doi: 10.5216/rpt.v50i2.69473

OPINION ARTICLE

THE ECOLOGY OF HERD IMMUNITY

Fernando Dias de Avila-Pires

ABSTRACT

The COVID-19 pandemic that began in early 2020 is currently the subject of thousands of articles on the various aspects of its epidemiology. One recurrent theme is the phenomenon of *herd immunity* or *herd effect*. In this article, I present a short history of the concept, the arguments around its nomenclature, and the ecologist's view of the herd effect, using the case history of the sleeping sickness control in Africa.

KEY WORDS: Herd immunity; convergence; ecology; sleeping sickness.

INTRODUCTION

My present objective is to clarify the nomenclature and meaning of the vaccine strategy to protect communities and not simply individuals, commonly known as *herd immunity*. It is necessary to approach it from the historical point of view as it involves the theory of evolution and a mathematical approach to epidemiology and infection control.

Convergent evolution may result in parallel solutions for similar needs or roles in unrelated taxa. In the present case, I discuss the similarities in the convergent survival needs and the dissemination and dispersal of a virus and of a hematophagous fly. Although a host must carry viruses and flies can fly, they are both limited by the need to preserve energy and by chance. The physics of energy conservation is the same in both non-living and living systems. Convergence in evolution means that unrelated species may adopt similar ways of life. This is a special case of homoplasy, which involves the evolution of convergent and parallel structures and behavior (Haas & Simpson, 1946; Hall, 2003; Hall, 2013).

Instituto Oswaldo Cruz, Department of Tropical Medicine, Manguinhos, Rio de Janeiro, Brazil. Retired.

Fernando Dias de Avila-Pires: ORCID https://orcid.org/0000-0003-1054-4573

Corresponding author: Fernando Dias de Avila-Pires, Rua Bico de Lacre, 79, CEP 88050-150 Florianópolis, Santa Catarina, Brazil. E-mail avilapires@gmail.com

Received for publication: 18/2/2021. Reviewed: 14/5/2021. Accepted: 16/6/2021.

According to Malein (1920), in March 2020 the Oxford English Dictionary defined *immunity as resistance to the spread of a contagious disease within a population that results if a sufficiently high proportion of individuals are immune to the disease, typically as a result of having been vaccinated against it*. In addition, immunity may also be due to a genetic characteristic or resulting from a natural infection.

Medical statistics became popular with Charles Darwin's cousin Sir Francis Galton, whose ideas have been used and abused since the middle years of the 19th Century. Bernard (1865), decrier of the concept of mathematics in biology, and of the mean values in physiology, criticized the attempt by a physiologist to determine the *mean composition of the European urine* by the analysis of urine collected from an international railway station pissoir.

Fierce arguments issued among mathematicians, as exemplified by the Pearson (1904) and Wright (1904) polemic discussions.

Early in the 20th century, statistical methods and concepts were eventually introduced into medical research. Malariologist Ronald Ross defended the idea that the epidemiology of infectious diseases should be approached mathematically (Heesterbeek & Roberts, 2015). At the same time, his contemporary Giovanni Battista Grassi, an Italian zoologist, solved the riddle of the malaria transmission by epidemiological/ecological methods (Capana, 2006). Since then, a large number of publications on the history of medical statistics applied to epidemiology provided a clear vision of this subject, which is outside the scope of the present article. (Fine, 1993; Farewell & Johnson, 2010; Schiøtz, 2015).

THE CONCEPT OF HERD IMMUNITY/HERD EFFECT

The idea behind the concept of herd immunity appeared in several observations, both in the laboratory and in the field in the early 20th century. Veterinarians who dealt with the health problems of herds were the pioneers. Eichhorn and Potter (1917) applied this concept to the problem of vaccination and abortion in cattle. Topley returned to it in 1919 and did not use the expression *herd immunity*, which had been used by Adolph Eichhorn in a *Report* to the Washington DC: United States Department of Agriculture in 1916 (Potter & Eichhorn, 1916).

In 1920 Smith et al., used the expression *immunity of the herd: The temporary dying out of the infection indicates that natural immunization of a herd to* Vibrio fetus *proceeds quite rapidly. Another outbreak may be expected when the immunity of the herd has declined in the absence of the infecting agent and the latter is reintroduced from without, or it may reappear at any time when a vibria of higher virulence is brought in*.

