. Our experiments have been carried on with cave, blind beetles, from the Cholevidae family, on a glass plate, which represents a bidimensional space. From the obtained data the conclusion is that the displacement is not hazardous, but brownian persistent or fractal regardless of time. This strategy in orientation tends to optimize the flow of matter and energy in time, and it is an internally derived proprioceptive or internally stored genetic information.

1. INTRODUCTION

The obtainment of food, necessary for surviving and reproduction could define, in a simple manner, the life. But many problems are arising from such a simple definition. From the selection perspective or by analyzing the locomotion models, or/and the feeding activity, these problems can be decoded. One of them is represented by the way individuals are moving. The searching behaviour depends on three kinds of factors [1]: the biological characteristics and abilities of an insect, including locomotory patterns and perception of sensory information; external environmental factors, and internal factors. Moreover, the interpretation of the individual dynamics and the adaptative value of different searching behaviors can be studied from the locomotory patterns point of view.

The "classical" interpretation of the movement design converged to the idea of randomness, of an erratic and irregular, difficult to quantify behaviour [9]; otherwise these authors suggest that the movement is a more complicated process than a simple correlated walk. Anyway, the idea of randomness is an assertion that opposes to the idea of energy economy, "obligement" for any living being. Also, if foragers maximize the long term net rate of energetic gain, the reproductive success is maximized [7].

The selection, exercised through the ecological factors, favours only some of the feeding activity strategies. According to [5]:

$$P_i = P_m + P_a + P_{g+r},$$

where P_i, P_m, P_a and P_{g+r} are the rates of energy intake, energy for maintenance, energy for activity and energy for growth/reproduction, respectively. Measure of activity over time P_f, the foraging power is incorporated into the energetic budget as a component of P_a. We do not insist on the efficient way the energetic budget could be administrated, but P_a must be minimized, because it should be more invested in P_{g+r}, and implicitly, P_f must have small values. All this can be expressed in an efficient foraging activity and consequently, imposes a judicious explorative behaviour of the space.

The fractal geometry as instrument in ecology has been described or used by different authors [3, 2, 12, 4, 13, 11, 10, 6, 14].

Our interest with this study was to define the locomotory pattern of the beetles without exteroceptive conditionings as landscape topography, temperature, pheromones, etc., and even the visual ones.

2. MATERIAL AND METHODS

The experiments were carried on in the cave - laboratory of Moulis (France), with a species of cave beetles: *Speonomus emiliae* (Cholevidae: Bathysciinae). These are detritivorous and blind, whom main ways for orientation are the mechanical, gustatory and olfactory senses. The individuals were bred separately, in special plaster boxes, at 10°C temperature and 100% relative humidity; the same conditions were kept during the experiments.

For the experiment the individuals (only males) were placed on a fine-rugged glass plate (53 cm/65 cm) and the path was marked with a pencil at about 1 cm behind the body of the moving beetle (distance tested experimentally for not affecting their behaviour), for about 15 minutes. We have overlooked the agitated individuals path, a partially subjective selection, but determinated by the speed of the movement of the individual and the absence of characteristically right-left prospection movements of the antennae. After each individual, the glass plate was carefully washed.

Each trail was drawn on paper, then digitized using a table digitizer attached to a microcomputer.

3. RESULTS

For the beetles movement study, the curves that have been obtained (see example in Fig. 1) were mathematically treated with the box dimension method, one of the methods used in fractal geometry to compute the fractal curves [6]. It consists in applying N-dimensional grid of boxes of side length r to cover the object (the curve in our case) (Fig. 2);.fractal dimension in this case is the slope of the curve from the double-logarithmic regression of the counts of grid cells versus resolution [10]. 25 values for r were utilised for constructing the regression line (Fig. 3). Following this procedure, some values have been obtained and are presented in Table I. According to them, and therefore, to the fractal dimension (with an average of 1,2) our beetles' movement is brownian persistent or fractal regardless of time. So, it is neither a liniar motion (D = 1), nor a typical brownian one (D = 2).

