Fractal model of emergence of a proto-plant

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ABSTRACT Sectional model of the tree's system branches, which was published earlier, was extended in the range (0,1) for model's allometric parameter μ, binding magnitude of the green biomass of a tree and its size (for spruce $\mu \approx 1.83$). The model has shown presence of a biomass of branches in this range that indicates, according to fractal geometry, on the placement of a green biomass in the form of set of "points". In turn according to contemporary notions about endosymbiotic character of appearance of organelles in eukaryotic cell this was interpreted as begin of endosymbiosis of cyanobacteria and a host (protist) and has been modeled by the groups placement of growing number of points on an interval under initial limitation the number of points per group. The limitation is connected to the initial absence in protist an infrastructure which is need for the growing number of cyanobacteria. It has been demonstrated that initially in course of increasing total number of points the parameter μ decreases from 1.0 to 0.25 under the fixed number of points per group and then increases to 1.0 under the fixed number of groups. This gives an initial deceleration of growth of proto-plant's size (a characteristic geometrical size of the point set) and then the exponential growth after deliverance from limitation of point number per group in course of host evolution. Similar initial deceleration of growth can be seen now also in higher plants. Morphological analogy of situations of beginning the plant embryogenesis and of seed germination with the situation described by the model of proto-plant appearance is discussed.

Keywords: sectional model of a tree, fractal parameter, set of photosynthetic points, group placement, endosymbiosis, trajectory of evolution, proto-plant, initial deceleration of growth.

INTRODUCTION

In [1] has been allocated the sectional tree structure with periodic growth, which can be described by a simple model of the dynamics biomass of section using the notion of co-axial adjacent virtual trees, nested each to other and periodically appearing on the top of the tree. Biomass of each next virtual tree is part of previous one and accordingly, the biomass of each section consisting of biomasses of its branches, may be calculated as the difference between biomasses the two adjacent virtual trees. Considering the dynamics of real tree biomass known and taking it for the virtual tree as

32   an initial approximation, we can thus obtain the dynamics of biomass distribution along sections (and

33   height) of the real tree [1]. When using assumption about the monotony and limited dynamics of the

34   green biomass of a tree this model has demonstrated some of the properties of a tree existing in reality.

35   The model showed also the possibility by varying the three parameters to obtain the biomass

36   distributions in height (sections) of the tree that may be associated with a rather distant from each other

37   tree species [2]. This model has been used as a basis for analyzing the dynamics of distribution and

38   distant transport of assimilates along the freely growing tree using "diffusion" formulation of transport

39   mechanism of mass-flow. The model of distant transport has shown the possibility of the so-called "a

40   respiratory barrier" associated with the power-law dependence of costs on the breath on the magnitude

41   of biomass, as well as the effect of the stratification of the tree by interleaving groups of the donor and

42   acceptor sections [3]. Combination of sectional model and the two-dimensional model of biomass

43   dynamics of a tree growing not freely [4] has demonstrated that the lower sections of a tree growing in

44   a limited area (polygon) in the community are in oppression and die (more rapidly in comparison with

45   the freely growing tree). As a result, at the top of the tree new sections appear and they are growing

46   freely, and the bottom sections die, i.e. occurs wave of biomass that moves up along the tree stem [5].

47   In [6] the sectional tree model was extended to the branches system that carry green biomass of

48   respective sections of tree. Parametrizing model of branches system using nature data [7] about

49   lifespan $t_{D,j}$ of spruce branches of four orders ($j = 1, ..., 4$) showed that in this case model of system of

50   regular branches must also take into consideration two known features of spruce – initial growth

51   deceleration [8] and existence and role of inter-verticil branches [9, 10]. The combined model is in

52   good agreement with natural data and with other publications. Model only regular branches showed

53   only the branches of the 1st order, and when it is complemented by sub-model of the initial

54   deceleration of growth it shows the branches of all 4 orders [6, fig. 2b, d]. This article discusses some

55   of the consequences of interpretation of the allometric parameter μ linking green biomass *B* and

56   geometric size *H* of a tree

$$B \sim H^{\mu} \tag{1}$$

58   as a fractal parameter, and dissemination of model to the range μ (0, 1). For spruce the value of

59   parameter was obtained μ ≈ 1.83 [6]. It lies in the range [1, 2) corresponding to a set of linear elements

60   (conifer needles) [11].

