Species Senescence and Fractal Properties of Ageing

Igor Popov*

Saint-Petersburg State University, Faculty of biology, Department for applied ecology, 199178 Saint-Petersburg, 16 Linia VO, 29, Russia

Abstract: The senescence of species and species groups is a real phenomenon similar to the senescence of an individual. The most remarkable evidence of it is an extinction of numerous species groups, which cannot be explained by negative impact of environmental changes. The mechanism of species senescence can be characterized as follows: the organisms tend to produce the copies of themselves, but they cannot reproduce their exact copes for indefinitely long time, that is why the species inevitably change in process of change of generations of its representatives, even if the species is already well adapted to environment; such a continuous species transformation takes place in definite directions because of various constraints even if such directions are not rational and lead to extinction. The species senescence indicates on the fractal properties of ageing: it is scaleless, and existing at all biological objects, one of which is a part of the other.

Keywords: Species, senescence, fractal, extinction, palaeontology, mechanisms of ageing.

INTRODUCTION

One of the primary objectives of gerontology is a counteraction to the senescence of the *Homo sapiens* species representatives. What if not only organisms age, but the whole species as well? In such case the objectives of gerontology have to be extended: it should counteract not only ageing of individuals, but the species ageing too. Species senescence is discussed rarely now, but the topic seems to be important. What if we will become extinct like dinosaurs? Analysis of species senescence is significant not only for the evaluation of the *Homo sapiens* species senescence, but for the general understanding of the mechanisms of ageing. The explanations of such mechanisms are numerous, and the searches for the new ones do not stop. If not only cells and organisms age, but the species and groups of species as well, the senescence can be considered as such a general feature of living object, which exists in every level of organization of living matter. Probably, some aspects of ageing can be seen better at the level of species, and that is why the information of species senescence can clarify mechanisms of the ageing of individuals, including the ageing of humans. The mathematic notion "fractal" can be used to characterize such a universal character of ageing. It was coined to name a figure, in which the parts are similar to the whole [1]. Revealing fractal properties is considered as a method of analysis of complexity, including the complexity of biological processes, and as a resistance to the costs of reductionism [2]. This notion stresses all general, which takes place in the processes of different scales, i. e. the processes in cell, individual, species, groups of species and up to entire biosphere.

The present paper focuses on the discussion, if there are reasons to consider species senescence as a reality. Meanwhile the species senescence is regarded as such a change of species and species groups, which is similar to the senescence of an individual, i. e. indicates to the end of their existence even if any negative impact of environment is exerted upon them. Such a precise definition is necessary, because the other phenomenon also can be named "species senescence" (which is probably related to the above mentioned), that is the increasing of a share of old individuals in the total number of species representatives [3].

HISTORY OF THE PROBLEM

During the period of evolutionary biology formation the viewpoint, that species have the lifecycle similar to the lifecycle of an individual, was often taken as self-evident. Before Darwinian time it was clearly expressed by some scientists. So, Italian palaeontologist Giovanni Batista Brocchi (1843) wrote rather expressively that in the process of evolution of a group its vital force weakens, the growth becomes difficult, the ability to breed reduces; the evolution of the group comes to end when new organisms achieve only embryonic stage, the faint beginning of life that animates it just disappears, and all dies together with it [4]. In parallel the opposite viewpoint was also expressed. Jean-Baptiste Lamarck (1809) claimed, that the species extinction is almost impossible, and if the ancient animals differ from modern ones, this means that they just transformed into others; while the real extinction

*Address correspondence to this author at the Saint-Petersburg State University, Faculty of biology, Department for applied ecology, 199178 Saint-Petersburg, 16 Linia VO, 29, Russia; Tel: +79117368402;
E-mail: igorioshapopov@mail.ru

can take place very rarely, and mainly the humans are responsible for it [5].

Both concepts acquired advocates and opponents during 19th century. The facts and speculations concerning species senescence became one of the sources of the non-Darwinian concepts on evolution and particularly the concepts of directed evolution or orthogenesis. The main idea of them was the following: the organisms have a predisposition to vary in definite directions, and this very predisposition determines evolution, while adaptation is not a mainstream of it. Yet in 19th the terminological confusion arose: Lamarckism, orthogenesis, the concept of species senescence interlaced. The most well-known term orthogenesis was coined to designate constraints on variation [6], was soon popularized as designation of series of forms, which could be composed among related species [7], but later it was often used to name the concept of species senescence [8-10].

The popularity of the concepts of directed evolution and species senescence increased in the end of XIXth century, reached a high point in the first third of XXth century. Numerous interesting facts, which afforded grounds to claim on the species senescence, were established in that period. For example, Burnet Smith generalized the data on development of gastropods and revealed the characters indicating on senescence (thickening of shell, growth of tubercles and spines up to the merging in crest or keel, lack of abutment of the last coil of shell, etc.), and then compared them with the transformations observed in fossil record [11]. Such a comparison showed much in common, i. e. the concept of recapitulation turned out to be applicable not only to embryogenesis, but to the whole life cycle. Smith described some particularities of the gastropod species senescence. The rates of senescence differed in different groups; species demonstrating senile features never give birth to any descendents, which could be detected in the next geologic layers; such senile groups were either side-branches of phylogenies or their final stages; the characters of senescence appeared not simultaneously.

The other palaeontologist Charles Emerson Beecher, which dealt with brachiopods and trilobites, also conducted a research on species senescence. He showed that the growth of spines is an indication of this phenomenon, and such process is similar to the lifecycle of organism having spines. As far as a germ grows up, the smooth larva acquires spines, which continuously grow reaching the maximum to the end of lifespan. Likewise the first representatives of a group have smooth surface, but in what follows the forms with spines originate and evolve. The highest development of spines and other complex outgrowths indicate the senescence of a group. After the appearance of such senile species the group usually becomes extinct, and in a case of persistence it is represented by primitive members, which do not have such structures. “Spinocity” turned out to be widespread not only among animals, but among plants and protists. Traditionally the spines are being considered as protective adaptation, but Beecher pointed out that their adaptive significance cannot be revealed in some cases. The spines originate irrespective of the advantage to organism being just a display of a stage of evolution [12].

