Parasites, Pests, and Pets in a Global World: New Perspectives and Challenges

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Abstract

Taking into account that most of the known living organisms are parasites and that they exert a strong influence on the functioning of ecosystems, we can consider parasitism as a successful strategy for life. Because of the harm that parasites can inflict on man and domesticated animals, which can be expressed as economic loss, many parasites become pests. In natural ecosystems, parasites contribute to the prevention of continuous exponential growth of populations and, therefore, they also need to be conserved. The exotic pet trade may result in translocation of exotic species together with their microparasites and macroparasites, potentiating a risk of transmission of exotic diseases to native fauna and to humans. Within this context we need to increase our knowledge of parasites and parasitic diseases of wildlife. Prevention seems to be the choice for managing parasite exposure. This may be achieved through educational programs that refocused on discouraging people to import exotic pets, together with stronger legislative measures to control wildlife trade. © 2009 Published by Elsevier Inc.

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Life has been defined as a systemic activity that catalyzes conversion of entropy into information.[1] To achieve this and to complete their life cycles, organisms use different strategies. One of these strategies is parasitism, a symbiotic association involving parasitic organisms together with their respective hosts within a more or less intimate interaction, temporal or permanent, with unilateral benefit. The parasite has a physiologic and ecologic dependence on the host that provides the habitat and resources.

To have a living habitat gives 2 significant advantages to parasites: environmental stability and protection against predators,[2] but they must be able to obtain and metabolize nutrients from the host and develop mechanisms to protect themselves from the host's defense systems.

Some ecologic concepts allow us to better understand the concept of parasitism.[3,4] Parasites are adapted to exploit small and discontinuous (in space and time) habitats, and they must develop strategies for successfully finding the host and mechanisms for attachment and/or for penetrating it. They represent the extreme in specialized resource exploitation and this fact, coupled with the complexity of their life cycles, allows coexistence of many species in parasitic communities. Parasites exist under non-equilibrium conditions because they have a low

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probability of colonizing a host and a high probability of extinction.

Nevertheless, among all associations between heterospecific organisms, parasitism is probably the most difficult to be defined with precision because it represents or groups a wide range of metabolic and physiologic dependence,[5] pathological effects and mortality,[6,7] and also ecologic relationships between parasites, hosts, and environment.[3,8,9] Parasites differ from predators in respect of several biologic characteristics, such as their feeding strategy, size, reproductive potential, population size relative to that of the host/prey, specificity, outcome of a single act on host/prey population, superinfection by a single species, density-dependent effects, lethality, or the duration of the interaction.[2,10] Parasites may also be distinguished from mutualistic organisms, mainly from an evolutionary point of view: a parasite and its host, as species competing for the same resources, constitute 2 separate units of selection, whereas a mutualist and its host are components of a single unit of selection.[4]

Microparasites (e.g., viruses, bacteria, protists) have been defined as small organisms that multiply within the host at high rates of reproduction with short generation times, induce a durable immunity, have unstable populations, and are responsible for epidemic diseases. Macroparasites (e.g., helminths, arthropods, other metazoans) are large parasites that normally do not reproduce themselves within the host, show much longer generation times than microparasites, do not induce a durable immunity, have stable populations, and usually are responsible for endemic diseases.[11]

According to the location of the parasite on or within its host, we can distinguish between: 1) ectoparasites, which are in direct contact with the outside, as well as with its propagules; 2) mesoparasites, which are located in an organ with direct communication with the exterior; and 3) endoparasites, which are in a cell, tissue, or organ without direct contact with the outside, making the release of their propagules more problematic.[12] All of these parasites are at the same trophic level, in contrast to the structuring of hyperparasites, which parasitize other parasites.

Most of the modes of transmission shown by parasites are currently known: contact between hosts belonging to the same species and from infected to uninfected individuals; consumption of infected hosts; by biting vectors; and by active free-living stages. Vertical transmission can be defined as the direct transmission or infection from a host to its offspring (e.g., direct contact, transplacentally, transovarially, lactation). Complementing vertical transmission is horizontal transmission, which includes the remaining modes of transmission, both direct and indirect, of parasites between host individuals. The mode of transmission used by a parasite is linked to its virulence and host specificity. Horizontally transmitted parasites are known to be more virulent than those that are vertically transmitted.[13]

Parasites in a Global World

If we adapt ecologic terminology to parasites,[10] we can use the following definitions: an infrapopulation is composed of all parasite individuals belonging to a concrete species, which are found in a host individual at a particular moment; a metapopulation is formed by all infrapopulations of a parasite species, which are found in all host individuals of the same species in a concrete ecosystem or location; and, finally, a parasite suprapopulation includes all parasites of a determined species, in all of their developmental stages, which are located in all hosts (belonging to one or several species) present in a particular location and at a specific time.

