ქ. უკლება, მ. ჩაკვეტაძე

რეზიუმე

ადამიანის ნაწლავის მიკრობიოტა, ცნობილი როგორც მიკროფლორა, შედგება მილიონობით მიკროორგანიზმისგან რომელიც ქმნის ეკოსისტემას და უმნიშვნელოვანეს როლს თამაშობს ორგანიზმის იმუნური სისტემის განვითარებაში.

იმუნური სისტემის მოდულაციის გზით, ნაწლავური მიკრობიოტა ეხმარება ორგანიზმს მრავალი დაავადების პრევენციაში, როგორიცაა: ათეროსკლეროზი, სიმსუქნე, დიაბეტი ,გაღიზიანებული ნაწლავის სინდრომი,ალერგიები, ფილტვის ქრონიკული ობსტრუქციული დაავადება და სხვა.

დისბიოზის მკურნალობა საჭიროებს პრებიოტიკებისა და პრობიოტიკების გამოყენებას,ასევე - ბალანსირებულ კვებას და ჯანმრთელ ცხოვრების წესს.

A Mathematical Model of Mammalian Life-History Traits Based on the Life-Continuity Coefficient

Akaki Dzneladze, Akaki Girgvliani
Akaki Tsereteli State University

Abstract: *This paper proposes a mathematical model describing the interdependence of mammalian life-history traits based on a novel concept, the life-continuity coefficient. This coefficient is defined as the expected number of offspring produced by a female individual that survive to sexual maturity. The model integrates maternal and offspring survival, fecundity, reproductive cycles, and mortality factors within a unified framework. It provides a basis for analyzing life-history strategies and their evolutionary optimization*.
Keywords: *life-history traits, mammals, life-continuity, survival probability, fecundity, mortality intensity.*

Introduction. Life-history traits are quantitative characteristics of organisms that determine their ability to survive and reproduce [1]. In mammals, such traits include lifespan, age at sexual maturity, gestation length, duration of the reproductive period, fecundity, body mass, brain size, and the duration of parental care.

Mammalian species differ substantially in their life-history traits. These differences suggest that life-history traits do not evolve independently but form a system of evolutionary trade-offs. Traditional life-history theory interprets these traits as adaptive responses to environmental conditions that maximize reproductive success.

The main assumption of this paper is that natural selection shapes life-history traits in such a way that the life-continuity of the species is maximally ensured. In this study, life-continuity is understood not merely as the birth of offspring, but as the successful survival of offspring to sexual maturity, when they themselves become capable of reproduction.

The aim of the paper is to develop a mathematical model based on the life-continuity coefficient, which describes the interdependence of the main life-history traits in mammals.

Existing Theoretical Approaches. Life-history theory considers growth, development, survival, reproduction, and aging as interconnected biological processes. According to the classical approach, natural selection promotes the evolution of life-history traits that increase survival and reproductive success under given ecological conditions [1,2,3,4].

One of the most widely used models in life-history theory is the Euler–Lotka equation, which links population growth rate to age-specific survival and fecundity [1,3]. This equation is effective for evaluating population growth. However, its main criterion is the rate of population increase, whereas the continuity of a species depends not only on the birth of offspring but also on their survival to sexual maturity.

Age-related mortality dynamics are often described by the Gompertz–Makeham model [5].This model is useful for describing the age-related increase in mortality, but it does not include all reproductive and parental-care components of the mammalian life-history.

Allometric approaches and Charnov’s models [6,7,8,9] occupy an important place in the study of mammalian life-histories. These models connect body size, age at maturity, adult mortality, growth, and fecundity.

Existing models provide important information about particular aspects of life-history. They describe population growth, age-specific mortality, allometric relationships, fecundity, and survival. Nevertheless, there remains a need for an integrated approach that combines maternal and offspring survival, the number of reproductive cycles, fecundity, and the attainment of sexual maturity by offspring within a single criterion.

The Life-Continuity Coefficient. Population growth does not always imply that the continuity of species life is ensured. A population may increase at the expense of sexually immature or post-reproductive individuals. Therefore, it is not sufficient to estimate only the number of offspring born; it is also necessary to take into account their survival to sexual maturity.

The life-continuity coefficient is defined as the expected number of offspring produced by one female individual during her lifetime that survive to sexual maturity. From an evolutionary perspective, it may be assumed that life-history traits of a species are shaped so that, under given environmental conditions, this coefficient approaches a maximum or near-maximum value.

According to this approach, life-history traits are considered as an integrated system that ensures the continuity of life of the individual, its offspring, and ultimately the species.