German palaeontologist Karl Beurlen presented a general characteristic of species senescence in a series of publications on extinction [13-15]. He analyzed the explanations of extinctions by external influences, and came to the conclusion that they are hardly acceptable, because the extinction can take place without significant changes of environment and on the contrary, sometimes the extinction do not take place, while the environment changes (Such cases can be revealed at the Cainozoic mammals). That is why the action of environment is “secondary” or “modification” force influencing species extinction. This means that the processes causing extinction have to be looked inside the organisms. Beurlen analyzed the characters of animals, which appear before extinction - hypertrophied development of some organs (like, for example, tusks at mammoths and mastodons), “over-specialization”, increasing of variation, pathologies. He considered all these features as “pathologies in general sense”, which result in the decrease of fertility and extinction. Comparing species evolution with the organism lifecycle he claimed that species have to be considered as “Big individuals” (“Grossindividuen”), because they suffer the transformations similar to the changes of individual from birth to senescence and death. “Pathologies” were identified with diseases, i. e. the senescence and diseases also identified.

Abundant material on species senescence was collected by British palaeontologist William Dickson Lang. He investigated bryozoans of Cretaceous and found out that in various groups of bryozoans the thickening of zooidal skeleton took place. At least 11 phylogenetic trends of Bryozoans evolved in that way during Cretaceous, and the end of them was always the same: the skeleton became thick, the space for the viscera became so small, that the live of such organisms became impossible and they became extinct. Keeping calcium such organisms built graves for themselves [16]. The bryozoans having chitin are the most "perspective", while when calcium skeleton originate at them, their destiny becomes predetermined. Lang found out similar facts at other invertebrates, such as molluscs and brachiopods. Their evolution also took place in accordance with definite plan: shells become thicker, did not change back, the group became extinct. The studies of Lang were presented in manuals on palaeontology, that is why his ideas were being spreading in scientific community for a long time. However they hardly became popular. The colleagues of Lang criticized his interpretation pointing out that keeping calcium could result from increasing of salinity of the ocean.

Several others authors of manuals and generalizing treatises on palaeontology and evolution also considered species senescence as a real phenomenon. One of the most famous treatises "Bases of Paleonthogy" by German palaeontologist Karl Zittel, which was reprinted, reedited and translated several times, contain such interpretation [17]. The American scientists William H. Twenhofel and Robert R. Schrok [18] also wrote about it generalizing paleontological material on invertebrates. The other American palaeontologist Richard Lull also included analysis on "phylogerontic characters" in his treatise on evolution. From his point of view, all these characters (outgrowths, spines, crests, overdevelopment etc.) come to keeping "dead matter" (inorganic substances) in an organism [19].

Some scientists were carried away by these facts and speculations. So, a French writer Henri Decugis wrote a book: "Senescence of living world" [20], in which he tried to prove that absolutely all present species have senile characters and are close to extinction. Whales, brachiopods, south-American mammals edentates, the fishes having disk-like form, etc. - all species turned out to be either too big, or too archaic, or too flat, or too bizarre. Decugis believed that only human can resist species senescence due to mentality. Such a treatise can look absurd, but it is difficult to challenge it. It is well known that many species became extinct, and it is logical to suppose that the modern ones will extinct too; that is why the current stage of their existence can be considered as an evolution towards extinction, i. e. senescence. How to estimate, whether they started to age, or not? It s difficult to answer such questions, that is why the scientists often just spoke ironically about it. So, Glen Jepsen criticizing advocates of orthogenesis (1949), compared their views with a claim of a pessimist reading the list of the persons, which died over past year: so many great men died, while any great man was born [21].

In what follows the species senescence was also discussed sometimes, and not only in a field of palaeontology. This topic arose based on date on biochemical evolution. So, Alexander Blagoveshensky conducted profound research on the concentration of alkaloids in plants, and came to the conclusion, that this concentration increases in process of evolution. Such a tendency seemed to be a display of senescence. The most primitive plants "hardening" in morphological evolution have the highest concentration of alkaloids. At the beginning of the plant group evolution they produce many aliphatic and reach in energy substances, but then more and more cyclic ones appear, while the cyclic substances are the dead end for metabolism, because they are just kept in an organism not being involved in chemical reactions. That is why the plants having many cyclic substances represent the end of a group evolution [22].

An indication on species senescence was discovered in a specific field of zoology - "biospeleology", i.e. the studies of fauna of caves and other underground habitats. Some caves are populated by fishes, crustaceans and insects having specific characters: reduction of sight, pallid coloration, highly developed organs of touch, etc. Pallid and "unhealthy" appearance of such creatures provoked an idea on degradation and senescence in evolution. The French zoologist Albert Vandel elaborated an evolutionary concept based on the studies on these animals. His main idea was the following: it is not necessary to look for the sources in evolutionary biology somewhere outside the organism, any external factor, environment and selection is necessary. As well as the organisms, the phyletic trends originate, evolve, reach flourishing, age and die. Vandel himself faced with such species, which were "ill and old", that is why they were forced to hide in dark and wet shelters in order to avoid extermination by "young and healthy" ones. Vandel investigated such organisms over decades, and interpreting his data he always stated, that specific features of cave inhabitants just pretend to be adaptation, while adaptationistic explanation in this case is the same, that the consideration of catarrh, rheumatism and other diseases as adaptations to senility [23].

Any claim on species senescence was blamed by Darwinians. They evaluated them as follows: "Inadmissible in natural sciences phantasmagoria" (A. Weismann) [cit. from 24]. "A viewpoint that phylogenetic trend pass the lifecycle, starting from birth and ending by death of species (or a group), has to be rejected as evidently antiscientific" [25]. "Anthropomorphic and tautological viewpoint" [26]. It is difficult to find out more weighty arguments, but under the pressure of the popularity of Darwinism the evolutionary concepts containing the claims on species senescence came into shadow over last decades.

EVIDENCE OF SPECIES SENESCENCE

The most convincing evidence of species senescence is the difficulty of explanation of species groups extinction, especially of that groups, which dominated over significant part of biosphere (ammonoideans, dinosaurs, pterosaurs, rudists, etc.). Their extinction is usually explained by unfavourable change of environment or appearance of new competitors, but such explanations always turn out to be insufficient, and searches for new explanations do not stop. The greatest unclearness is a selective character of extinction of species belonging to definite groups of high taxonomic level, while extinct and persisted species could not differ in respect to capacity to resist negative impacts. Why, for example, in the end of Mesozoic at the cephalopods all ammonoideans became extinct, while nautiloids persisted? Why crocodiles and turtles persisted when dinosaurs became extinct? Why rudists became extinct, while oysters persisted? Why bonny fishes forced out many cartilagous fishes, but had not done the same with sharks and rays? Why mammals could exterminate dinosaurs eating their eggs, while could not do the same with turtles and crocodiles? The list of such questions can be very long. To answer them some scientists express a viewpoint, that the survived species had a good luck by chance [27]. However the survived species had some "non-casual" characters. In a period of flourishing of extinct species they were in primitive, non-variable and not-numerous condition. It would seem, that after negative change environment or appearance of competitors, at least a part of the representatives of widely distributed dominating groups would survive (like, for example, ammonoideans), but such groups became totally extinct, but their more primitive and not numerous relatives survived (like nautiloids). This means, that some processes of self-evolution preventing their further existence took place at the extinct organisms. Such an interpretation corresponds well to the fact, that above mentioned extinctions are slow and gradual processes occurring over millions of years. D. Donovan, a researcher of extinct cephalopods, compared such a process with a famous Haydn's symphony, in which the musicians leave orchestra by turn, and finally the symphony stops with the absence of performers [28].