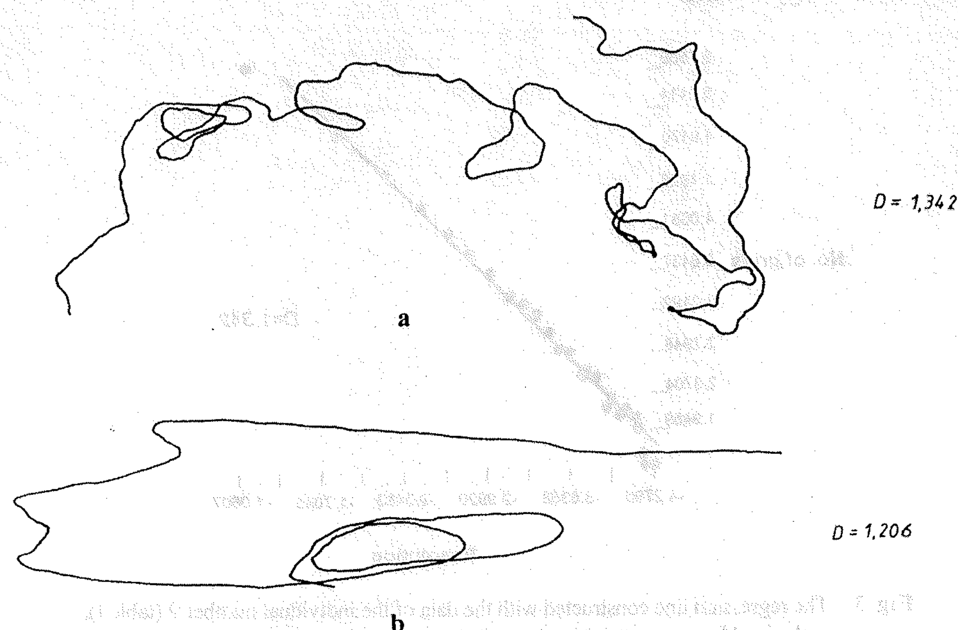

Fig. 1 – Examples of beetles movement, with different values of the fractal dimension. **a.** pathway of individual number 9 (in table I), **b.** pathway of individual number 19 (in table I).

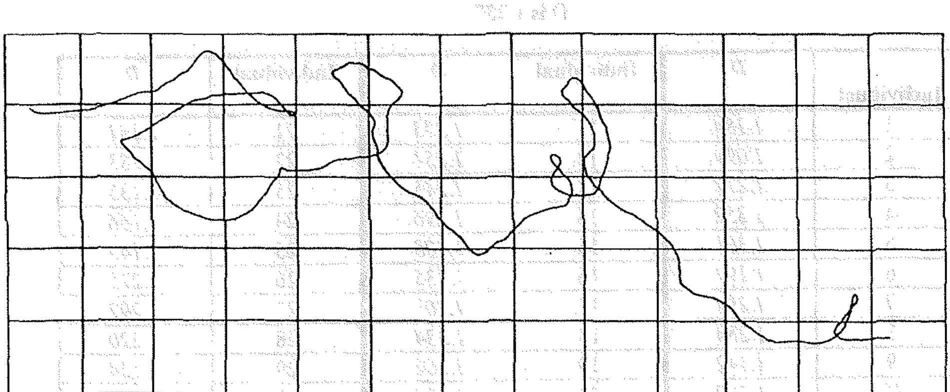

Fig. 2 – Example for the box dimension method, applied to the pathway of individual number 12 (in table I).

Otherwise, for the typical brownian motion there are no correlations between the displacements in succesive time intervals. It means that at every stage and on every scale of Δt, all directions of displacement are equally likely. A particle (or individual) in a persistent motion that moves in the same direction at time t will tend to keep the direction regardless of Δt [11]. Thus, the motion is determined and the particle does not move randomly. This strategy tends to optimize the flow of matter and energy in time.

