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SPATIAL VARIATION OF THE LAND SNAIL *BREPHULOPSIS CYLINDRICA* (GASTROPODA, PULMONATA, ENIDAE): A FRACTAL APPROACH

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Spatial Variation of the Land Snail *Brephulopsis cylindrica* (Gastropoda, Pulmonata, Enidae): a Fractal Approach. Kramarenko, S. S., Dovgal, I. V. — The results of investigations of intrapopulation patterns in the land snail *Brephulopsis cylindrica* (Menke, 1828) variation are discussed in the article. The self-similar intrapopulational groups (demes) with sets of random (chaotic) and ranked (clinal) patterns of morphological characters were observed. It is argued that the self-similar elements lead to the formation of spatial variability patterns with distinct fractal nature. Thus the relative roles both of the random and the regular components can be detected for separate characters according to the degrees of nearness or remoteness of fractal dimension to 2.0.

Key words: land snail, *Brephulopsis cylindrica*, population, variation, fractal analysis.

Пространственная изменчивость наземного моллюска *Brephulopsis cylindrica* (Gastropoda, Pulmonata, Enidae): фрактальный подход. Крамаренко С. С., Довгаль И. В. — Представлены результаты изучения внутрипопуляционной изменчивости наземного моллюска *Brephulopsis cylindrica* (Menke, 1828). Установлено наличие внутрипопуляционных групп (демов) с преобладанием случайных (хаотичных) или закономерных (клинальных) элементов. Показано, что наличие таких самоподобных элементов приводит к формированию паттернов пространственной изменчивости отчётливой фрактальной природы. Установлено, что с помощью сравнения степени близости или удалённости фрактальной размерности от величины 2,0, можно оценить относительную роль случайной и закономерной компонент.

Ключевые слова: наземный моллюск, *Brephulopsis cylindrica*, популяция, изменчивость, фрактальный анализ.

Introduction

Brephulopsis cylindrica (Menke, 1828) is an endemic species for Crimea and Southern Ukraine (Kramarenko, 1995; Vitchalkovskaya, 2008). The species inhabits various climatic and geographical zones (ranging from Crimean *Mts* to Steppe) and areas with xerophilous vegetation and forms populations with spatial extension up to several hundred meters.

Assuming that the dispersal of this species does not exceeds several meters per year (Kramarenko, 1997) we hypothesized that spatial isolation should lead to the formation of heterogeneous (fractal-like) intrapopulation structure of the morphological variation.

It is agreed that fractals are a shape made of parts similar to the whole in some way (Mandelbrot, 1982). Fractal analysis is defined as the group of methods for quantifying of the any complex patterns which are difficult to description. The fractal dimension (D_F) describing how the detail in a pattern changes as the pattern is examined at varying scales. This scaling is generally referred to as complexity. It is believed that the higher the dimension, the more complex the pattern. For spatial and temporal variability, D_F can range from 1 (values within spatial and temporal range of analysis fall on a line) to 2 (which indicates so much variation that an entire two-dimensional surface is covered by the extent of variation). Large D_F values indicate the importance of short-range variation, while small D_F values reflect the importance of long-range variation (Burrough, 1981).

Fractal analysis, which is based on self-similarity (the manner in which a pattern at one scale is repeated at other scales), has been useful in characterizing ecological parameters in several studies of the marine gastropod and bivalves (Kostylev et al., 1997; Kostylev, Erlandsson, 2001; Erlandsson, McQuaid, 2004).

Thus, the aim of the present study was to analyze the intrapopulation patterns in variation of the shell size and form of land snail *B. cylindrica* with the use of the fractal approach.

Material and methods

A total of 15 samples of the land snail *B. cylindrica* from a population located in the Peschanoe village vicinity (Bakhchisaray district, Crimea; 44.845° N, 33.621° E), were collected in August 2005. The size limits of the population investigated were ca. 400 m in length and 10 m in width.

Samples were taken along transect directed axially to the longer edge of the population at 25 m intervals. Only adult individuals of *B. cylindrica* with shell aperture with reflected lip were collected. The sample size comprised 30 mollusk individuals except for two samples with 19 and 20 individuals respectively.