The other evidence of species senescence is the existence of several "laws" or "rules" revealed in fossil record:

- "Cope's rule": at the initial stage of group evolution the organisms are non-specialized, but than the specialization progresses and finally became so narrow, that the organisms loss the capacity to react rapidly to the environmental changes and became extinct [29].
- "Deperet's law": the animals of big or giant size cannot represent initial stage of a group evolution, but always represent its final stage; in process of group evolution the gradual growth of size often takes place [30].
- "Law of inertia": if a trend of evolution had been formed, it progresses up to the maximum even if it leads to non-adaptive direction, i. e. after the achievement of well adaptive condition, the species continue to evolve "by inertia" [31, 32].
- "Law of irreversibility" or "Dollo's law": "The organism cannot even partly return to the condition of its ancestors, even if it will turn out to be in analogous conditions" [33].
- "Law of decrease of variability" or "Rosa's law": in process of evolution of a group its capacity to vary comes to zero, that is why it cannot react to environmental changes and become extinct [34].

Universality of these laws and rules was often challenged, because numerous exceptions in them have been found, and the statistics resulted in contradictive conclusions [35]. However at least some animal groups demonstrate such regularities (like above mentioned bryozoans and molluscs). Hence it appears a question, why such phenomena cannot be called senescence?

FALLOUT OF THE SPECIES SENESCENCE ANALYSIS FROM MODERN STUDIES

The studies on extinctions of remote past are being performed very intensively due to explicit applied significance: since the change of Earth inhabitants means the characteristic of geological layer, it provides grounds for geological studies including the looking for mineral deposits. Such studies are coordinated by global international projects. Several general reviews were published. The species senescence is not mentioned at all there. Moreover, a tendency to ignore all biological factors exists in palaeontology. Some authors develop extremely ectogenetic view concerning evolution: if it were not for stimulating impulses of environment, the life would stand at the level of protobionts [36]. Evolving organisms are considered as amorphous mass, which changes exclusively because of external influences. If such a concept would be in use in the studies of man, this would mean, that without the changes of environment the man would not grow and age remaining in a condition of child for indefinitely long time.

The great majority of interpretations of the extinctions mechanisms focus on abiotic factors. In this connection many hypothesis were formulated: 1. The solar system's revolution round the centre of galaxy causes the change of cosmos condition around the Earth (cosmic rays, magnetic fields, etc.), which makes negative influence on biosphere, namely the mass extinctions. 2. Big meteorites fall sometimes on the Earth causing natural disasters. 3. Supernova's explosions influenced biosphere killing almost all living organisms on the Earth. 4. Volcanic activity increased in some moments causing natural disasters and negative changes in biosphere. 4. Sometimes the sudden orogenic processes took place, which changed climate and other environment characters. 5. Oceanic inversion, i. e. zones of up- and down welling, was changed sometimes changing climate and causing mass extinctions. 6. Sudden changes in air transparency caused mass changes of vegetation and, correspondingly, animal world. 7. Gas composition of atmosphere, and in particular the oxygen concentration, changed causing mass extinctions, because some organisms did not have time to adapt to new conditions. 8. Solar activity explosions exerted negative influence on biosphere. 9. Level of Ocean was being changed causing sudden changes of environment. 10. Sometimes a Moon emitted flows of dust shadowing Earth and suppressing vegetation and whole biosphere. 11. Photoperiodic patterns changed because of some cosmic processes, and some organisms could not adapt to such changes. 12. There is an additional planet "Nemesis" in solar system, which moves by very big orbit approaching the Earth once per several millions years and causing natural disasters [37-39].

The biotic factors are being analyzed rarely. If they are taken into account, usually the primary action of the origination of new organisms is postulated, but not a mass extinction: new organisms appear and exterminate their predecessors. Although in modern studies a more complex scheme is usually outlined: exclusion of one species by the other could turn out to be a catastrophe for that species, which are not related directly with a new one, but are ecologically linked with the old one. For example, if the flowering plants forced out the coniferous plants, they automatically exterminated the animals adapted to the life at the expense of coniferous. Such a case could "shake ecological pyramids", cause "crisis" and finally global change of flora and fauna [40].

These hypothesises are often stay on the edge of science and science fiction, but they are still in use. Number of them is continuously increasing, although they always are either unconvincing or insufficient, because they do not explain the selective and gradual character of extinction. These problems are less visible in the most synthetic concept of bio-events, that is the concept of O. Walliser [38]. His main idea is following: the changes in biosphere are very numerous and manifold, their causes - as well; different impacts can cause similar events, and on the contrary, similar impacts could cause various events. So, the whole Earth history demonstrates a complex tangle of circumstances, and in different periods different factors were of the major significance. Thus, at the border of pre-Cambrian and Cambrian time the change of biosphere was caused by "biological innovation" - appearance of skeletons and other particularities, which resulted in "Cambrian explosion" of new phylums. In what follows, the change of climate because of glaciations caused the change of biosphere in Ordovician-Silurian boundary. In the middle of Devonian the level of Ocean was changed (black shale deposits marked it), and the next significant change took place (Kellwasser event). At the end of Paleozoic the extinction took place as a culmination of long climate changes related with Ocean level changes. Intensive Jurassic evolution of ammonoideans demonstrates an example of event determined by orogenic factors. Finally, the mass extinction of the end of Mesozoic demonstrates a remarkable example of extinction caused by cosmic impact.

Taking into account the questions mentioned above, the last interpretation seems to be especially improbable, but now it is impossible to get without such a hypothesis, because an iridium anomaly was discovered relatively recently: a high concentration of iridium was noted in the borderline between Mesozoic and Cenozoic, while such a concentration is usually considered as an indication of meteorites. Coincidence of the time such an anomaly and the time of final extinction of many groups of organisms gave an occasion for impressive stories about world-wide catastrophe, when the sky became dark of dust for years over whole Earth causing downfall of biosphere. The simple question: why many organisms persisted, was just overlooked. However the communication of iridium anomaly was published in "Science" and other prestige editions [41], that is why it is not done to ignore such a speculation.

