Practical importance of parasitic diseases: An outlook from the point of view of ecological parasitology

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Some tendencies in the global parasitological situation are considered from the point of view of ecological parasitology. As the world's human population continues to increase, it is very likely that the role of parasitic diseases in global health will also increase in the future. Most of well-established agents of infection continue to exist and require huge funding for their control and treatment. Moreover, 'new' infectious diseases are starting to be important, and they are very likely to become even more important in the future because of the rising density of the human population and the number of domestic animals, as well as the very low rate of natural selection for gene combinations governing resistance to parasites in the human population. From an ecological parasitology perspective, the appearance of such 'new' infections as Lyme disease, ehrlichiosis, AIDS, and others is considered to be inevitable, considering the rise of the human population. The evolution of agents of 'new' lethal infections is a real danger. Considerable additional funding for research, prophylaxis and treatment of parasitic infections will be needed to overcome the effects of parasites in the future. This is the result of our high density and the very low rate of natural selection. The cloning of animals avoids the need for sexual reproduction, which evolved partly to resist numerous parasites. If it becomes common, cloning will need an enormous arsenal of drugs and careful management to protect such 'monogenetic cultures', which are especially vulnerable to parasitic infections.

Key words: evolution of parasitic diseases, *Homo sapiens*, human population, ecological parasitology, animal cloning, global health

Developing the means to ensure healthy living and working conditions for the current and future human generations during intensive economic and social development is an important aim of ecological investigation. Numerous ecological problems related to the rise of the world population, such as pollution of the environment, disappearance of rare species, shortage of fresh water, habitat destruction, diminishing stability of the energy balance in the biosphere, climate change, and others have been a continual focus of interest for ecologists [6, 8, 12, 15, 20, 23, 26, 27, 42]. However, the role of parasitic diseases in global health during the current marked rise of the number of human beings and domestic animals has been insufficiently emphasised in the ecological literature. The main aim of this paper is to specify some tendencies for the future of mankind during the continuing population rise, based on the fundamental rules of ecological parasitology.

One of the most important achievements of ecological parasitology in the 20th century has been the understanding that agents of parasitic disease are normal co-habitants of any biocenosis, and that parasites and epidemics are important among wildlife to maintain the qualitative and quantitative stability of biocenoses [2, 4, 7, 16, 21]. Each population of free-living organisms is parasitized by numerous species of parasites [32]. Moreover, the number of parasitic organisms, including those of viral, bacterial and protistal origin, is much larger than the number of free-living ones. Parasitism influences host mortality and fecundity, and thus represents an important evolutionary force [2, 7, 16, 21, 38] that is likely to contribute to the evolution even of such global biological phenomena as sex and sexuality [16–18]. From the point of view of ecological parasitology, parasitism and parasitic diseases can be regarded as a mechanism for the regulation of host population density and stabilisation of ecosystems [4, 6, 7, 19, 21, 32].

According to different estimations [35], the overall species number of microorganisms, protists, plants and animals varies from 5 to 30 million. Approximately 2 million species have been described. The great majority of living organisms are of microscopic and small size, while the larger animals constitute an insignificant part of the biota [6, 15]. Taxonomic diversity, including the ratio between microscopic and macroscopic organisms (Fig., A), is an important factor stabilising the biosphere [6, 23, 24, 40]. The latter is a closed system, in which a very large part of the production and destruction of organic matter depends on numerous microscopic and small organisms [6, 15, 22]. This is the main explanation for why microscopic and small organisms clearly predominate in abundance in comparison to macroorganisms. Each species has an unlimited potential for reproduction [12, 22–24, 41]. Parasitism regulates host population density via diseases [4, 6, 7, 21]. If the density of any population increases notably (Fig., B), it usually becomes susceptible to epidemics that stabilise it, in accordance with the ecological potential of the environment, via reduced fecundity and increased mortality. As a result, the size distribution of living organisms fluctuates according to an evolutionarily-developed ratio (Fig., A). It is important to note that the parasitic regulation of each species abundance depends on the density of the host population [4, 6, 19]. Furthermore, parasitic regulation of a host population usually commences before a species destroys its environment, particularly its food resources, which is important as it helps to maintain stability of ecosystems. Additionally, this is a unique mechanism regulating the density of living organisms, including numerous species of predators [7, 21].