The shell height (HS) and shell width (WS) were measured with a digital calliper to the nearest 0.05 mm according to Sverlova et al. (2006). The height/width shell ratios (shell form index — FS) were also computed.

For estimating the *B. cylindrica* intrapopulation morphological differentiation index value (*Mst*) the general linear model (GLM) was used. The latter was based on the analysis of the morphological variation for two shell traits and a height/width shell ratio. The *Mst* index was properly calculated as a ratio of variance components. This index accounts for the measure of intrapopulation morphological differentiation and is similar to Wright's F-statistics that is common in use for genetical data (Kramarenko, 2009).

The Moran's spatial autocorrelation index was measured to describe the micro-spatial patterns of the morphological variation. Spatial autocorrelation is defined as the association of the values of one geographically distributed variable with the values of the same variable at other localities (Sokal, Oden, 1978). Thus, spatial autocorrelation index (Moran's *I*) is the expression of similarity between neighboring locations (Moran, 1950).

The relationship between *Mst* values and number of samples was analyzed for the assessment of the morphological rarefaction (Hurlbert, 1971). For this aim, 25 data sets containing samples from 1st to 15th were formed in random order. The procedure for the taking of samples in analysis ($i = 2–15$) was based on generation of the pseudorandom variable (using Microsoft Office Excel). The mean values and standard deviations ($Mst \pm SD$) for the morphological differentiation index were calculated dependent on number of samples used in the analysis.

Fractal dimension (D_F) was calculated from the semivariogram (which is a log-log plot of $\gamma(h)$ and h):

$$\log \gamma(h) = c + d \cdot \log h, \quad (1)$$

$$D_F = 2 - 0.5 \cdot d, \quad (2)$$

where d is the absolute slope of the regression line, $\gamma(h)$ is the semivariance, h is the lag (Milne, 1992).

All statistic procedures were carried on using software PAST 2.14 (Hummer et al., 2001) and SAM (Spatial Analysis in Macroecology) v. 4 (Rangel et al., 2010).

Results

The shell measurements (height, width and height/width ratio) for 15 sites within studied population are presented on fig. 1.

As can be seen from figure 1, the two pattern variants can be distinguished in spatial intrapopulation variation of *B. cylindrica.* The shell height varies chaotically within sample sites Nos 9–15 (fig. 1, *A*). The clinal pattern (fig. 1, *B*) has been revealed in the shell height variation within sample sites Nos 1–5, the shell width variation within sites Nos 1–6, and the shell height/width ratio variation within sites Nos 10–15.

The significant values of the intrapopulation morphological differentiation index were noted for all shell traits. The samples from this local population were more variable for the shell width ($Mst = 0.409 \pm 0.071$) in relations to the shell height ($Mst = 0.183 \pm 0.085$) or shell height/width ratios ($Mst = 0.118 \pm 0.028$).

The random distribution of the shell height variation within the population is shown on fig. 2, *A* as a result of the spatial autocorrelation analysis. At the same time the clear clines in the spatial variation distribution for the shell width and shell height/width ratio were noted within studied population (fig. 2, *B, C*).

The measure of uncertainty increases with increasing level of the intrapopulation differentiation of morphological shell traits. Thus, the highest degrees of *Mst* values detected in singles sites within the population *B. cylindrica* were reported for the shell width ($Mst = 0.158–0.678$), whereas the lowest ones were revealed in the shell height/width ratios ($Mst = 0–0.113$) (fig. 3). Furthermore, the assignment of the *Mst* estimates increases significantly with increasing the number of samples (independently of their positions within a studied population).

The fractal dimension values ranged from $D_F = 1.731$ (for the shell width) to $D_F = 1.963$ (for the shell height) (fig. 4). Notice that D_F value for the shell height was close to 2.0 which indicates the dominating of chaotic pattern in spatial arrangement of the intrapopulation morphological variation. It should be mentioned that the similar results have been obtained using Moran's *I* coefficients (fig. 2, *A*).