Thus, even in the most synthetic concept on extinction explanation the biotic factors are not stressed, and the notion "senescence" is absent at all. In the other reviews on extinction the species senescence is not considered too [26, 39, 42]. It is evident, that historical concurrence of circumstances resulted in the complete fallout of the species senescence even from the studies devoted directly to the reasons of species extinctions. It was happened partly because the authors analyzing species senescence hardly formulated the mechanism of this phenomenon. Numerous terms were coined for it (orthogenesis, typolisis, phylogeronty, etc.) or blurred speculations on the disharmony or loss of plasticity were presented [9]. However the mechanisms of the ageing of individuals are also not enough clear, but it does not mean that the ageing of individual does not exist. That is why there are reasons at least to consider the possibility of species ageing as well.

MECHANISM OF SPECIES SENESCENCE

It is difficult to recognize the process of species senescence, because it is hardly compatible with Darwinian scheme of evolution. If to interpret evolution consistently in accordance with natural selection theory, any extinction is problematical, because even if the environment was changed negatively, the species have to change adapting to it and continue its own existence. According to the modern "evolutionary synthesis", a species absorb mutations as a sponge, that is why it possessees a great storage of hidden variations, and it reveals them in a case of necessity (when conditions change or new competitors appear). As regards the groups of higher taxonomic levels they possess much higher robustness, because they contain more variations, and are more widely distributed. In such a case the genera, families, orders, etc. have to be everlasting. However the fossil record shows the opposite situation: many groups of high taxonomic level could not change in rational direction and became extinct without any descendants. The species inability to change in desirable directions means the existence of various constraints on variation: it does not pass in every possibly direction, but moves "down the roads". In addition to fossil records, there are other indications on the existence of such definite directions of variations. The remarkable evidence is the fact, that it is impossible to create some variations in process of mass breeding and selection of some organisms (for example, blue-eyed Drosophila). The analysis of variety of any group results in a conclusion, that a real number of variations is lesser then that number, which can be modelled: there are no six-legged mammals, no viviparous birds or turtles, no infusorians weighting 100 kg, etc. [43]. Now such cases are usually considered as "developmental constraints": in the traditional scheme of mutation-selection an additional element have to be introduced, that is the way from gene to phenotype; such a way is determined by individual development, which has some own forces influencing phenotype [44, 45]. However it is not necessary to use such a complicated scheme. Many facts could be explained by more simple processes. In this connection the old studies of D'Arcy Thompson (1860-1948) about the "growth and form" are still the most deep and interesting in this field. He explored the correspondence of biological phenomena with mathematical and physical laws and formulas using various examples, and showed that many biological characters are constrained by physical processes. Such constrains were traced from some trivial cases as a limitation of size of flying animal up to the minute details of crystallization and surface tension processes in cells and tissues. For example, some Radiolarians and other invertebrates possess silicate spicules, which have definite form due to chemical and physical characteristics of silicates, and not because such a form was especially significant for the struggle for existence (as Ernst Haeckel claimed). Concerning Radiolaria, D'Arcy Thompson added that several kinds of them are equally drifted by waves irrespective of form specificity [46]. Such cases mean that just physical and chemical processes can create various constraints: if silicate can form only three-edged crystals, so the spicules cannot be four-edged. Moreover, in process of growth and complication a system of correlations develops creating more and more constraints on variation. The more complex is organism, the more numerous are constraints. So, the most primitive organisms can synthesize every necessary organic substance, but such a capacity decreases over progressive evolution, and the highest organisms become more and more dependent from consumption of specific nutrition [47]. The number of other constraints also continuously increases. Probably, this is the main reason of the fact, that new phylums do not originate for a long time. The main body plans appeared in pre-Cambrian time and then they just transformed revealing their potencies, not giving birth to others. The taxonomic level of new groups continuously decreases since Cryptozoic time. Over recent time just new populations or species originate. Traditional explanation of such a phenomenon means, that new ecological conditions prevent an appearance of a new phylum, because the ecosystems become more and more packed. However such an explanation does not take into account the fact, that different phylums or body plans can be very similar in respect to ecology. That is why the ecological obstacle for a new phylum origination is not bigger than for a new species. Moreover, the vast expanses of land were "free" for a long time after Cambrian, but any new phylum originated there. Mass extinctions or other "crisis" also regularly created new space, but it was populated by the representatives of the already existed phylums. Therefore, there was the other obstacle to the origination of new phylums - the constraints on variation and the growth of their number over evolution. Such a process can be considered as an ageing of species groups.

Thus, various constraints, which can be mostly reduced to physical and chemical processes, form definite directions of evolution irrespective of their advantages or disadvantages. Meanwhile the species cannot remain unchanged, because a variation takes place inevitably over reproduction. Organisms cannot produce their exact copies for indefinitely long time because of mutations, recombinations or just because of complexity of processes involved in reproduction. Some mistakes in the making exact copies of living organism are inevitable, that is why the species change over the change of generations of their representatives, even if the species are already well adapted to their environment and even such an environment does not change. Such a transformation takes place more rapidly at the complex organisms, than at the simple ones, because the mistakes of copying the complex system are more probable than of the simple one. Therefore the species of simplest organisms can evolve very slowly despite their capacity to reproduce rapidly, and on the contrary: the species of highest organisms evolve rapidly despite slow change of generations.