Human beings evolved in natural biosphere conditions that existed long before the unfavourable changes induced by anthropogenic disturbance. The early biological evolution of *Homo sapiens* as of any other biological species, was controlled by parasites and natural selection. The devastating epidemics of plague, cholera, smallpox, malaria and the remarkable losses due to various helminthiases, which were especially dramatic in cities and during wars in the 14th–19th centuries, were well documented [5, 10, 13, 28, 34]. In the developing world, especially in the tropics, parasitic diseases, including yellow fever and other arboviruses, rotaviruses, tuberculosis, trypanosomiasis, malaria, leishmaniasis, filariasis, schistosomiasis and numerous other infections, are still causing mass morbidity and high mortality [30]. During the past 200 years the human population has increased more than 5 times; currently it numbers

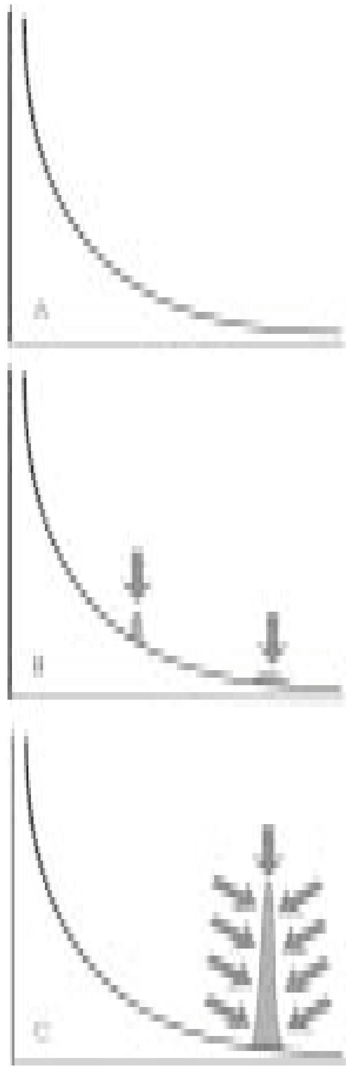

Fig. Diagrammatic representation of natural (A) and disturbed (B, C) relationship between abundance (ordinate) of living organisms and their linear dimensions (abscissa) in the biosphere. A – the evolutionarily-developed distribution of these quantities. The great majority of organisms are microscopic or small in size (bacteria, fungi, protists, invertebrates). They clearly predominate in number, while the large organisms (vertebrates) constitute a minute part of the biota. An increase in abundance of any population (B, shaded area) is normally accompanied by epidemics (arrows) which finally stabilise the number of each species in accordance with opportunities available in the ecosystem. C – the current distribution of different sized organisms in the biosphere due to anthropogenic disturbance. The huge peak in the number of large species (shaded area) is due to the marked increase in the human population and the number of domestic animals. Such disproportion causes many parasitological problems which are likely to be even more severe in the future because of the burgeoning of well-established, and the appearance of ‘new’, agents of infection the function of which, in an evolutionary context, is to stabilise the rise resulting from unlimited breeding of any living organism in the biosphere. A return to stability may be caused by massive epidemics of parasitic diseases. Additional explanation is given in the text.

