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Controversies in parasitology

Most of the species on Earth are parasites

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Parasites exert a cohesive force that holds ecosystems together [1, 2]. That concept resulted from my being appalled over the way ecologists and conservation biologists were ignoring parasites as biological entities. Sure, they were treating them as pesky hazards of survival, along with adverse weather, stiff competition and predation, but no parasites appear on any of their lists of species to be saved. My initial response was my now famous slogan, "Equal Rights for Parasites!" [3–5]. Upon further pondering, I concluded that not only are they equal, but that parasites are greater than equal. Parasites are the majority of species on Earth. Furthermore, if they really are, then most biological knowledge stems from studying the minority of species.

To explore this situation, I emulated Albert Einstein. He is supposed to have imagined that he was travelling through space riding on a beam of light [6]. This fantasy adventure led to his discovery of the theory of relativity. My version of an Einsteinian trip was to imagine that I was travelling through our biosphere riding on parasites. What I saw was astounding! I saw very clearly that parasites were running the world, holding it together and managing it [1, 7].

Since my theory grew out of the notion that parasites were the majority of species, I often wonder if they really are. Thompson [8] describes parasitism as "the most common lifestyle on Earth" and states that "a significant proportion of the world's species are parasites". Parasitism is indeed a lifestyle and not a phylogenetic category. As such, parasites exploit all the free-living taxa.

From a purely practical aspect, the exact number of parasites will not be accurately known until all of their hosts have been described. This seems to be impossible due to the sheer magnitude of the situation, coupled with the shortage of taxonomists [9]. Estimating ratios of parasites to free-living species seems more feasible. Toft [10] estimates that 14.5% of eukaryotic species are parasites. This seems rather low. May, in 1988 [11], recognised that parasites account for about half of the species on Earth and in 1992 [12] he offered a ratio of four parasites for every free-living host.

Poulin [13] examined the relation between host body size and the description of new species of parasites. He reasoned that the more thoroughly the host group was known, the better their parasites would be known. Still he concludes that we are unlikely ever to obtain an accurate number of parasitic species. It is difficult to argue against this position. And, to make matters worse, we are losing species faster than we can classify them [14]. The prudent biologist might be tempted to give up on this apparently futile pursuit. However, it might be even more prudent to undertake a very different approach.

From a theoretical aspect, the exact number, or even the exact ratio, is not as important as the fact that parasites outnumber free-living species. With

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parasites being the majority, the consequences are staggering. Most biological studies, especially in ecology and evolution, have been done on free-livers. That is, the great bulk of our knowledge of biology comes from studying the minority of species!

Mathematicians are able to compare sets of infinities using Cantor's rule [15]. They do so by pairing elements in one set with those in another set. If no elements are left unpaired, then the two sets are equal. If, however, one or more elements in one set cannot be paired, then that set is the larger. Perhaps we can use Cantor's rule to compare the set of parasites with the set of free-living species.

Every free-living species has parasites. Any that are reputed not to have any have not been adequately studied. If each free-living species has at least one parasite species unique to it, then the number of parasite and free-living species would be equal.

We know that some parasites have many species of hosts. *Trichina spiralis*, "the king of helminth parasites", has 104 hosts in eight orders of mammals and one of birds [16].

However, we also know that some free-living species are hosts to many species of parasites. The American robin (*Turdus migratorius*) has at least 62 [17, 18]. The European starling (*Sturnus vulgaris*) has 126 species of helminths [19]. We (*Homo sapiens*) host at least 149 species [20]. And, these figures do not include the microbes. We have anywhere from 50 to 500 species of bacteria in our mouths [21].

Furthermore, we know that parasites themselves can have parasites. The famous statement of Jonathan Swift [22] comes to mind, "Fleas... ad infinitum". In Lyme disease, the blood-sucking, black-legged tick *Ixodes scapularis* is an ectoparasite of several species of warm-blooded vertebrates, the white-footed mouse *Peromyscus leucopus* and the white-tailed deer *Odocoileus virginianus* being the most famous, and is also the vector host of the bacterium *Borrelia burgdorferi* [23].

So, the data do not exactly produce a neat one-to-one match. Some parasite species have several species of hosts and some host species have several species of parasites. Nevertheless, after evaluating the above data, I conclude that the number of parasite species is much greater than the number of free-living species. Am I right? I really would like to know what other parasitologists think.

A standard way to test theories is to set up hypotheses and to try to prove them false. The hypothesis that parasites are the majority of species could be proven wrong if it could be shown that even one free-living species, which has been adequately studied, has no unique parasites; thereby, according to Cantor's rule, the unpaired element would be in the set of free-livers. Or, perhaps on a different twist, does anyone know of a well-studied host which has only one parasite? If that parasite were not unique, its host would be an unpaired element. What is the lowest number of parasite species in one host species? Perhaps readers can think of other tests.