Good illustrations of the evolution mechanisms characterized above represent the evolutionary transformations of the cephalopod molluscs - nautiloids and ammonoideans. These groups demonstrate much in common: both had external shells subdivided into sections, the section contacting with environment contained viscera, while the others were filled with gas, which provided some buoyancy. A line marking the sections on the surface of shell ("suture line") serves as a diagnostic character between these groups. This line is straight or slightly bent at the nautiloids, but it is very sinuous at the ammonoideans (Figures **1,2**). First ammonoideans had the line similar to nautiloid's one, but then the complexity of line progressed. The late ammonoideans (ammonites) demonstrate fanciful decorations on the shell surface. Usually in general outline of these molluscs the complication of suture line (and, correspondingly, the septa between cameras) is considered as an adaptation to the strength increasing in relation with the adaptation to the life in deep waters. However more thorough analysis does not confirm such an explanation. Nautiloids having simple line are well adapted to the deep waters. The modern nautiloids were registered at the depth up to 504 m, while the estimated depth is 800-850 m [48]. The calculations on the resistance of the animal to water pressure also do not confirm the benefit of sinuous septa. Firstly, the vulnerability of the animal to the strong water pressure was related not with the septa complexity, but in the soft tissues contact with environment and internal cavity. Secondly, the straight of the shell depends rather on its radius and thickness, than on septa complexity [49]. Thirdly, an evolutionary inertia is observed in this case: over-complication of the septa does not contribute the strength increasing, but rather on the contrary. There are other hypothesises about the complex line benefits, but absolutely all of them are deconstructed by the well-known fact, that all ammonoideans became extinct unlike nautiloids, although nautiloids seemed to be "less fittest". Evolution of the whole shell shape is also difficult for understanding. The researchers of cephalopods often make the following conclusions: «What influence, if any, environmental factors can have had in driving this evolution, in accordance with the classical Darwinian adaptive canon, remains wholly unknown. Numerous claims in the literature to the contrary are almost invariably tautological. In short, we now know rather well how the ammonites evolved, but not why» [50].

«The shells of Calloman's Cardioceratidae got larger form time to time, they got smaller, they got fatter, they got thinner again, they acquired a cadiconic shell form, they lost it in due course. Were these changes adaptive responses to different environmental demands which then changed again, and led to a change of different direction? Were they not? If not, why did they happen at all? Some of the changes affected animals over a wide area of the globe, so the adaptation to local environmental changes is not a plausible explanation" [28].

Figure 1: A representative of nautiloids - *Nautilus inornatus* (Museum of natural history, Paris).

Figure 2: A representative of ammonoideans, *Ammonites perarmatus* (Museum of natural history, Paris).

Partly because of such enigmas, the studies of ammonoideans were always the source of various heresies in evolutionary biology including the concepts of species senescence [9]. Complication of suture line and whole shell looks like predetermined process similar to the growth of crystals. In some moment such a process resulted in the dead end: the shells became so complex, that any other transformation was possible. At this moment the extinction took place. Nautiloids, on the contrary, were relatively simple and could reproduce their "copies" without "mistakes" for a longer period, that is why they persisted despite numerous competitors. Meanwhile the competitors rather contributed their persistence: because of them nautiloids do not increase in number and do not spread over larger territory, that is why their "copying" takes place slowly, the evolution also passes slowly, and they changed a little over many millions years. Moreover, nautiloids have a long lifespan, reproduce slowly giving birth to small number of descendents. They produce very big eggs and, correspondingly, small number of them. Ammonoideans could reproduce much more rapidly producing numerous small eggs and planctotrophic larvae. The modern "living fossils" or other primitive organisms are often similar with nautiloids in this respect: they either reproduce slowly, or have a small distribution area, or have a long lifespan, or indicate an initial stage of a group evolution, or have all these characters (a reptile tuatara, *Sphenodon punctatus*, a mollusc *Neopilina galatheae*, a fish *Latimeria chalumnae*, etc.). On the contrary, among these organisms there are no species reminding the final stages of the evolution of a group (pterosaurs, ichthyosaurus, etc.). Living fossils provide additional evidence, that after mass extinctions not the members of dominating groups survived, but on the contrary, the members of primitive ones, which were persisted in small numbers since very remote past.

"Living fossils" allow to precise the scheme of the species ageing, that is to characterize the condition of acceleration or delay of senescence. If the evolution results from "mistakes" of exact-copying of organism, it takes place rapidly when rapid "copying" takes place. If the size of population does not change, such "mistakes" take place rarely, because only small part of offspring survive, therefore that descendents, which have more probability to appear, i. e. the most similar to parents. In such conditions the rare variations can appear very rarely, i. e. over many generations. On the contrary, if the offspring increases rapidly, the possibility to rapid appearance of rare variations appear. So, the macroevolution phenomena can take place in the large territory in the moment of rapid distribution of a new group, and not in the small remote islands.

Similar processes can be easily modelled in laboratory or in process of breeding of domestic animals and plants. Without big elimination of offspring, when the great majority of organism descendents survive, but not only the most probable ones, the rapid appearance of new kinds of variation or anomalies takes place. In such conditions a species changes "in space in time" giving birth to numerous subspecies, races, populations, stocks, etc. More than hundred years ago one of the founders of genetics Hugo de Vries conducted such experiments, discovering several "mutations". His results can be explained not by the fact that he discovered a species being in a condition of mutation - *Oenothera lamarckiana* (as he and his followers believed), and not by the fact that an untypical hybrid species turned out to be in his disposal (as his critics claimed), but by the fact that he created the conditions, in which the small number of organisms very rapidly give birth to very numerous descendents. He planted all seeds from a few number of plants and had received 54000 plants after two generations. In such an abundant outcome some abnormal variations appeared - giant plants, the plants with untypical leaf form, the plants with read nervure, etc. [51] In natural environment such variations could be detected only in very big series of samples. It is important to emphasize, that such an experiment represents just an analogy of macroevolution, and not is its reconstruction. The organisms, which are used in such experiments, are already the results of macroevolution, and are unable to repeat the events of remote past. The use of actualism approach has significant limitations in respect to the study of evolution: not all mechanisms can be reconstructed in experiment or observed in nature now.

FRACTAL PROPERTIES OF SENESCENCE

Based on the characteristic of species senescence, the senescence of any living object can be characterized: living object cannot remain unchanged; its changes are not always healthy, the changes take place in definite directions, that is why they inevitably result in unfavourable characters appearance, which do not allow its further existence. Such a characteristic does not contradict the data on senescence of cells and organisms. Studies on molecular and physiological bases of ageing revealed many processes related with senescence. Absolutely all of them mean some changes in an organism. These changes not always mean deteriorations or damages, but they possess the above mentioned property: they are inevitable, not always healthy, can take place only in definite directions.

Among numerous interpretations of ageing mechanisms the concept of telomeres is especially consonant to the above formulated characteristic of species ageing: terminal parts of chromosomes of somatic cells become shorter in process of cell division, that is why in some moment they cannot divide anymore, therefore some organs and tissues cannot function normally causing senescence [52]. Probably, in a whole genome something can "shorten" after copying, and such a process results in inability to reproduction of it in a moment. However the telomere concept is being only partly confirmed, like many other concepts aiming to explain the organism senescence. This means that ageing results from numerous processes, and different processes may cause it at different organisms. That is why only certain processes related with senescence can be suppressed, while if to suppress one processes, the other one will inevitable originate. That is why the senescence hardly could be totally exterminated. Most likely in a case of species the mechanisms are numerous as well, while sole genetic factor is also absent.