61   Figure 1 shows dependence $t_{D,j}(\mu)$ of lifespan for system of the *j*-orders branches. It shows features

62   of the model system of regular branches, which was augmented by the sub-model of initial growth

63   deceleration for the range of fractal parameter μ (0, 1) with the set of other parameters of spruce from

64   [7, 12]. This range according to the ideas of fractal geometry [11] corresponds to the set of points. In

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65   this range of μ there are the branches of first 3 orders, i.e. biomass is placed along height of "tree" in

66   the form of green "dots" what is not observed visually in the higher plants. The article [12]

67   demonstrated that the appearance of branches of orders $j = 1, 2$ and 3 in this range of μ is a

68   consequence of accounting initial deceleration in growth model.
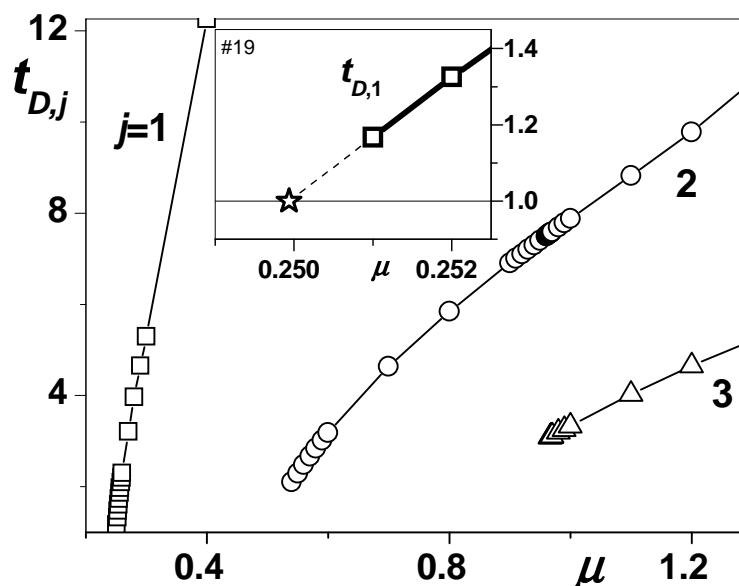

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70   Fig. 1. The dependence of the lifetime of the *j*-branches $t_{D,j}$ of regular branches' model with adding of the sub-model

71   of initial growth deceleration [6]; other parameters are as for spruce [6, 7]. Inset for the 1-branch in a larger scale, an

72   asterisk ▯ the appearance of the 1-branch for parameter set μ#19 [6].

ON THE FRACTAL PROPERTIES OF SETS OF POINTS ON THE INTERVAL

74   The mechanisms of photosynthesis of higher plants and cyanobacteria are practically identical. This

75   is due to the history of the appearance of plants in symbiosis and / or endosymbiosis of cyanobacteria

76   and protists. According to [13-15], chloroplasts of modern plants are the descendants of the

77   cyanobacteria which undergone transformation in the course of evolution after the organization of

78   endosymbiosis with protists. Thus, photosynthesis in plants and is now being performed by "point"

79   elements (chloroplasts), placed in the cells of green biomass of plants [15, 16]. Features of placing a

80   set of points in space affect the value of a fractal parameter and thus the efficiency of using of sunlight

81   in the plant growth. It should be noted that a tree and set of points are natural objects of the fractal

82   geometry, which allows using its methods directly [11].