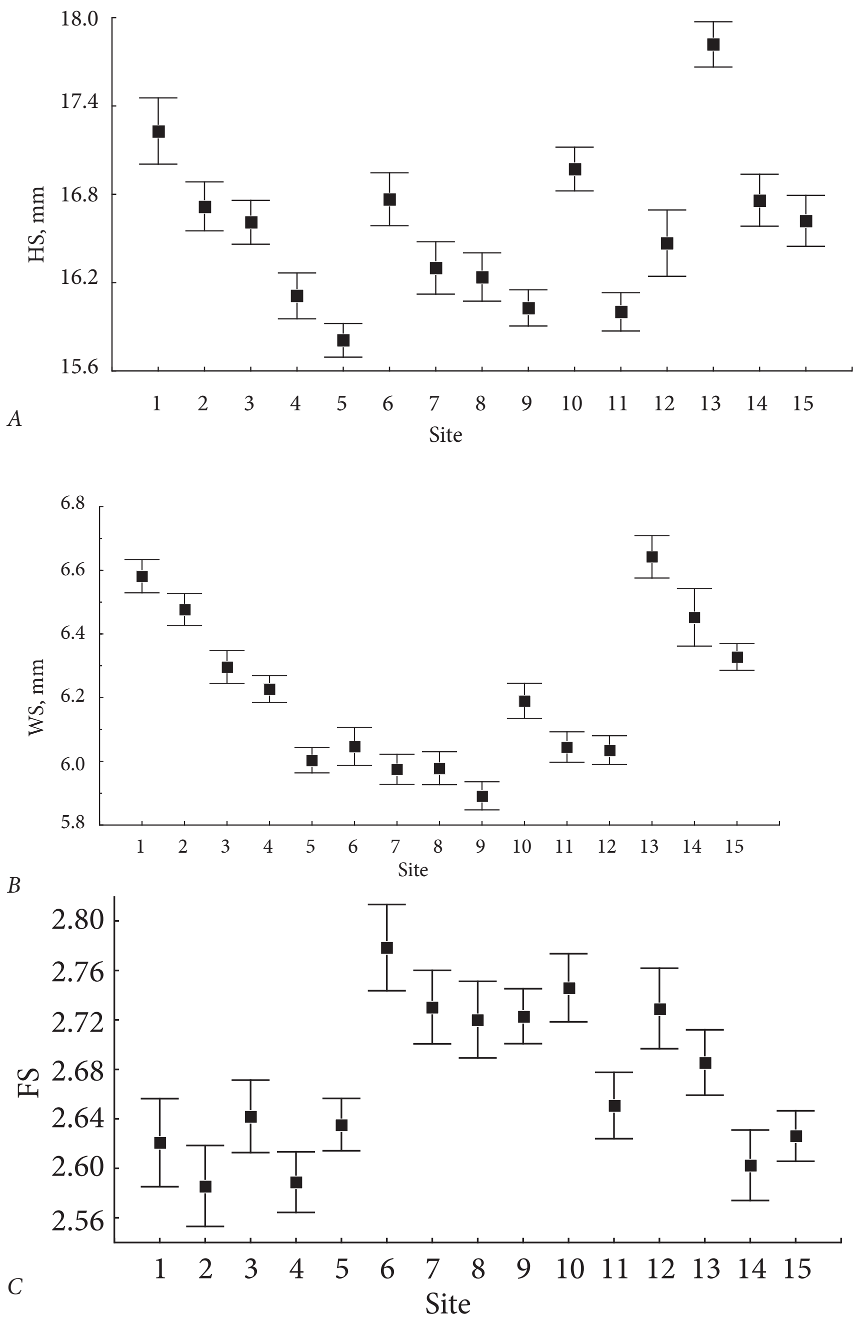

Fig. 1. The variation of morphometric shell traits in *B. cylindrica* from different sample sites: *A* — shell height (HS); *B* — shell width (WS); *C* — shell form index (FS).