approximately $6 \cdot 10^9$ and is estimated to rise to over $8 \cdot 10^9$ in 2030. Currently, people use approximately 10% of all biosphere production. This exceeds the permissible proportion of consumption of biota resources by large animals by approximately a factor of ten [15]. The current rise of the number of human beings and domestic animals (Fig., C) is based not only on increased food production and industrialisation, but is also related to the revolutionary development of medicine and medical industry, which involve considerable expenditure on research, prophylaxis and treatment of parasitic diseases. The current marked disturbance in the distribution of living organisms according to their size due to a significant rise in the number of human beings and domestic animals (Fig., C) is one of the most dramatic illustrations of the conflict between mankind and the biosphere. This leads to conflict between the ecosystem stabilising mechanisms represented by agents of parasitic diseases, on the one hand, and the rise of the global population, on the other. Human beings have been increasingly affected by diseases caused by viruses, bacteria, protists, helminths, and arthropods. The majority of well-established diseases such as arbovirus infections, tuberculosis, bacillary dysentery, pneumococcal pneumonia, salmonellosis, malaria, leishmaniasis, schistosomiasis, and many others still exist and require massive funding for their control and treatment, in part due to the development of resistance by many strains of parasites to commonly used therapeutic drugs. For example, because of the emergence of drug-resistant strains, tuberculosis has returned and now kills over 2 million people a year [37]. According to recent estimates [36], malaria is responsible for about 1 million deaths and over 200 million episodes of clinical disease in tropical Africa. About half a billion people in Africa, Asia, and South America are exposed to endemic malaria, which is estimated to cause 2.5 million deaths per year, of them, 1 million are children [33]. Over 40 million people have been estimated to be infected with trematodes causing liver and lung infections [30]. The number of reports of such traditional helminthiases as fascioliasis and anisakiasis has also increased significantly in human beings since 1980 [14, 25]. Even developed countries are not always able to prevent the great losses and mortality caused by well-established agents of parasitic diseases. An epidemic of drug-resistant tuberculosis [37] and an outbreak of encephalitis caused by West Nile virus [11] in and around the New York City in the 1990s are the examples. The outbreak of tuberculosis lasted for years and cost about US$ 1 billion. A low rate of natural selection for parasite-resistant gene combinations in the human population must also be taken into consideration as a factor contributing to the currently increased human mortality and morbidity from parasitic infections, but this is difficult to estimate. Health agencies certainly need to be improved permanently all over the world to control parasitic infections.

Due to unlimited global migration and the remarkable variety of both habitat and diet, people are exposed to more agents of parasitic diseases than any other species [3]. In spite of the efforts of medical research, *Homo sapiens* is one of the most parasitised of all animals. Approximately 400 species of protists, helminths and arthropods (excluding ticks and trombiculid mites) have been reported as parasites of human beings under natural conditions [3]. The great majority of them are rare. However, even obscure parasites represent an important evolutionary reserve as possible agents of important diseases in the future. Numerous human opportunistic infections may be a good illustration of this tendency. For example, being considered a rarity until the discovery of the Human Immunodeficiency Virus (HIV), cryptosporidiosis now accounts for up to 50% of all cases of chronic diarrhoea [30]. It is important to note that, from the point of view of ecological parasitology, the appearance of 'new' human diseases is not an accident but a biological inevitability related to the rise of the world population (Fig. 1, C). Human beings form a huge ecological niche, which is currently insignificantly inhabited by parasites due to the efforts of medicine and the medical industry. One of the current theories of the evolution [22] predicts that such 'relatively empty' ecological niches themselves stimulate the evolution of their exploiters. This is in accordance with an important and well tested rule of ecological parasitology which states that a marked rise of density of any population creates favourable conditions for the distribution of parasites and epidemics [7]. The current demographic 'explosion' of the human population is such a case. Such 'new' infections as the Acquired Immunodeficiency Syndrome (AIDS), Lyme disease, ehrlichiosis, and some others, which were recognised for the first time only in the second part of the 20th century, are burgeoning. Rotavirus infections kill about 600,000 children world-wide, and currently there is no way to prevent the infection [39]. Two decades after AIDS was first recognised as a new infection, about 50 million people became infected and approximately 20 million died [31]. This is very close to the number of Europeans killed during the most devastating epidemics of plague in the 14th century [9]. Because of the rise of the global population and the number of domestic animals, the importance of parasitic diseases for mankind is likely to increase in the future due to burgeoning of well-established infections and the appearance of 'new' ones. The appearance of 'new' agents of lethal parasitic diseases, especially those of viral and microbial origin, which have a great advantage in the rate of evolution and adaptation to new hosts due to their huge fertility and speed of reproduction, is very likely. Such infections are an ecological factor which tends to stabilise the rise both of human and domestic animal populations (Fig. 1, C). It is important to note that, because of a decreased mortality from parasitic infections in developed countries and thus a very low natural selection rate for gene combinations to resist parasites, the number of susceptible individuals permanently increases in the human population. Correspondingly, this leads to an increased probability of devastating epidemics. Due to the current molecular revolution in biology, development of genomic technologies, and computational advances, the perspective of new drugs and vaccine production has increased remarkably. However, these advanced biochemical and molecular methods are expensive. Furthermore, global problems such as drug-resistant pathogens, appearance of 'new' infections decreasing natural selection and thus the accumulation of susceptible gene combinations in the human population remain. African countries, which are home to an estimated about 70% of all HIV-infected people, currently receive a mere US$ 160 million for AIDS prevention. However, the World Bank estimates that Africa alone needs about US$ 1–2.3 billion for this purpose [9]. The pharmaceutical industry is spending huge funds on research and development. For example, the Centre for Medicine Research International in the United Kingdom spent over US$ 40 billion for these purposes in 1999 [1]. Unfortunately, about one-third of the world's human population does not have access to essential drugs [33]. Parasitic infection is an important problem for both public health and economic and social stability in every nation, especially in developing countries. The AIDS epidemic markedly stimulated biomedical research and pushed it into the global political arena. Mankind will certainly need to provide considerable additional funding to maintain healthy life in the future. This is the cost of our high density and the very low rate of natural selection. A return to the natural proportion of large organisms in the biosphere (Fig. 1, A) may be caused by massive epidemics of parasitic diseases. The evolution of agents of 'new' lethal infections, especially airborne ones, which have a rapid rate of distribution, is a real danger.