Since it is possible to reveal common features in the senescence of biological objects, one of which is a part of the other, there are reasons to consider senescence as fractal and general property of life, and to trace it up to the highest scales up to entire biosphere. The above mentioned fact of the impossibility of the origination of new phylums over last hundreds of millions years can be considered as a display of such a process: the biosphere is unable to fulfil some functions possible in remote past. The fact of current destruction of biosphere also partly indicates on its senescence. Now it is not a biosphere anymore, it is the sphere of human activities resulting in destruction of natural ecosystems.

If to consider senescence as a fractal, the ageing of individual cannot be considered as a specific character similar to Mendel's factors, which can be either supported or eliminated by selection. That is why the widespread view, that some organisms age, while the others - do not, have to be rejected. To confirm such a viewpoint several examples of "non-ageing" species are cited: some species of rockfishes, bivalve mollusks, turtles, hydrozoans, and, partly, some mammal species - bow-headed whales and mole-rats. The evidence of "non-ageing" or "negligible senescence" is the following: these organisms live for a long time, grow up to the end of life, do not lose the capacity to breed up to the death, the probability of their death does not change during their life in adult condition, the aging is "close to zero" [53, 54]. However the concept of negligible senescence contains significant gaps in substantiation. The units of senescence measurement similar to the units of length and mass measurement do not exist, that is why the claim of “zero” senescence is not enough substantiated. A viewpoint, that the probability of death does not change with ageing, is based on the data on isolated long-livers, which seemed to be healthy, but there are no direct data on the probability of their death and its change during the life. Such data cannot be obtained at all for many species. Firstly, some of these animals leave in deep ocean, and their observations are hampered; secondly, some of them are being intensively exterminated by humans, they have little chance to reach the maximum lifespan, and the circumstances of their death in old age in natural condition cannot be studied. Meanwhile such information is necessary to estimate the possibility of “non-ageing”: if the “non-ageing” organisms can die by themselves, if they have maximum and average lifespans, if the probability to became long-liver differs for different species representatives, this means that their ageing is just slow, but is not “zero”. The representatives at least of one species with “negligible senescence” - freshwater pear mussel, *Margaritifera margaritifera* - usually die long before reaching maximum lifespan; they have less chances to live 100 years, than, for example, 50 [55]. This means that they really age, but relatively slowly, and it is not well noticeable. Most likely the same situation concerns the other “non-ageing” organisms. Their slow ageing is related with slow metabolism rates: any change in an organism takes place slowly, that is why the ageing is slow too. Moreover, such organisms are primitive and simple, if to compare them with mammals, i. e. the organisms with “normal” ageing. The simplicity and complexity in this case can be estimated by quantity and variety of components of an organism. Fishes, bivalves and reptiles contain fewer components than mammals, the fewer components result in fewer changes and, correspondingly, slow ageing. On the contrary, the complex structure provokes more changes in an organism, and the ageing takes place more explicitly. That is why “non-ageing” species can hardly be revealed at the highest organisms. If some mammal species are being included in the lists of “non-ageing” ones, it always takes place with reserves, because the senescence always still exist at them. So, mole-rats can live more than other rodents and do not demonstrate senile characters over most part of the lifespan, but the senescence at the end of life still takes place at them. The period of senescence occupies only 15 % of lifespan. If the men would age in same rates, the senescence would appear after 100 years of life [56]. Such data on whales are not available. At the most famous long-liver only eyes were explored to determine the age (it was estimated as 211 years). From the viewpoint of hunter, which killed this whale, it was old, because its meat and blubber were tough [57]. Such mammals remind the primitive “non-ageing” animals, because they also suffer fewer changes than their relatives. The mole-rats live in underground, are not exposed to sunlight, are characterized by slow metabolism, relatively low body temperature. The bow-headed whales live in Arctic, where the nutrition is relatively pure and the temperature is low, that is why all changes in their organism take place relatively slowly.

PHENOMENON OF MAN AND THE SPECIES SENESCENCE

If to consider the species *Homo sapiens* irrespective of all manifestations of its intellect, its existence seems to be an indication of hominids senescence. One of the senile features is an origination of “anomalies” and “over-specializations”, i. e. that forms, which demonstrate maximum of differences from initial “non-specialized” representative of the group. The modern humans can be considered as such an anomaly if to compare them with their remote ancestors and their relatives. The other indication on senescence is the reducing of a species number. It also takes place among hominids: now it is represented by sole species, while earlier several hominid species existed simultaneously. The “law” of size increasing also can be detected, because primitive hominids were much smaller than modern humans.

There are some circumstances, which accelerate human evolution. Human is the most complex organism. This means that reproduction of its exact copies is hampered more than that of any other organism; that is why the species representatives will change more rapidly with the change of generations that the representatives of other species. These changes take place in a frame of constraints specified by historically emerged organisation. The number of constraints at human is bigger, than at any other organism, because the human organism is the most complex one. Thus, from the one hand, the change of the species must take place, but from the other hand it is impossible. At all groups, which have been extinct over long history of biosphere, such situation indicated proximity of extinction.

Thus, if to ignore all specific differences between human species and all other animals, the typical pattern of evolution arises: some time an origination of initial “type” took place; it evolved in definite directions, the number of its variations increased; then the variety was lost; the specialization and "overgrowth" progressed, the indications on imminent extinction appeared. "Imminent extinction" in geological sense could mean millions of years. It is difficult to point out definite time-frames, because now human evolution is influenced by several contradictive forces. From the one hand, lifespan is increasing; change of generations ("self-copying") slows down; that is why the change of species and, correspondingly, senescence, slows down too. From the other hand, population increases, the "self-copying" progresses, that is why evolution progresses and senescence approaches. Human species possesses an intellect, and it would seem that it can control its own evolution. The achievements of a human thought progress, but the irrational activities (wars, destruction of biosphere) progress too. This means that there are grounds to hope, that human species will resist species senescence, but now it does not do anything to control own evolution letting it take its course. It happens in part because the studies on species senescence fall out of science, although this process really exists. It is interesting, that similar conclusion was made from a research, in which the species senescence was considered as increasing of old representatives share in a species. Such phenomenon also takes place at hominids, and it also results in "regression" - decrease of number of descendents [58].