Рис. 1. Изменчивость морфометрических признаков раковины *B. cylindrica* с различных пробных площадок: *A* — высота раковины (HS); *B* — ширина раковины (WS); *C* — индекс формы раковины (FS).

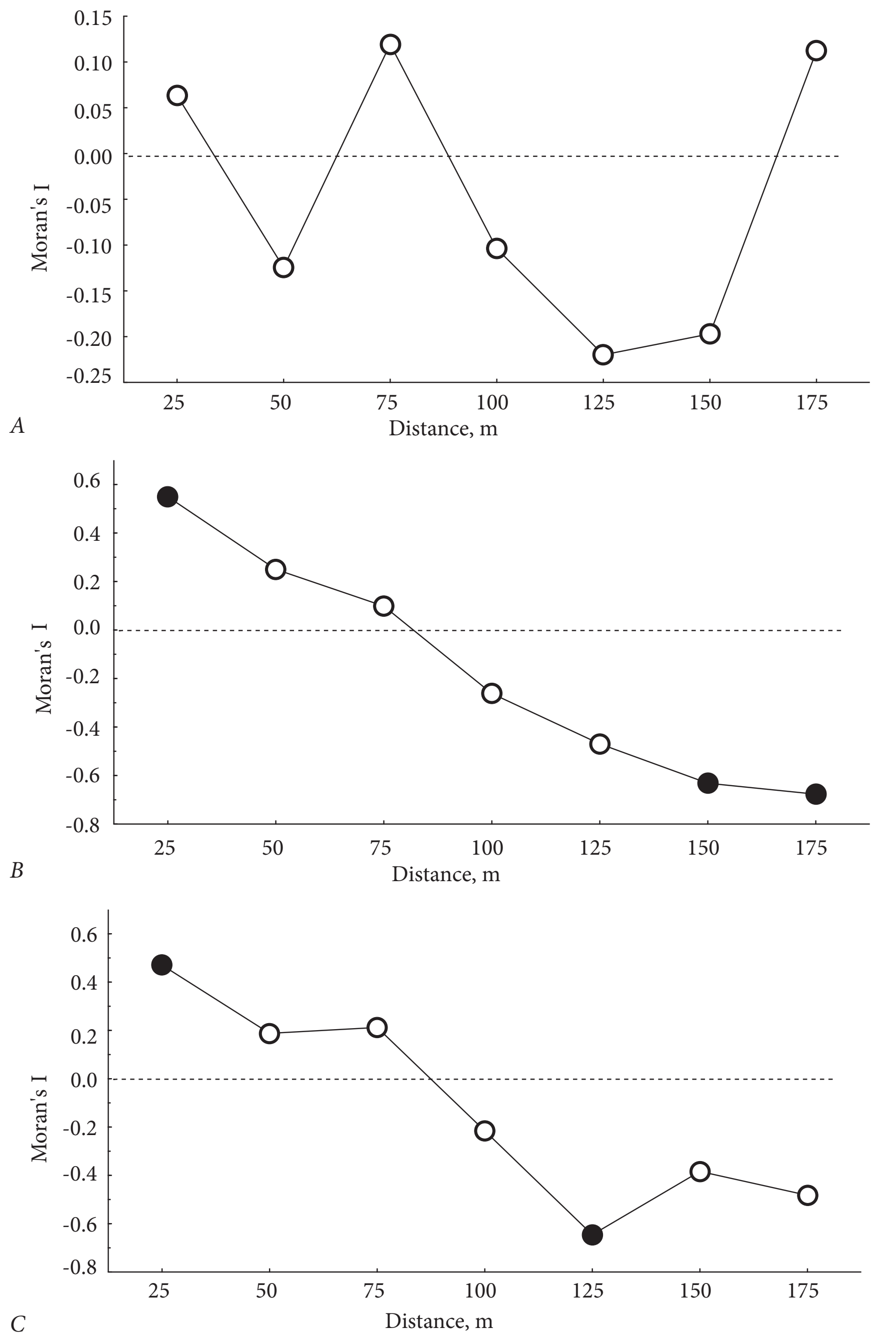

Fig. 2. Moran's index for morphometric shells traits of *B. cylindrica* of the studying population: *A* — shell height (HS); *B* — shell width (WS); *C* — shell form index (FS). Significant values of Moran's index indicated as solid circles.