Bacteriologists Topley & Wilson in 1923, working with laboratory mice showed that unless there was a steady influx of susceptible mice in a colony infected with a bacterium, the rising prevalence of immune individuals would end an epidemic. In their *Report*, the expression *immunity of a herd*, not *herd immunity* was used for the first time, with an important comment, which has since been generally ignored: *Consideration of the results obtained during the past five years, both in experiments which have formed the subject of reports and in many others not yet recorded, has led us to believe that the question of immunity as an attribute of a herd should be studied as a separate problem, closely related to, but in many ways distinct from, the problem of the immunity of an individual host.* […] *We have referred above to the need for a careful study of the factors determining the immunity of a herd as distinguished from the disease in the unimmunized segment as a result of immunizing a proportion of the population.*

In 1925 Topley et al., returned to this subject, and the matter of nomenclature was soon the object of a fierce dispute.

Fine et al. (2011) remarked that *the term "herd immunity" is widely used but carries a variety of meanings. Some authors use it to describe the proportion immune among individuals in a population. Others use it with reference to a particular threshold proportion of immune individuals that should lead to a decline in incidence of infection. Still others use it to refer to a pattern of immunity that should protect a population from invasion of a new infection.*

Jacob & Reuben (2000) outlined the nomenclature and the conditions for the manifestation of the *herd effect* and eventually, Anderson & May (1985) and more recently in 2020 Jones & Helmreich aptly clarified the source of the disputed expression *herd immunity*.

No matter what name we use, herd immunity or *herd effect* as suggested by Fox et al. (1971) and by Jacob & Reuben (2000), meaning a portion of the population not immunized but protected from infection, has been recently mentioned in the news.

Notwithstanding the warnings concerning the idea of the natural community immunization, the pandemic that begun in 2020 revived and popularized the idea that an epidemic would dwindle and burn itself out like a fire when the scattered vegetation would lead to its extinction (Fine et al., 2011; Naafs, 2018; Ribeiro et al., 2020).

Jones & Helmreich (2020) reported on the proposed attempt by many countries to adopt this concept in the expectation that the epidemic would end when a sufficient number of the population had been immunized by exposure. In the United Kingdom, adviser Graham Medley said that *We are going to have to generate what we call herd immunity, which would require "a nice big epidemic"*. Furious criticism elicited a response from the authorities who denied that this idea had not ever been part of their plan.

THE ECOLOGICAL APPROACH: What the control of sleeping sickness teaches us about the COVID-19 pandemic?

From the point of view of the ecologist, the herd effect is a special case of population ecology, control, and survival. Gregarious behavior occurs in many taxa and it may be the result of independent evolution. Protection in numbers is a well-known phenomenon. Flocks of birds, school of fishes, herds of mammals – and planes in war missions are good examples of this, but Hamilton (1971) defends the opposite view, known as the *selfish theory*. This argument is not included in our present objective except for the notion that population ecology is too complex a subject to be approached in this analysis of herd behavior.

From the ecological point of view, parasite survival depends on genetic variation, mutation, selection, resilience, energy conservation, chance; it also depends on the respective hosts in relation to species, sex, age, dissemination, dispersion, geographical distribution and others.

Within this context, Glover (1967) discussed the ecological efforts to control sleeping sickness and nagana in East Africa and Northern Nigeria. These efforts are germane to our present discussion of the 2020 pandemic of COVID-19 caused by the virus SARS-CoV-2.

In Africa, sleeping sickness in man and nagana in non-human animals is the outcome of the infection by *Trypanosoma rhodesiense, Trypanosoma brucei, Trypanosoma gambiense, Trypanosoma vivax*, among other species transmitted by tsé-tsé flies of genus *Glossina* (Buxton, 1955). Glower (1967) recognized that the control of tsé-tsé flies should be based on the practical application of ecological knowledge, which is also valid for the control of human epidemics. As did Phillips as early as 1930.

Swynnerton (1925), described how: Jack (Shircore, 1914) has experimented on a large scale in the destruction of game-but while, here and there, the *checking of particular movements, large or small, of game animals may, if it is also feasible, be very necessary, no one wishes to exterminate our wonderful African fauna, a heritage of the Empire, of posterity, and of the scientific world, if we can control the tsé-tsé otherwise.*

Matthiessen & Douthwaite (1985) reported on the results of the control programs directed mainly to the three strategies: elimination of flies, removal of vegetation and eliminating mammal game species: Removal of mammalian hosts between the 1920s and 1960s resulted in the slaughter of 1.3 million game animals and extensive bush clearance. The same occurred in Tanzania as described by Malele (2011).