CONCLUSION

The senescence of species and species groups is a real phenomenon similar to the senescence of an individual. The most remarkable evidence of it is an extinction of numerous species groups, which cannot be explained by negative impact of environmental changes. The mechanism of species senescence can be characterized as follows: the organisms tend to produce the copies of themselves, but they cannot reproduce their exact copes for indefinitely long time, that is why the species inevitably change in process of change of generations of its representatives, even if the species is already well adapted to environment; such a continuous species transformation takes place in definite directions because of various constraints even if such directions are not rational and lead to extinction. The condition of slow species ageing is a simple structure or primitiveness of its representatives, slow reproduction rate, stable population, and stable environment. On the contrary, the condition of rapid evolution and, correspondingly, relatively rapid ageing is a complexity of structure, expansion and increasing of population, intensive metabolism, non-stable environment. The existence of species senescence indicates on the fractal properties of ageing: it is scaleless, and existing at all biological objects, one of which is a part of the other. The general mechanism of a biological object ageing is a change of its components, which takes place inevitably, has limits, and not always healthy. Since the absence of changes in an organism is impossible, total elimination of senescence is impossible too. Only its separate manifestations can be excluded.

AKNOWLEDGEMENT

The possibility to work in the libraries and museums of Paris provided by "La Fondation Maison des Sciences de l'Homme" contributed the fulfilment of this research.

REFERENCES

[1] Mandelbrot B. Les objets fractals, forme, hasard et dimension. Paris: Flammarion 1975.

[2] Dewey TG. Fractals in molecular biophysics. Oxford New York: Oxford University press 1997.

[3] Ruiz-Torres A, Beier W. On aging and life span of human species based on its evolution from Australopithecus up to modern human. Open longevity science 2008; 2: 107-113. http://dx.doi.org/10.2174/1876326X00802010107

[4] Brocchi G. Conchiologia fossile subapennina, con observazioni geologiche sugli Appennini e sul suolo adiacente: In 2 vol. Milano: Giovanni silvestri 1843.

[5] 1809, cit. from Lamarck JB. Philosophie zoologique ou exposition des considerations relatives a l'histoire naturelle des animaux. Paris: Martius 1873.

[6] Haacke W. Gestaltung und Vererbung. Eine Entwickelungsmechanik der Organismen. Leipzig: T. O. Weigel Nachfolger 1893.

[7] Eimer Th. Orthogenesis der Schmetterlinge. Ein Beweis bestimmt gerichteter Entwickelung und Ohnmacht der naturlichen Zuchtwahl bei der Artbildung. Zugleich eine Erwiderung an August Weisman. Leipzig: W. Engelmann 1897.

[8] Gould SJ. The Structure of evolutionary theory. Cambridge: Harvard Univ Press 2002.

[9] Popov I. Orthogenesis versus Darwinism. A historical issue. Saint-Petersburg: Sant-Petersburg University press 2005. (In Russian with summary in English).

[10] Popov I. Directed evolution of mankind and biosphere. In: Cigna AA, Durante M (eds) Impact of Radiation Risk in Normal and Emergency Situations. Springer Verlag 2006. pp. 211-218. http://dx.doi.org/10.1007/1-4020-4956-0_21

[11] Smith B. Senility among Gastropods. Proceedings of the Academy of Natural Sciences of Philadelphia 1905; LVII: 345-361.

[12] Beecher C K. The origin and significance of spines: a study in evolution. American Journal of science 1898; VI: 1-20. http://dx.doi.org/10.2475/ajs.s4-6.31.1

[13] Beurlen K. Vom Austerben der Tiere. I. Die Einwirkungen der Umwelt. Natur und Museum 1933; 63, 1: 1-8.

[14] Beurlen K. Vom Austerben der Tiere. II. Das Gepräge der aussterbenden Tiergruppen. Natur und Museum 1933; 63, 2: 55-63.

[15] Beurlen K. Vom Austerben der Tiere. 3. Der Artentod und der Individualtod. Natur und Museum 1933; 63, 3: 102-106.

[16] Taylor PD. W. D. Lang, orthogenesis and the evolution of Cretaceous cribrimorph bryozoans. In: Jackson PNW, Spencer Jones MES (eds) Annals of Bryozoology. Dublin: International Bryozoology Association 2002. pp. 275-299.

[17] Zittel K. Grundzüge der Palaeontologie (Palaeozoologie). München [u.a.]: Oldenbourg 1895.

[18] Twenhofel WH, Shrock RR. Invertebrate Paleontology. New York: McGraw-Hill Book 1935.

[19] Lull RS. Organic evolution. New York: The Macmillan company 1947.

[20] Decugis H. Le viellissement du monde vivant. Paris: Masson et C-i. 1943.

[21] Jepsen GL. Selection, "Orthogenesis", and Fossil Record. Proceedings of the American Philosophical Society 1949; 93, 6: 479-501.

[22] Blagoveshensky AV, Alexandrova EG. Biochimicheskiye osnovy filogenii visshekh rasteniy. Moscow: Nauka 1974. Благовещенский А.В., Александрова Е. Г. Биохимические основы филогении высших растений. - М.: Наука, 1974. 101 с. (In Russian. "Biochemical bases of phylogeny of high plants").

[23] Vandel A. Biospéologie. La biologie des Animaux Cavernicoles. Paris : Gauthier-Villars Éditeur 1964.

[24] Davitashwilli LSh. Prichiny vimiraniya organismov. Moscow: Nauka 1969. Давиташвили Л. Ш. Причины вымирания организмов. М.: Наука, 1969. 440 с. (In Russian. "Causes of extinction of organisms").

[25] Davitashwilli LSh. Istoria evolutionnoy paleontologii ot Darwina do nashikh dney. M.L.: AN SSSR 1948. Давиташвили Л. Ш. История эволюционной палеонтологии от Дарвина до наших дней. - М.;Л.: АН СССР, 1948. 575 с. (In Russian. "History of evolutionary paleontology from Darwin up to today").

[26] Bonis L de. Evolution et extinction dans le règne animal. Paris: Masson 1991.

[27] Clarkson ENK. Invertebrate Paleontology and Evolution. Blackwell Science Ltd. 1998.

[28] Donovan DT. Ammonites in 1991. In: House MR (ed) The Ammonoidea: Environment, Ecology and Evolutionary Change. Systematics Association Special Volume. 1993. No 47. Oxford: Clarendon Press, pp. 1-12.

[29] Cope ED. Primary factors of organic evolution. Chicago: Open Court Publishing 1896.

[30] Depéret Ch. Les Transformations du monde animal. Paris: E. Flammarion 1907.

[31] Döderlein L. Phylogenetische Betrachtungen. Biologisches Centralblatt 1888; 7: 394-402.