The implications of parasites being the majority are very revolutionary for the entire field of biology. As per Kuhn [24], a scientific revolution entails a paradigm shift. Biologists must now view the world upside down and inside out, shifting their paradigm so that free-living species are viewed as devices used by parasites to propagate themselves. A nice parallel with Dawkin's selfish gene [25] comes to mind.

These implications are even more startling. The co-evolution of host–parasite relationships is very well established and much literature is devoted to it [8]. But, what is driving this co-evolution? My reading of the literature gives me the impression that the hosts are evolving to survive in the biosphere and the parasites are evolving just to be able to ride along with their hosts. If parasites are the majority, then perhaps it is they who are doing the driving and the hosts are just the vehicles. Or, more likely, there is a royal battle for overall control. At any rate, parasites are not just passengers, like children squabbling over who gets to sit where. Parasites are the true engines of evolution!

To recognise this close, dynamic, host–parasite interrelationship, I have coined the name "biocartel" to describe this association and have designated it to be the basic unit of evolution [26].

Finally, the most drastic paradigm shift caused by parasites being recognised as the majority would be in academics. Parasitology should be a predominant field in biology. Instead, it currently plays just a minor role. Most biologists get through

school, even graduate school, without ever taking a course in parasitology. How can any biologist, no matter what the field, ever understand biology without taking a course about the majority of species?

References

[1] Windsor DA. Endangered interrelationships; the ecological cost of parasites lost. Wild Earth 1995–96;5(4)78-83.
[2] Windsor DA. Equal rights for parasites. Perspect Biol Med 1997;40:222–229.
[3] Windsor DA. Heavenly hosts. Nature 1990;348:104.
[4] Windsor DA. Editorial. Equal rights for parasites. Conserv Biol 1995;9:1–2.
[5] Windsor DA. Equal rights for parasites. BioScience 1998;48:244.
[6] White M, Gribbin J. Einstein: a life in science. New York: Dutton, 1994;93.
[7] Windsor DA. Stand up for parasites. Trends Ecol Evolut 1997;12(1):32.
[8] Thompson JN. The coevolutionary process. Chicago: University of Chicago Press, 1994;121–33.
[9] Wilson EO. Time to revive systematics. Science 1985;230:1227.
[10] Toft CA. Communities of species with parasitic life-styles. In: Diamond J, Case TJ, editors. Community ecology. New York: Harper & Row, 1986;445–63.
[11] May RM. How many species are there on Earth? Science 1988;241:1441–1449.
[12] May RM. How many species inhabit the Earth?. Scient Am 1992;267(4):42–48.
[13] Poulin R. How many parasite species are there: are we close to answers?. Int J Parasitol 1996;26:1127–1129.
[14] Sprent JFA. Parasites lost? Int J Parasitol 1992;22:139–151.
[15] Gamow G. How to count infinities. In: One two three . . . infinity. New York: Mentor Books, 1947;25–34.
[16] Zimmerman WJ. Trichinosis. In: Davis JW, Anderson RC, editors. Parasitic diseases of wild mammals. Ames, IA: Iowa State University Press, 1971;127–38.
[17] Cooper CL, Crites JL. A check list of the helminth parasites of the Robin *Turdus migratoris* Ridgway. Am Midl Nat 1976;95:191–194.
[18] Peters HS. A list of external parasites from birds of the eastern part of the United States. Bird-Banding 1936;7:9–27.
[19] Cooper CL, Crites JL. Additional check list of the helminths of the starling (*Sternus vulgaris* L.). Am Midl Nat 1976;95:191–194.
[20] Swellengrebel NH, Sterman MM. Animal parasites in Man. Princeton, NJ: Van Nostrand, 1961;1–652.
[21] Hamilton G. Open wide, we're going to explore. New Scientist 1998;157(2125):32–37.
[22] Swift J. In: On poetry, a rhapsody, 1733. Cited in Bartlett J. Familiar quotations, 13th ed. Boston, MA: Little, Brown, 1955;296a.
[23] Ostfeld RS. The ecology of Lyme-disease risk. Am Scientist 1997;85(4):338–346.
[24] Kuhn TS. The structure of scientific revolutions, 2nd ed. Chicago: University of Chicago Press, 1970;1–210.
[25] Dawkins R. The Selfish Gene. Oxford: Oxford University Press, 1976;1–352.
[26] Windsor DA. The basic unit of evolution is the host–symbiont "biocartel". Evol Theory 1997;11:275.