It is very likely that the important issues of animal cloning [29] may aggravate parasitological problems of mankind. One of the recent theories of the evolution of sexual reproduction suggests that sex and sexuality evolved, in part, to resist numerous parasites [16–18]. Due to recombination, each new sexual generation is genetically different from its parents and thus is a 'new habitat', to which the agents of infectious diseases need to adapt. Due to natural selection, this adaptation takes time and is costly in energy for the parasites. From the point of view of the theory of sexual selection, cloning bypasses the evolutionarily-developed sexual reproduction which continually provides hosts with new gene combinations to resist parasites. Adopting cloning as a common means of reproduction necessitates providing additional funding to resist parasitic infections.

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References

1. Agnew B. When pharma merges, R & D is the dowry. *Science.* 2000. Vol. 287, No. 5460. P. 1952–1953.
2. Anderson R. M., May R. M. Coevolution of hosts and parasites. *Parasitology*. 1982. Vol. 85. P. 411–426.
3. Ashford R. W., Crewe W. *The parasites of Homo sapiens. An annotated checklist of the Protozoa, helminths and arthropods for which we are home.* Liverpool School of Tropical Medicine. 1998. 128 p.
4. Balashov Ju. S. The significance of V. N. Beklemishev's concepts of parasitic systems and ecological groups of species for the development of parasitology. *Parazitologiya* (St. Petersburg). 1991. Vol. 25, No. 3. P. 185–195 (in Russian).
5. Beaver P. C., Jung R. C., Cupp E. W. *Clinical parasitology, 9th edition.* Philadelphia: Lea and Febiger. 1984. 825 p.
6. Begon M., Harper J. L., Townsend C. R. *Ecology. Individuals, populations and communities.* Oxford, Blackwell. 1989. Vol. 1. 667 p. (in Russian).
7. Beklemishev V. N. Disease agents as members of biocenoses. *Biocenotic bases of comparative parasitology.* Moscow: Nauka. 1970. P. 334–352 (in Russian).
8. Boyle T. J. B., Boyle Ch. E. B. (Eds.). *Biodiversity, temperate ecosystems, and global change.* Berlin et al., Springer-Verlag. 1994. 456 p.
9. Cohen J. Ground zero: AIDS research in Africa. *Science.* 2000. Vol. 288, No. 5474. P. 2150–2153.
10. Cox F. E. G., Kreier J. P., Wakelin D. (Eds.). *Topley & Wilson's microbiology and microbial infection, 9th edition.* London: Arnold. 1998. Vol. 5. 701 p.
11. Enserink M. New York's lethal virus came from Middle East, DNA suggests. *Science.* 1999. Vol. 286, No. 5444. P. 1450–1451.