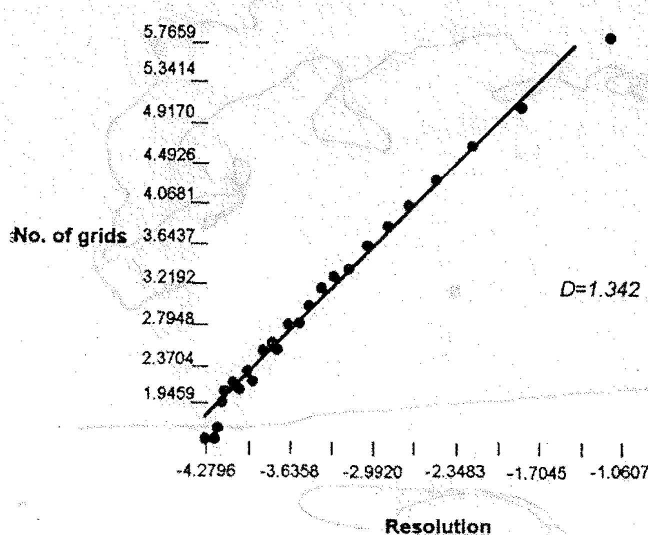

Fig. 3 – The regression line constructed with the data of the individual number 9 (table I), obtained by computing 25 values of r by the box dimension method.

Table I

The calculated values of D (fractal dimension), for 30 males of Speonomus emiliae.- The average value of D is 1.237 –

Individual	*D*	Individual	*D*	Individual	*D*
1	*1.184*	11	*1.273*	21	*1.141*
2	*1.094*	12	*1.251*	22	*1.283*
3	*1.277*	13	*1.245*	23	*1.135*
4	*1.352*	14	*1.296*	24	*1.166*
5	*1.301*	15	*1.408*	25	*1.145*
6	*1.197*	16	*1.135*	26	*1.272*
7	*1.294*	17	*1.203*	27	*1.297*
8	*1.284*	18	*1.334*	28	*1.220*
9	*1.342*	19	*1.206*	29	*1.124*
10	*1.299*	20	*1.190*	30	*1.160*

4. CONCLUSIONS

K a r e i v a and S h i g e s a d a [9] have analysed the insects' movement by polygonal approximation. The appliance of fractal geometry, in this case, did not concern the length correction, because the animal's movement is not linear, but the degree in which the bi- or tridimensional space is covered. We have already touched the problem of energy economy in space exploitation, as a feature defining any living being. It can be efficient if a maximum of points in space can be covered with low energy consumption. If the straight line satisfies the first condition, the classical brownian motion, which practical covers the space, does not satisfy the second one. The main solution is offered by the persistent motion, that ensures the covering of the space without touching all its points and so, without an excessive energy consumption.

Besides the energetical efficiency of the displacement, another fractal strategy ought to be taken into account. The food resources have a fractal disposal in the environment, *i.e.* the plants in a field, and also the geometry or the heterogeneity of the environment (in our special case, the cracks network in a massif) is fractal.

J o h n s o n *et al.* [8] have simulated the diffusion of Tenebrionid beetles in a fractal environment in the absence of natural obstructions (*i.e.* vegetation) and they prooved that the beetles move in the same fashion as they do over long time scales in grass. Our experiment prooves that the beetles move in a fractal regarding of time way, even in the absence of many external conditionings, as the rough landscape, the presence of predators, the food resources, etc. Thus, the way beetles move is an internally derived proprioceptive or internally stored genetic information [1], trying to cover the available space in a optimum way, and by not wasting too much energy.

Our experiments tested the null hypothesis of the beetles movement in the absence of stimuli or environmental heterogeneity and need to be completed with the assessment of how movement in the natural environment departs from this hypothesis, owing to the distribution of resource or chemical cue or other stimuli, even if there are well known the difficulties for pursuing such experiments in the underground world.

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Institute of Speleology "Emil Racovitza"
Department of Cluj-Napoca

Escuela Tecnica Superior de Ingenieros de Minas
Barcelona, Spain