Рис. 2. Индекс Морана для морфометрических признаков раковины *B. cylindrica* исследованной популяции: *A* — высота раковины (HS); *B* — ширина раковины (WS); *C* — индекс формы раковины (FS). Достоверные значения индекса Морана обозначены залитыми кругами.

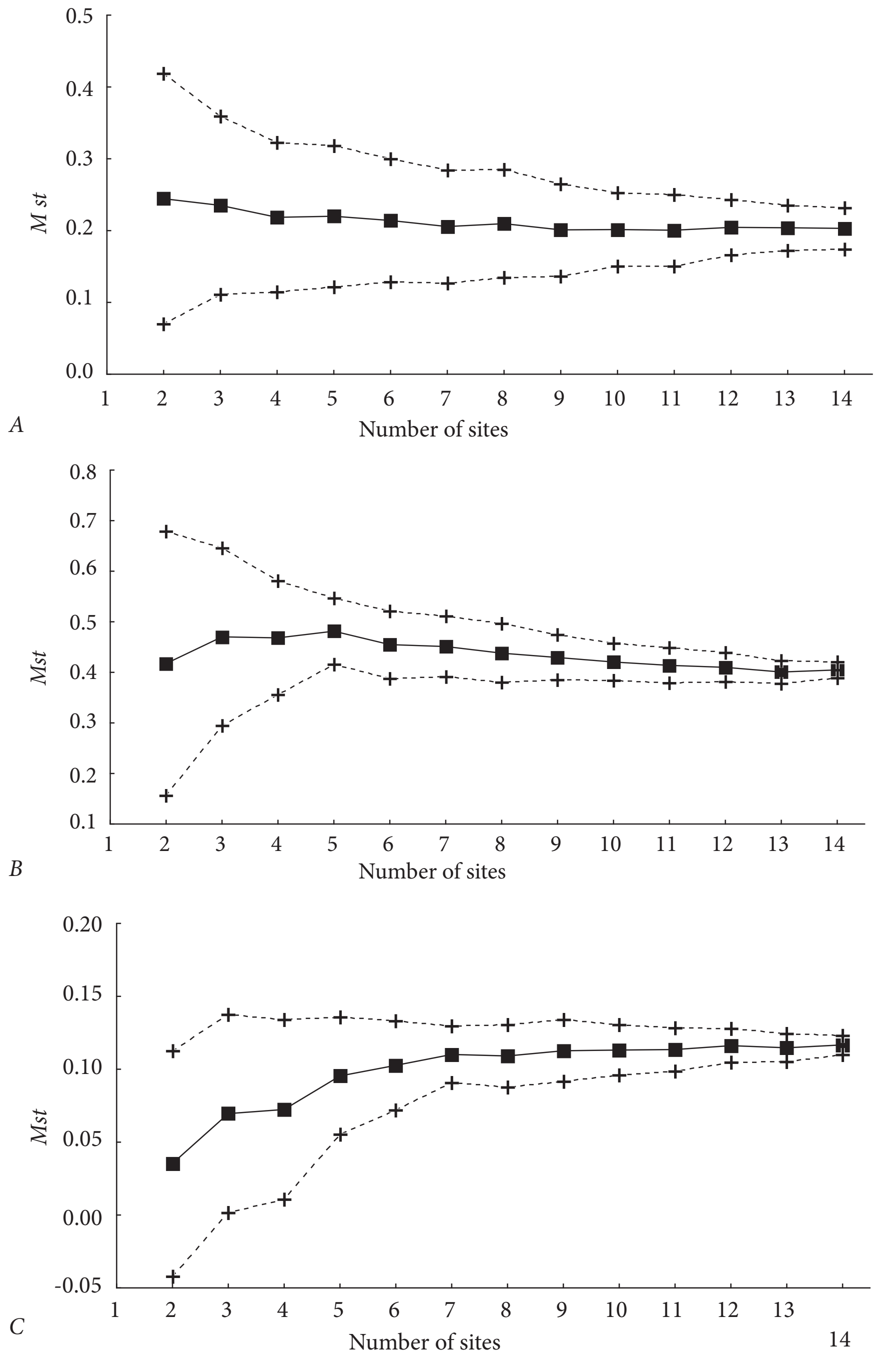

Fig. 3. The dependence between intrapopulation variation (*Mst*) and the sample sites number in *B. cylindrica*: *A* — shell height (HS); *B* — shell width (WS); *C* — shell form index (FS) (95 % confidence interval is indicated by dotted lines).

Рис. 3. Зависимость внутрипопуляционной изменчивости (*Mst*) *B. cylindrica* от количества пробных площадок: *A* — высота раковины (HS); *B* — ширина раковины (WS); *C* — индекс формы раковины (FS) (пунктирными линиями обозначен 95 %-ный доверительный интервал).

The fractal design was also supposed for specific pattern of the intrapopulation morphological variation in the shell width and the shell height/width ratio in *B. cylindrica* (fig. 4, *B*, *C*).