12. Giliarov A. M. *Populational ecology.* Moscow University Press. 1990. 191 p. (in Russian).
13. Gilles H. M., Warrell D. A. (Eds.). *Bruce-Chwatt's essential malariology, 3rd edition.* London et al. 1993. 340 p.
14. Gorokhov V. V., Sergiev V. P., Romanenko N. A. Anisakiasis as an increasing ecological and social problem. *Med. Parasitol*. (Moscow). 1998. No. 4. P. 50–54 (in Russian).
15. Gorshkov V. G. The limits of biosphere stability. *Izv. Vses. Geogr. Obsh.* 1987. No. 4. P. 290– 300 (in Russian).
16. Hamilton W. D. Pathogens as causes of genetic diversity in their host populations. Anderson R. M., May R. M. (eds.). *Population biology of infectious diseases.* Berlin et al.: Springer-Verlag., 1982. P. 269–296.
17. Hamilton W. D. The seething genetics of health and the evolution of sex. In: Osawa S., Honjo T. (Eds.). *Evolution of life. Fossils, molecules, and culture.* Tokyo: Springer-Verlag. 1991. P. 229–251.
18. Hamilton W. D., Axelrod R., Tanese R. Sexual reproduction as an adaptation to resist parasites (A review). *Proc. Natl. Acad. Sci. USA*. 1990. Vol. 87. P. 3566–3573.
19. Kennedy C. *Ecological parasitology.* Moscow: Mir. 1978. 230 p. (in Russian).
20. Koenig R. Wildlife deaths are a grim wake-up call in Eastern Europe. *Science.* 2000. Vol. 287, No. 5459. P. 1737–1738.
21. Kontrimavičius V. L. Parasitism and the evolution of ecosystems. *Zhurn. obsh. biol.* 1982. Vol. 43, No. 3. P. 291–302 (in Russian).
22. Lekevičius E. Only the ecosystem is alive: a partly untraditional point of view on the evolution of life. Vilnius University Press. 2000. 108 p. (in Lithuanian).
23. Levin S. *Fragile dominion. Complexity and commons.* Reading, Helix. 1999. 264 p.
24. Margalef R. *A view of the biosphere.* Moscow: Nauka. 1992. 214 p. (in Russian).
25. Mas-Coma M. S., Esteban J. G., Bargues M. D. Epidemiology of human fascioliasis: a review and proposed new classification. *Bull. WHO.* 1999. Vol. 77, No. 4. P. 340–346.
26. Mikheev A. V., Galushin V. M., Gladkov N. A., Inozemtsev A. A., Konstantinov V. M. *Nature conservation, 3rd edition.* Moscow: Prosvesheniye. 1987. 256 p. (in Russian).
27. Myers N., Mittermeier R. A., Mittermeier C. G., da Fonseca G. A. B., Kent J. Biodiversity hotspots for conservation priorities. *Nature.* 2000. Vol. 403, No. 6772. P. 853–858.
28. Palmer S. R., Lord Soulsby, Simpson D. I. H. (Eds). *Zoonoses.* Oxford: Oxford University Press. 1998. 948 p.
29. Pennisi E., Vogel G. Clones: a hard act to follow. *Science.* 2000. Vol. 288, No. 5472. P. 1722–1727.
30. Peters W., Gilles H. M. *Colour atlas of tropical medicine and parasitology, 4th edition.* Mosby-Wolfe. 1995. 248 p.
31. Piot P. Global AIDS epidemic: time to turn the tide. *Science.* 2000. Vol. 288, No. 5474. P. 2176–2178.
32. Price P. W. *Evolutionary biology of parasites*. Princeton and New Jersey: Princeton University Press. 1980. 237 p.
33. Reich M. R. The global drug gap. *Science.* 2000. Vol. 287, No. 5460. P. 1979–1981.
34. Shuvalova E. P. (Ed). *Tropical diseases, 2nd edition.* Moscow: Medicine. 1979. 592 p.
35. Skarlato O. A. The introductory word at the opening of the session. Yurtsev B. A. (Chief ed.). *Biological diversity: the approaches to study and conservation.* St. Petersburg: Zoological Institute. 1992. P. 5–6 (in Russian).
36. Snow R. W., Craig M., Deichmann U., Marsh K. Estimating mortality, morbidity and disability due to malaria among Africa's non-pregnant population. *Bull. WHO*. 1999. Vol. 77, No. 8. P. 624–640.
37. Stokstad E. Drug-resistant TB on rise. *Science*. 2000. Vol. 287, No. 5462. P. 2391.
38. Valkiūnas G. Bird Haemosporida. *Acta Zool. Lituanica.* 1997. Vol. 3–5. P. 1–607.
39. Wickelgren I. How rotavirus causes diarrhea. *Science.* 2000. Vol. 287, No. 5452. P. 409–411.
40. Wilson E. O. (Ed.). *Biodiversity.* Washington: National Academy Press. 1988. 521 p.
41. Wöhrmann K., Jain S. K. (Eds.). *Population biology. Ecological and evolutionary viewpoints.* Berlin et al. Springer-Verlag. 1990. 456 p.
42. Yablokov A. V., Ostroumov S. A. *Living resource conservation: problems and prospects.* Moscow: Lesnaya promishlennost. 1983. 269 p. (in Russian).