83   Assuming that the initial invasions of cyanobacteria into the cell of endosymbiosis' host were

84   sporadic and have not lead directly to a compact placement and considering that protists are by several

85   orders bigger than cyanobacteria, we can estimate the parameter μ for the set of N_p points in an interval

86   using the usual algorithm of box counting [11]. Placing points of a set not in the groups of points on an

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87   interval but with uniform random placement or with placement with fixed step leads to $\mu \approx 1.0$.

88   Placement in groups of points on the interval gives $\mu < 1$. It can be noticed that Cantor point sets,

89   which often considered as a simple example [11], are actually group placements with $\mu < 1$.

90   For group placements of points on the interval [12]: 1) the value μ is practically independent of A –

91   relative value of on-off space ratio for stepper placement of groups; 2) μ depends on type of the

92   placement of points in the groups; 3) for stepper placement of groups the value μ quite resistant to

93   accidental and rather large deviations of groups' location.

FRACTAL TRAJECTORIES OF PROTO-PLANT EVOLUTION

95   Endosymbiosis is cohabitation of protist and cyanobacteria within it, as a natural development of

96   their symbiosis during the trophic relations between "heterotrophic protists" and "photosynthetic

97   prokaryotes" [13: 25]. Thus cyanobacteria, being in the capsule, the inner wall of which has the same

98   properties as the outer wall of the host, appeared in natural conditions close to them in symbiosis and

99   in result continued normal existence in endosymbiosis [17]. Endosymbiosis begins with a minimal

100   number of cyanobacteria inside the host – $N_p = N_g * n_g$ and in groups – n_g (N_g is the number of groups).

101   This is determined by the initial lack in host of a necessary system for supplying cyanobacteria and

102   distribution of their products (i.e. an infrastructure). The number of groups N_g, seems less critical,

103   since supplying them in this case is local and may be carried out at symbiotic level. During evolution

104   of endosymbiosis, the number of groups N_g containing 1 and / or 2 dots at first should increase and

105   then upon reaching a certain level of supplying (appearing infrastructure) quantity n_g of

106   cyanobacteria per group may start to increase. Fig. 2 shows the dependence of $\mu(N_g)$ (empty

107   symbols) for some fixed values of n_g. The parameter μ decreases from 1 to ≈ 0.25 with the growing

108   number (from 1) of groups N_g and a minimum fixed number ($n_g = 2$) of points per group. The same

109   figure shows the dependence of $\mu(n_g)$ with increasing n_g for several fixed values N_g (black symbols).

110   The parameter μ increases weakly with the number of points in the group n_g at a small fixed number

111   of groups N_g (≥ 2). When N_g value is large then the parameter μ increases at first rapidly with n_g and

112   then slowly, remaining slightly less than 1. The abscissa in Fig. 2 shows the evolutionary "time" T_2 as

113   the total number of doublings corresponding active (not fixed) variable – N_g or n_g (chloroplasts
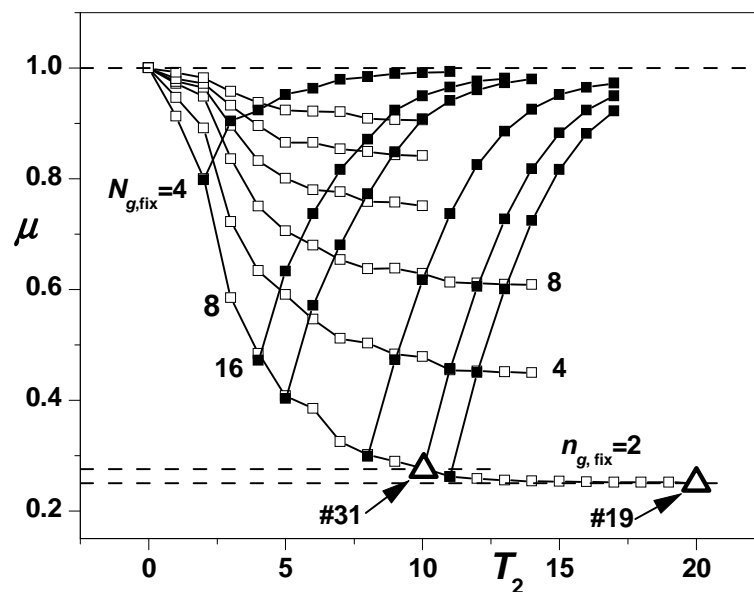
114   reproduce by dividing in half).