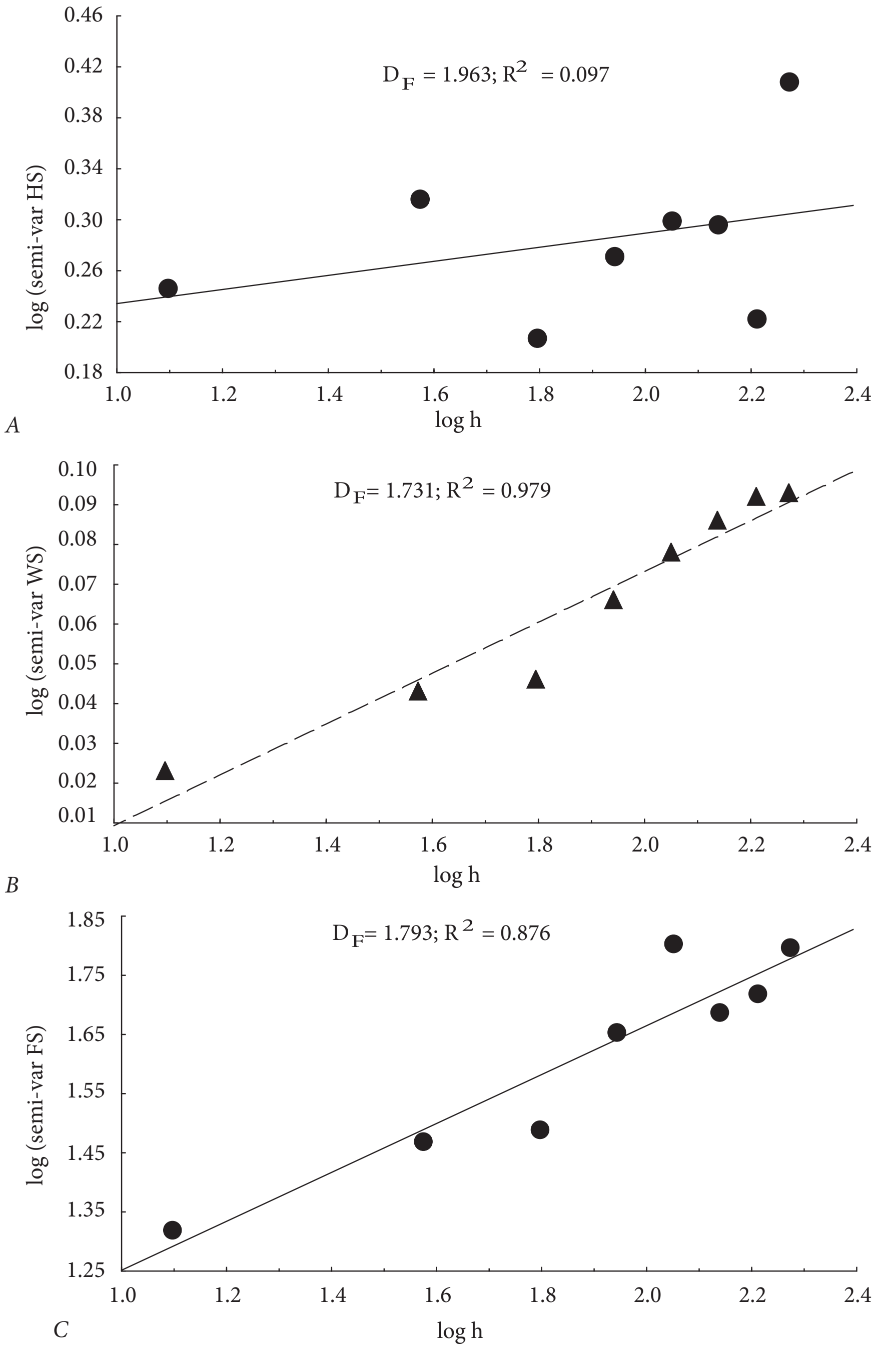

Fig. 4. Plots of the logarithms of semivariance versus logarithms of spatial scale (in meter) for morphometric shells traits of *B. cylindrica* of the studying population. D_F — fractal dimension value; R^2 — determination coefficient): *A* — shell height (HS); *B* — shell width (WS); *C* — shell form index (FS).

Рис. 4. Графики зависимости семиварианcы от размерности пространственной шкалы (в метрах) для морфометрических признаков раковины *B. cylindrica* исследованной популяции. D_F — фрактальная размерность; R^2 — коэффициент детерминации): *A* — высота раковины (HS); *B* — ширина раковины (WS); *C* — индекс формы раковины (FS).

Discussion

The obtained results indicate the presence of sufficient variation in the morphological shell traits of the land snail even within a single population without the isolation barriers. Similar results were obtained for the shell and shape variation of the land snails *Cepaea hortensis* (Müller, 1774) (Bengtson et al., 1979) and *Chondrina clienta* (Westerlund, 1883) (Baur, 1988), which inhabit area of similar size (not more than 0.5 km^2).

It should be mentioned that the *Mst* values obtained for investigated population were higher than the *Mst* values observed in the local population of *B. cylindrica* when smaller scale analysis was in use (Kramarenko, 2009). Presumably, this result is due to the fact that under increasing of used scale the greater numbers of the land snails' intrapopulation groups (dems) were included in analysis.