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PARAZITINIŲ LIGŲ PRAKTINĖ REIKŠMĖ: PROGNOZĖ EKOLOGINĖS PARAZITOLOGIJOS POŽIŪRIU

Santrauka

Atskleistos kai kurios globalinės parazitologinės situacijos plėtros tendencijos ekologinės parazitologijos požiūriu. Žmonių ir naminių gyvūnų populiacijos gali toliau augti tik didinant parazitinių ligų tyrimo, profilaktikos ir gydymo finansavimą. Kadangi parazitizmas – nuo populiacijų tankio priklausantis reiškinys, o žmonių ir naminių gyvūnų skaičius pasaulyje be paliovos didėja, parazitinių ligų vaidmuo ateityje taip pat sparčiai didės ir turės dar daugiau praktinės reikšmės nei dabar. Išlieka dauguma senų, gerai žinomų infekcinių ligų, kurių profilaktikai ir gydymui reikia nepaprastai daug lėšų. Atsiranda ir plinta naujos parazitų sukeliamos ligos. Tokių naujų infekcijų kaip Laimo liga, erlichiozė, AIDS ir kitų XX a. antrojoje pusėje atsiradimas ir spartus plitimas ekologinės parazitologijos požiūriu yra dėsningi reiškiniai, susiję su dramatiškai padidėjusia biosferos egzistavimo dėsnių ir augančios žmonių populiacijos disproporcija. Didžiulis papildomas finansavimas bus reikalingas ateityje, siekiant išvengti didėjančio parazitų poveikio žmonijai. Gyvūnų klonavimas yra žingsnis atgal nuo vyraujančio biosferoje lytinio dauginimosi, kuris evoliucionavo kaip vienas iš parazitams pasipriešinimo būdų. Masinis gyvūnų klonavimas pareikalautų didžiulių lėšų apsaugoti nuo parazitų tokias monogenetinių kultūras, kurios yra ypač jautrios infekcijoms.

Raktažodžiai: parazitinių ligų evoliucija, *Homo sapiens*, žmonių populiacija, ekologinė parazitologija, gyvūnų klonavimas, sveikatos apsauga