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Fig. 2. Two-dimensional images of three-dimensional trajectories of dependencies $\mu(N_g, n_g)$. Examples of combined trajectories: part $n_{g,\text{fix}}$ at a fixed value n_g (empty squares) and part $N_{g,\text{fix}}$ at a fixed N_g (filled squares), $A = 0.005$. Empty triangles - $\mu_{\#19}$ and $\mu_{\#31}$ correspond to nature data [7] and their model interpretations [6] (see inset in Figure 1, #19).

Consider the possible trajectories of the endosymbiotic proto-plants in space (μ, N_g, n_g). It is evident that the proto-plant begins as a series of infestations by solitary cyanobacterium into the host's body in random places of an interval. Since the reproduction of it is not possible, then $\mu = 1$ regardless of the number of points. When cyanobacterium gain an opportunity of dividing with the restriction $n_g \leq 2$, and is removed the restriction (if it was) on the number of groups N_g, evolution begins on a trajectory $n_{g,\text{fix}} = 2$ (Fig. 2) going with decreasing to $\mu \approx 0.25$. When at some moment T_2 immediately or gradually in the course of evolution is removed the restriction of division cyanobacteria in groups, the evolution of proto-plant goes over to the appropriate trajectory $N_{g,\text{fix}}$ (Fig. 2), which leads to an increase in magnitude of μ to the value of 1. When fractal parameter μ reaches 1 the situation is already corresponds to the sets of linear elements, i.e., the piecewise linear or continuous filling of interval (considering the real size of the green "point"). This assembly procedure is shown in Fig. 3 for multiple combinations of fixed values $n_{g,\text{fix}}$ and $N_{g,\text{fix}}$. Thus, during the evolution of proto-plant the dependence $\mu(T_2)$ of the fractal parameter must go out from the 1, to pass through a minimum and then again tends to the value 1. In this picture, obviously, profound detalization is possible, depending on symbiotic "experience" of protist and cyanobacteria – for example, trajectory could start with $n_{g,\text{fix}} = 4$, as shown in Fig. 2, or depending on value N_g of host, at which the trajectory type is changed, but it does not change the nature of the trajectory of the proto-plant. It may be noted that it follows from this the countability of set of variants of this evolution, which led every the proto-plant into state of a plant

138   with $\mu = 1$ in different evolutionary times T_2 and, consequently, could give different previous and / or

139   subsequent histories of plant evolution. In Fig. 2 positions at the trajectory $n_{g,\text{fix}} = 2$, corresponding to

140   the values μ (#19 and #31) received for the two sets of natural values of $t_{D,j}$ for spruce [7], are marked

141   by asterisks. It is evident that a proto-spruce (# 19) spent on the evolution approximately twice as