Temporal Structure and Mathematical Formulation of the Model. Let us consider a mammalian species in which a female individual mates again only after the completion of parental care for the offspring. For such a species, the temporal structure of the life-history can be divided into the following stages: the period before mating, gestation, lactation, post-lactation parental care, and the independent existence of the offspring until sexual maturity (Figure 1).

Let us introduce the following notation:

t_s — age at sexual maturity;

t_m — average time from readiness to mate until mating;

t_g — duration of gestation;

t_n — duration of lactation;

t_c — duration of post-lactation care of offspring;

t_i — period of independent existence of offspring until sexual maturity;

t_r — duration of the reproductive period;

$\bar{n}_{offs}$ — average number of offspring per reproductive event;

$\bar{n}_{rep}$— average number of reproductive events during the lifetime. The average number of reproductive events may be written as: $\bar{n}_{rep} = \frac{t_r}{t_m+t_g+t_n+t_c}$.

Let the maternal and offspring survival probabilities be denoted as follows:

$P_M^m(t_m)$ — probability of maternal survival until mating;

$P_M^g(t_g)$ — probability of maternal survival during gestation;

$P_M^n(t_n)$ — probability of maternal survival during lactation;

$P_M^c(t_c)$ — probability of maternal survival during post-lactation parental care for offspring;

$P_O^n(t_n)$ — probability of offspring survival during lactation;

$P_O^c(t_c)$ — probability of offspring survival during the period of post-lactation parental care;

$P_O^i(t_i)$ — probability of offspring survival during independent existence until sexual maturity.

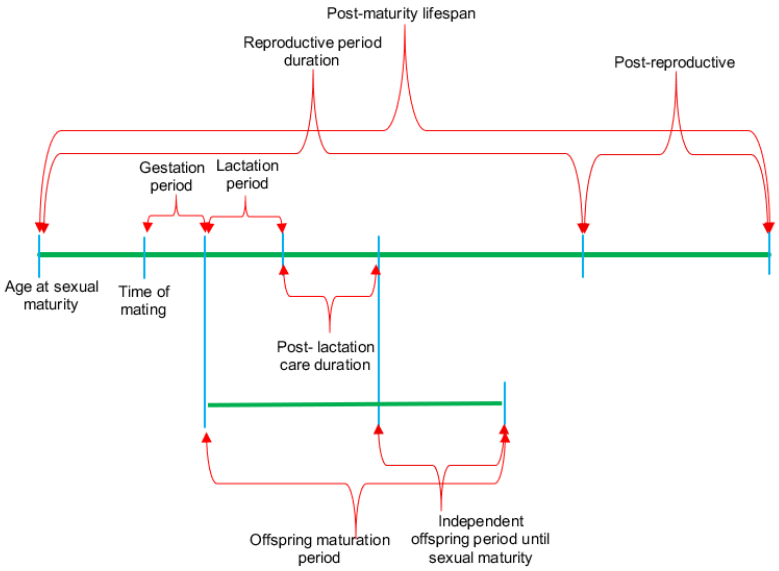


Figure 1. Schematic representation of the temporal characteristics of the life-history of a female mammal and her offspring.

The life-continuity coefficient can then be written as:

$$P_{lc} = P_M^m(t_m)P_M^g(t_g)P_M^n(t_n)P_M^c(t_c)P_O^n(t_n)P_O^c(t_c)P_O^i(t_i)\bar{n}_{offs}\bar{n}_{rep} \quad (1)$$

here, $P_{lc}$is the life-continuity coefficient of the species, that is, the expected number of offspring per female that survive to sexual maturity.

Assume that survival probabilities follow an exponential distribution. For each stage, $P(t) = e^{-\mu t}$, where μ is the mortality intensity of the corresponding stage. In this case, the model takes the following form:

$$P_{lc} = e^{-\left(\mu_M^m t_m + \mu_M^g t_g + \mu_M^n t_n + \mu_M^c t_c + \mu_O^n t_n + \mu_O^c t_c + \mu_O^i t_i\right)}\bar{n}_{offs}\bar{n}_{rep}. \quad (2)$$

This expression represents the basic mathematical form of the interdependence of life-history traits.

Mortality Factors. In mammals, mortality intensity depends on the combined effects of several factors. The main factors may include predation, starvation, environmental conditions, conflict among individuals, and infectious diseases.