At the same time the morphological rarefaction method demonstrated that unbiased values of the intrapopulation variation could be assessed using at least 5–8 samples with random arrangement within studying population. Thus, the change in sampling from "single population — single sample" to "single population — several samples" was required. However, in such an event, the analysis of interpopulation differentiations (i. e. early stages of an infra-species diversification) should be organized in form of nested ANOVA, namely, several independent samples must be collected within a studied population.

It can be seen that the intrapopulation variation in *B. cylindrica* as a rule can be expressed as a microcline pattern. The similar microclines have been previously reported for microgeographic variation of the freshwater gastropod *Potamopyrgus antipodarum* (Gray, 1843) (Haase, 2003) as well as for land snails *C. hortensis* (Bengtson et al., 1979) and *B. cylindrica* (Kramarenko, 2009). It is assumed that the formation of the microclines involved the relatively low level of the land snail dispersal and therefore the weak gene flow between populations that separated by few hundred meters.

At that the self-similar intrapopulational groups (demes) with sets of random (chaotic) and ranked (clinal) patterns of morphological characters are observed within the *B. cylindrica* population. In our opinion, these self-similar elements lead to the formation of spatial variability patterns with distinct fractal nature. As discussed above the fractal dimension close to 2.0 indicates the prevalence of chaotic components within the population. This ensured that the relative roles both of the random and the regular components can be detected for separate characters according to the degrees of nearness or remoteness of fractal dimension to that quantity. However, the question as to whether fractal dimension can to be a measure of the relative ages of populations needs further investigations.

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