142   much "time" than of the proto-spruce (# 31), and this was reflected in their "descendants" [6, fig. 5].
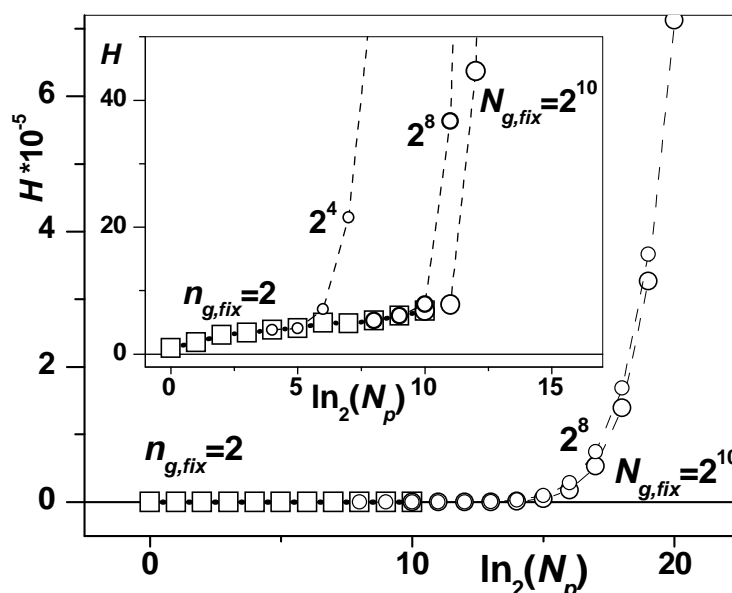

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Fig. 3. The initial deceleration of the proto-plant growth during endosymbiosis. The dynamics of the size $H \sim B^{1/\mu}$ of system of green "points" corresponds to an increase in their biomass (population, unit of biomass – a mass of cyanobacterium). Inset: movement along trajectories $\mu(n_{g,\text{fix}}, N_{g,\text{fix}})$ with an increase in the number of groups of N_g in the first portion, where the number of $n_{g,\text{fix}}$ points in the group (the squares) is fixed, and in the second portion $N_{g,\text{fix}}$ (circles, dashed) – increasing total $N_p = N_g * n_g$ by way doubling the number of "points" n_g in groups with using the combined dynamics of the fractal parameter $\mu(T_2)$ (see Figure 2.)

INITIAL GROWTH DECELERATION OF PROTO-PLANT

151   As seen from the foregoing, green biomass (i.e., the number of cyanobacteria involved in

152   endosymbiosis) is the leading variable in the evolution of proto-plant. Therefore, "turning over" the

153   ratio (1) and using the obtained dependence $\mu(T_2)$, we can calculate dynamics of the characteristic size

154   H of the system of points – $H(T_2) \sim (N_g(T_2) * n_g(T_2))^{1/\mu(T2)}$. Fig. 3 shows examples of the dynamics of

155   $H(T_2)$ demonstrating a very weak growth at the stage $n_{g,\text{fix}}$, which is replaced by an exponential rise on

156   stage $N_{g,\text{fix}}$.

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160   **DISCUSSION**

161   According to modern evolutionary theory (biogenetic law) "in embryonic development have

162   sometimes can be reproduced stages of evolutionary history" [14], i.e., may be the so-called

163   recapitulation, as which is usually understood a visually discernible similarity some stages of a modern

164   organism in embryogenesis and ontogenesis of its evolutionary ancestors. In this sense apparently, the

165   "punctiform recapitulations", which repeat visually sufficiently "strictly" the situation of occurrence of

166   proto-plant (at the beginning of the range $\mu < 1.0$ in Fig. 1), can be detected generally speaking in

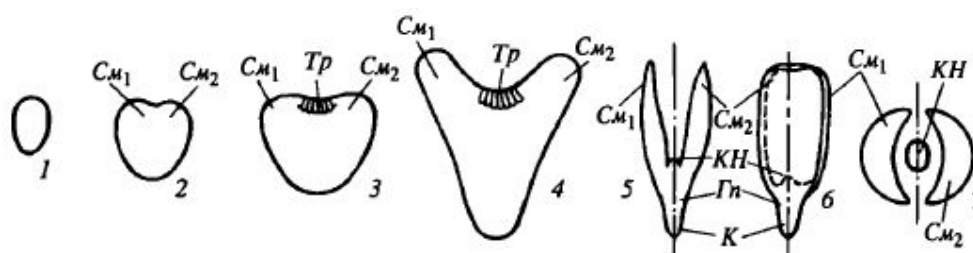167   higher plants twice.