The total mortality intensity μ can be expressed as the sum of its components:

$$\mu = \lambda_p + \lambda_s + \lambda_e + \lambda_c + \lambda_i \quad (3)$$

where λ_p is mortality intensity due to predation, λ_s is mortality intensity due to starvation, λ_e is mortality intensity due to environmental factors, λ_c is mortality intensity due to conflict, and λ_i is mortality intensity due to infectious diseases.

These mortality components may depend on body mass ω, brain size b, age a, resource availability ρ, and social structure or contact rate σ [10].

Under simplifying assumptions, the following relationships may be proposed: $\lambda_p = \kappa_p \frac{1}{\rho\omega}$, $\lambda_s = \kappa_s \frac{\omega a}{\rho}$, $\lambda_e = \kappa_e \frac{a}{b}$, $\lambda_c = \kappa_c \frac{a}{\rho}$, and $\lambda_i = \kappa_i \sigma \frac{\bar{n}^{offs}}{\omega t_n t_c}$, where $\kappa_p, \kappa_s, \kappa_e, \kappa_c$, and κ_i are proportionality coefficients.

In these relationships, an increase in body mass reduces the risk associated with predation but increases energetic requirements. Brain size may reduce vulnerability to environmental hazards. Mortality caused by infectious diseases may depend on fecundity, social structure, the duration of parental care, and ecological conditions.

The proposed relationships are heuristic and illustrative and should not be regarded as universal laws. They represent a modelling form whose parameters must be estimated on the basis of empirical data for particular species and environmental conditions.

Optimality Principle. As we mentioned above, the main evolutionary assumption of the model is that, in the process of natural selection, life-history traits are shaped in such a way as to maximize the life-continuity coefficient of the species.

If $\Theta = (t_m, t_g, t_n, t_c, t_i, t_r, \bar{n}_{offs}, \omega, b, \rho)$ is a set of the life-history traits of a given mammalian species, then the function $P_{lc}(\Theta)$ should attain a maximum or near-maximum value.

Thus, the evolution of life-history traits can be interpreted as a multi-parameter optimization process in which survival, fecundity, parental care, body mass, brain size, and resource availability play interconnected roles.

Model-Based Comparative Analysis. As a numerical illustration, the model was applied to two contrasting mammalian strategies: wolves [11,12] and deer [13,14]. The estimated life-continuity coefficient was approximately 3.9 for wolves and 1.8 for deer, reflecting differences in offspring survival and life-history strategies. The difference is primarily explained by higher juvenile predation and overall mortality in deer, whereas wolves benefit from lower adult mortality and extended parental care. This example illustrates that life-continuity is determined mainly by the structure of mortality rather than fecundity alone.

Applications of the Model. The proposed model may be used to:

- ✓ assess how close the life-history traits of a particular species are to evolutionary equilibrium;
- ✓ conduct sensitivity analysis and determine which trait has the strongest effect on the life-continuity coefficient of the species;
- ✓ evaluate the optimality of a species’ life-history strategy under current ecological conditions;
- ✓ identify species whose life-continuity is at risk.

Conclusion. This paper presents an approach to developing a mathematical model of the interdependence of mammalian life-history traits. The central concept of the model is the life-continuity coefficient, defined as the expected number of offspring produced by one female individual

that survive to sexual maturity.

The proposed approach differs from classical population models by focusing not only on the number of newborn offspring or the population growth rate, but also on offspring survival to reproductive age. The model provides a theoretical framework for comparing mammalian life-history strategies, assessing sensitivity of life-history traits, and analyzing evolutionary equilibrium.

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ძუძუმწოვრების სიცოცხლის ციკლის მახასიათებლების მათემატიკური მოდელი სიცოცხლის უწყვეტობის კოეფიციენტის საფუძველზე

აკაკი ძნელაძე, აკაკი გირგვლიანი

რეზიუმე

ნაშრომში შემოთავაზებულია სიცოცხლის უწყვეტობის კოეფიციენტზე დაფუძნებული მათემატიკური მოდელი, რომელიც განისაზღვრება როგორც ერთი მდედრი ინდივიდის მიერ წარმოშობილი იმ ნაშიერების მოსალოდნელი რაოდენობა, რომლებიც აღწევენ სქესობრივ მომწიფებას. მოდელი აერთიანებს დედისა და ნაშიერის გადარჩენას, ნაყოფიერებას, რეპროდუქციულ ციკლებსა და სიკვდილიანობის ფაქტორებს და შეიძლება გამოყენებულ იქნას ძუძუმწოვრების სიცოცხლის ციკლის სტრატეგიების შესადარებლად.

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