The efforts to starve the tsé-tsé flies taught us a lesson on *survival*, *chance* and *conservation of energy*. The flies hid in the shade in scattered bushes (Swynnerton, 1921). The need to get at their prey became more and more difficult, and the outlay of energy in the pursuit was greater than the gain in blood to compensate for the effort and the energy spent in the search for a suitable host.

So, as the population of game animals became rarified so did the flies, and there was no need (or possibility) to eradicate the host population (Phillips-Freitas et al., 2020).

The herd effect is based on a similar, convergent ecological principle. For a virus to replicate it must enter a cell. In order to survive, it must *find vulnerable hosts*, evade their defenses, and preferably, not kill the host (Alizon & Michalakis, 2015). When the chance of finding receptive and susceptible hosts becomes more and more difficult, as the majority of the population is immunized through infection or vaccination, the epidemic dwindles and may become extinct.

In both cases, there is an underlying ecological phenomenon: the role of energy spent in searching for a new host and the energy spent in search of food is ecologically both comparable and significant.

In the case of a virus infection "*With exhaustion of susceptibles, the epidemic dies down rapidly, and what cases occur will have little chance of passing on their infection."*[…] *the rate of spread of an epidemic* […] *is not only a function of the number or density of susceptible persons available* […]. (Macfarlane Burnet & White, 1972)

In the case of a predator, its survival - meaning the amount of energy spent - is a function of the number and *density* of their prey.

We must also be aware that:

1. The concept of group immunity is directly applicable only to isolated, randomly mixing populations, with few immigrants. However, truly random mixing can be presumed only in certain small closed populations and it never occurs in open populations.

2. Where individuals are either susceptible or fully immune, and immunity is durable.

3. The period of infectiousness must be short, and of approximately the same duration for all those who become infected.

4. The agent must only infect man and spread only by person-to-person contact.

5. The immunity must be long lasting, preferably for life.

6. All susceptible persons must have an equal chance of being infected, which can hardly occur in a large city and much less in a country.

In practice, the herd effect will be attained only through vaccination.

In the case of the present Covid 19 pandemic in Brazil, the possible development of natural herd immunity through the dispersal of the virus is not a viable or ethical option. This is due to its rates of morbidity and mortality, the variability of the period of infection among those who became infected; the possibility of the virus infecting domestic and wild animals and also its transmission to man; the longevity of immunity, even among those already vaccinated, the protection levels provided by different vaccines and finally, the fact that both in large cities and in the country susceptible persons do not have equal chances of acquiring the infection.

ACKNOWLEDGMENTS

I am grateful to Adriana Mohr and to my friends Felipe APL Costa and Alejandro Luquetti for the text, and for their most helpful suggestions.