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169   Fig. 4. The scheme of development of dicotyledons embryos. 1-4 - the early development of the embryo; 5, 6 - fully

170   formed embryo; view of two mutually perpendicular planes; 7 - a cross-section in the plumule embryos; CM1 and

171   CM2 - cotyledons, TP - growth point (before forming cone of growth CN); Hp - hypocotyl; R - root. Dashed line

172   shows the plane of symmetry (after [19: 144, Figure 70]).

173   The first time – in dicotyledons during embryogenesis when the seed embryo begins to turn green

174   due to the transformation of the existing leucoplasts into the chloroplasts [18] in course of the

175   transition from globular to heart phase of embryogenesis (Figure 4). [19]. The form (two cotyledons)

176   of the embryo in a heart phase and placement of chlorophyll [20] may be associated with the

177   appearance of "branches" of the first order in of proto-spruce (Fig. 1) with $\mu \approx 0.25$. Obviously, there is

178   no complete coincidence and can not be. The matter is that the proto-plant appeared at initial absence

179   of appropriate infrastructure and elements of the genome in the host, whereas a seed of higher plant in

180   early embryogenesis it all in some form already has. According to the model, we can assume that the

181   embryogenesis moves along a composit trajectory (of course, far more rapidly than a proto-plant has

182   appeared), which is similar essentially to that shown in Fig. 3, taking into account the differences of

183   their starting positions and structures. A distinctive feature of recapitulation, apparently, can be

184   considered a group character of plastids placement with fixed number of $n_{g,\text{fix}}$ in the group (Fig. 2,

185   open squares) during the growth of the total number thereof on the globular phase of embryogenesis

186   (Fig. 4 (1)) before and after the transition to the heart-shaped phase. The result of the plant

187   embryogenesis is the appearance of typically yellow, mature dry seeds, which have no active

188 chlorophyll (chloroplasts when ripe are converted to colorless plastids – leucoplasts [18, 21]), and are

189 able in this way to wait the appropriate conditions for germination.

190   The second time recapitulation can assume occurring during germination of mature dry, initially

191 yellow seed of a plant when embryo with the formed cotyledons begins to turn green as a result of the

192 transformation of existing colorless leucoplasts back in the green chloroplasts. Typically, this is a

193 natural process of increasing the number of active chloroplasts which is expressed in normal ontogeny

194 a plant. However for some economically important crops is observed, and it remains unclear [22] why

195 the seeds, sometimes remaining green when ripe, i.e., during germination having an additional

196 ("extra") chlorophyll, show poor germination, give low yields, and the poor quality of the product for

197 oilseeds. If we assume that the situation at the beginning of seed germination and activation of

198 "systemic" chlorophyll is reflected by the proto-plant model, then the role of "non-systemic" or excess

199 chlorophyll become clear. It is obvious that the activation of chloroplast in the embryo, having the

200 appropriate infrastructure is controlled by the genome. "Non-systemic" chloroplasts are not consistent

201 with infrastructure of embryo, are located quite randomly and are generating extra, "non-systemic"

202 oxygen that can damage cell structures [20, 23], i.e. adversely affect the process of germination and

203 further ontogeny. In addition, not only the quantity but also the spatial distribution of the additional

204 chloroplasts may be important as unacceptable for the existing infrastructure.

205   Thus formally in the ontogeny of the seed plants, there are two situations of recreating the

206 photosynthetic system, which are similar at least morphologically at a model situation of emergence of

207 proto-plant. In both uses the same elements that are in one of two states – leucoplasts and chloroplasts,

208 and presumably similar technologies switching them from one state to another. Evolution following the

209 principle of «Occam's Razor» not produces superfluous entities.

210   Apparently, in connection with the presented model it would be advisable conducting experimental

211 studies and model analysis of placement and transformation leucoplasts and chloroplasts in embryos

212 and plantlets of wild and related mutants of Arabidopsis in the early embryogenesis and germination

213 using fluorescence confocal microscopy [20].

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