[32] Abel O. Die biologische Tragheitsgesetz. Biologia generalis 1928 ; IV: 1-102.

[33] Dollo L. Les lois de l'évolution. Bulletin de la société belge de géologie, de paléontologie et hydrologie 1893 7: 164-166.

[34] Rosa D de. L'Ologénèse. Nouvelle théorie de l'évolution et de la distribution géografique des êtres vivants. Paris: Libraire Félix Alcan 1931.

[35] Hone DWE, Keesey TM, Pisani D, Purvis A. Macroevolutionary trends in the Dinosauria: Cope's rule.Journal of Evolutionary Biology 2005; 18: 587-605.Krasilov VA, Zubakov VA, Shuldinner VI, Remizovsky VI. Ecostratigraphia. Teoria i metody. Vladivostok: DVNZ RAN 1985. Красилов В. А.; Зубаков В. А., Шульдиннер В. И., Ремизовский В. И. Экостратиграфия. Теория и методы. Владивосток: ДВНЦ АН СССР, 1985. 148 с. (In Russian. « Ecostratigraphy. Theory and methods »).

[37] Walliser O. Towards a more critical approach to bioevents. In: Walliser O (ed) Global bioevents in Earth History. Berlin: Springer Verlag 1986. pp. 5-16.

[38] Walliser O. Patterns and Causes of Global Events. In: Walliser O (ed) Global and Event Stratigraphy in the Phanerozoic. Berlin: Springer 1996. pp. 7-19. http://dx.doi.org/10.1007/978-3-642-79634-0_2

[39] [39] Alexeev AS. Massoviye vimiraniya v fanerozoye. Dr. thesis. 1998. Алексеев А. С. Массовые вымирания в фанерозое. Авт. дисс. докт. геол.-мин. наук. М. 1998. 76 с. (In Russian. Mass extinctions in Phanerozoic).

[40] Zherikhin VV. Izbranniye trudy po paleoecologii M, KMK. 2003. Жерихин В. В. Избранные труды по палеоэкологии. М.: КМК, 2003. 542 с. (In Russian. "Selected papers on paleontology").

[41] Alvarez LW, Alvarez W, Asaro F, Michel H. Extraterrestrial Cause for the Cretaceous-Tertiary Extinction. Science 1980; 208, 4448: 1095-1108. http://dx.doi.org/10.1126/science.208.4448.1095

[42] Boucot AJ. Evolution and extinction rate controls. Amsterdam. New York: Elsevier Scientific Pub. Co. 1975.

[43] Popov I. The problem of constraints on variation, from Darwin to the present. Ludus Vitalis 2009; XVII, 32: 201-220.

[44] Maynard Smith J, Burian R, Kauffman S, Alberch P, Campbell J, Goodwin B, Lande R, Raup D, Wolpert L. Developmental constraints and evolution. The Quarterly Review of Biology 1985; 60: 265-287.

[45] Arthur W. The origin of Animal Body Plans. A study in Evolutionary Developmental biology. Cambridge: Cambridge University Press 1997. http://dx.doi.org/10.1017/CBO9781139174596

[46] Thompson DW. On Growth and Form. Cambridge: Cambridge Univ. Press 2004 (1 ed. 1917, 2 ed. 1942) (sixth printing of 1961 ed.).

[47] Lwoff A. L'évolution phisiologique. Étude des pertes de fonction chez les microorganisms. Actual. Sc. Industr. 1944; 970: 1-308.

[48] Saunders WB, Ward PD. Ecology, Distribution and Population Characteristics of Nautilus. In: Saunders WB, Landman NH (eds). Nautilus. The Biology and Paleobiology of a Living Fossil. New York: Plenum press 1987. pp 137-162.

[49] Hewit RA. Relation of shell strength to evolution in the Ammonoidea. In: House MR (ed) The Ammonoidea: Environment, Ecology and Evolutionary Change. Systematics Association Special Volume. No 47. Oxford: Clarendon Press 1993. pp. 35-56.

[50] Calloman J. Jurassic ammonites: real phylogeny in real time. In: The Lyell Meeting: Approaches to Reconstructing Phylogeny. The Geological Society, Burlington House, 2002. p. 7.

[51] de Vries H. Die mutationstheorie. Versuche und beobachtungen über die entstehung von arten im pflanzenreich. Leipzig: Veit & comp 1901-03.

[52] Olovnikov A. Telomeres, telomerase, and aging: Origin of the theory. Experimental Gerontology 1996; 31, 4: 443-448. http://dx.doi.org/10.1016/0531-5565(96)00005-8

[53] Finch CE. Longevity, Senescence, and the Genome. Chicago: University of Chicago Press 1990.

[54] Finch CE. Update on slow aging and negligible senescence - a mini-review. Gerontology 2009; 55: 307-313. http://dx.doi.org/10.1159/000215589

[55] Popov I, Ostrovsky A. Differences in the Lifespan of the Freshwater Pearl Mussel *Margaritifera margaritifera* as Evidence for the Infeasibility of Negligible Senescence (Based on Data for St. Petersburg and Leningrad Oblast). Advances in Gerontology 2011; 1,2, pp. 191-197. http://dx.doi.org/10.1134/S2079057011020135

[56] Mele J, Edrey YH, Lewis KN, Buffenstein R. Mechanisms of aging in the naked mole-rat: the case for programmed aging. Ross. Khim. Zhurn. (Zhurn. Ross. Khim. Ob-va im. D. I. Mendeleeva) 2009; 53, 3: 64-72 (In Russian) (Мил Дж., Эндрей Й., Люис К., Бафенстейн Р. Механизмы старения голого землекопа: случай запрограммированного старения // Российский химический журнал. Журнал российского общества им. Д. И. Менделеева. 2009. Т. 53. Биохимические подходы к решению проблемы старения . С. 64 - 72).

[57] George JC, Bada J, Zeh J, Scott L, Brown SE, O'Hara T, Suydam R. Age and growth estimates of bowhead whales (*Balaena mysticetus*) via aspartic acid racemization. Canadian Journal of Zoology 1999; 77, 4: 571-580. http://dx.doi.org/10.1139/cjz-77-4-571

[58] Ruiz-Torres A, Beier W. On aging and life span of human species based on its evolution from Australopithecus up to modern human. Open longevity science 2008; 2: 107-113. http://dx.doi.org/10.2174/1876326X00802010107

Received on 28-10-2014 Accepted on 24-11-2014 Published on 31-12-2014

DOI: http://dx.doi.org/10.12974/2309-6128.2014.02.02.3