REFERENCES

1. Alizon S, Michalakis Y. Adaptive virulence evolution: the good old fitness-based approach *Trends Ecol Evol 30*: 248-254, 2015.
2. Anderson RM, May RM. Vaccination and herd immunity to infectious diseases. *Nature 318:* 323-329, 1985.
3. Bernard C. *Introduction à l'étude de la médecine expérimentale*. Bailliere: Paris, 1865. 205p.
4. Buxton PA. *The Natural History of tsé-tsé flies*. University Press: Glasgow, 1955. 816p.
5. Eichhorn A, Potter GM. Contagious Abortion of Cattle. *Farmer's Bulletin 790*, Washington DC: United States Department of Agriculture, 1917.
6. Capana E. Grassi versus Ross: who solved the riddle of malaria? *Int Microbiol 99*: 69-74, 2006.
7. Farewell V, Johnson A. *The first British textbook of medical statistics*. JLL Bulletin: Commentaries on the history of treatment evaluation, 2010. Availlabe in https://www.jameslindlibrary.org/articles/the-first-british-textbook-of-medical-statistics/ Accessed in 14.mai.2021
8. Fine PEM. Herd Immunity: history, theory, practice. *Epidemiol Rev 15*: 265-302, 1993.
9. Fine PEM, Eames K, Heymann DL. Herd Immunity: A rough guide. *Clin Infect Dis 52*: 911-916, 2011.
10. Fox JP, Elveback L, Scott W, Gatewood L, Ackerman E. Herd immunity: basic concept and relevance to public health immunization practices. *J Epidemiol 94*: 179-189, 1971.
11. Glover PE. The Importance of ecological studies in the control of tsé-tsé flies. *Bull Org mond Santé 37:* 581-614, 1967.
12. Haas O, Simpson GG. Analysis of some phylogenetic terms, with attempts at redefinition. *Proc Amer Philos Soci 90*: 319-349, 1946.
13. Hall BK. Descent with modification: the unity underlying homology and homoplasy as seen through an analysis of development and evolution. *Biol Rev 78*: 409-433, 2003.
14. Hall BK. Homology, homoplasy, novelty, and behavior. *Dev Psychobiol 55*: 4-12, 2013.
15. Heesterbeek JAP, Roberts MG. How mathematical epidemiology became a field of biology: a commentary on Anderson and May (1981) 'The population dynamics of microparasites and their invertebrate hosts'. *Phi Trans R Soc B 370*: 1-9, 2015.
16. Hamilton W. Geometry for the selfish herd. *J Theo Biol 31*: 295-311, 1971.
17. Phillips-Freitas IT, Cupertino MC, Santos EC, Oliveira L, Geller M, Siqueira-Batista R. Human African trypanosomiasis: current standing and challenges. *Rev Patol Trop 49*: 133-148, 2020.
18. Jacob J, Reuben S. Herd immunity and herd effect: new insights and definitions. *Eur J Epidemiol 16*: 601-606, 2000.
19. Jones D, Helmreich S. The art of medicine. A history of herd immunity. *Lancet 396*: 810-811, 2020.
20. Macfarlane Burnet D, White D. *Natural history of infectious disease.* Cambridge University Press: Cambridge, 1972. 288p.
21. Malein F. *Herd Immunity - what's in a name?* Brit Soc Hist Med. Posted on 29th March 2020. Available in: https://bshm.org.uk/herd-immunity-whats-in-a-name/5/. Accessed in 30.jan.2021.

22. Malele II. Fifty years of tsé-tsé control in Tanzania: challenges and prospects for the future. *Tanz J Health Res 13*: 1-10, 2011.

23. Matthiessen P, Douthwaite B. The impact of tsé-tsé fly control campaigns on African wildlife. *Oryx 19*: 202-209, 1985.

24. Naafs MAB. Herd Immunity: A Realistic Target? *Biomed J Sciand Tech Res 9*: 1-5, 2018.

25. Pearson K. Report on certain enteric fever inoculation statistics. *BMJ 2*: 1243-1246, 1904.

26. Phillips JF. The application of ecological research methods to the tsé-tsé (*Glossina* spp.) problem in Tanganyika Territory: a Prelimin Account. *Ecol 11:* 713-733, 1930.

27. Potter G, Eichhorn A. *Report of The Twentieth Annual Meeting of the United States*. Live Stock Sanitary Association: Chicago, 1916. 86-92p.

28. Ribeiro GS, Hamer GL, Diallo M, Kitron U, Albert IK, Weaver SC. Influence of herd immunity in the cyclical nature of arboviruses. *Curr Opin Virol 40*: 1-10, 2020.

29. Schiøtz AEA. Medical statistics and epidemiology-the early history. *Norsk Epidemiol 25*: 3-9, 2015.

30. Shircore JO. Suggestions for the limitation and destruction of *Glossina morsitans*. *Bull 1ntomol Res 5*: 87-90, 1914.

31. Smith T, Little RB, Taylor MS. Further studies on the etiological role of *Vibrio fetus*. *J Exp Med 32*: 683-689, 1920.

32. Swinnerton CFM. An examination of the tsé-tsé problem in North Mosurise, Portuguese East Africa. *Bul Res 11*: 315-385, 1921.

33. Swynnerton FM. The Control of the tsé-tsé fly menace. *Nature 115*: 338-339, 1925.

34. Topley WWC. The spread of bacterial infection. *Lancet 5001*: 45, 1919.

35. Topley WWC, Wilson J. The spread of bacterial infection. The problem of herd-immunity. *J Hyg 21:* 243-249, 1923.

36. Topley WWC, Wilson J, Lewis ER. Immunisation and selection as factors in herd-resistance. *J Hyg 23*: 421-436, 1925.

37. Wright AE. Antityphoid Inoculation. *BMJ 2*: 1343-1345,1904.