Regarding parasite communities, we can differentiate a world (global) pool of parasite species, or a supracommunity. Today this concept is very relevant because of the intercontinental transport and economic interchange between distant regions (in a biogeographic sense) and, therefore, we can consider the Earth as a global home for most pathogens and infectious diseases. This global pool of parasite species is organized at a regional level in diverse metacommunities, which are distributed in large biogeographic regions as continents or subcontinents. At a local level, parasite communities are reorganized because of the existence of several “filters” (e.g., historic, cultural, environmental) that affect the dispersion of parasites. They, finally, constitute an infracommunity in each host individual, which includes all infrapopulations harbored by this specific host.

Host-Parasite Relationships

Because of their host dependence, the real biologic individuality of parasites has been questioned.[14] These authors consider the host-parasite duo as a “whole.” This system is also known as a “superorganism,” which possesses a “supergenome”[2] and receives resources from the outside, both partners being in competition for these resources. Then, an important consequence arises: each species’ genome is expressed within the context of the other species' phenotype. The concept of the "extended phenotype"[15] emphasizes that phenotypes of hosts and parasites result from interactions between the 2 genomes. However, it is also important to consider that host and parasite genotypes share control of the epidemiologic parameters of their relationship.[16]

The interaction between the host and the parasite is characterized by its asymmetry.[2] The host may reach its maximum fitness without the parasite, whereas the parasite without the host has no fitness at all. The fitness of a parasitized host is determined by various factors (e.g., availability of resources, competition). The resulting parasite-induced loss of host fitness (because of the damage caused and the competition for part of the resources used by the host) is defined as virulence,[17] which does not mean the same as pathogenicity. The life of the parasite is not of interest to the host, but the host's life is of interest to the parasite because the former is used as a habitat and as a vehicle. This second asymmetry has been used to define the concept of the cost of virulence. As a component of the parasite's fitness, virulence may also be used as a measure or index of the parasite survival within the host.[18] Parasite fitness is determined by the success of its transmission to new hosts. Therefore, the decrease of host fitness induces a concomitant decrease in parasite fitness, which needs to balance the costs and benefits associated with its virulence. The resulting self-limitation of virulence leads to the concept of optimal virulence. Host resistance has also been defined as virulence against the parasite, or host-mediated loss of fitness in the parasite, resulting in changes in its fecundity, density, and/or mortality.[2] The cost of resistance is expressed in terms of metabolic expense for the host and can vary throughout the host's lifespan.[19]

Certain parasites can infect their hosts vertically and horizontally. These 2 routes differ greatly in the way the parasite is transmitted and infects a new host, and infections resulting from each route may thus differ in terms of both host and parasite fitness. Hosts and parasites can have varied reactions to different routes of infection, which suggests that ecologic factors can shape the evolution of host and parasite life histories and, consequently, the evolution of virulence.[20]

Parasites and Biodiversity

It is more or less assumed that the number of parasite species exceeds that of free-living ones. Some estimations indicate that more than 50% of all known plants and animals are parasites, at least at some point in their life cycle, whereas others consider that the number of parasite species is around 4 times greater than that of free-living taxa.[3,21]

Although diseases and parasites may cause extinction, especially on islands,[22,23] in other scenarios they contribute in maintaining biodiversity and, therefore, might be conserved,[24] but generalizations are difficult to make.

Parasitism has also been considered responsible for much of the genetic diversity of natural populations and even as a major selective force resulting in the evolution of sex.[25,26] Parasites can contribute to an increase in genetic variability of host population by removing less heterozygous individuals, and this is considered to be a positive effect of parasitism.[27,28] Under certain environmental situations, parasites can become beneficial for their hosts, because they may protect hosts against predation and cannibalism and against other parasites (e.g., competition between parasite taxa); they may give advantages to parasitized hosts in interspecific competition (e.g., some host species can colonize new areas if the parasites they harbor are more pathogenic to endemic hosts); in sexual selection processes; or even in adverse environments (e.g., parasites may act as internal sinks for heavy metals in polluted habitats).[29]

Conflicts Between Parasites and Humans

One fundamental concept related to parasitism is the damage caused by the parasite to its host, which depends on certain characteristics of the parasite (e.g., host specificity, virulence, mode of transmission, intensity of parasitation, location on or within the host, composition of the parasitic community) and the host (physiologic status and resistance to a determinate parasite).

The effects of parasitism can vary greatly between individual hosts and also between host populations (see Pizzi and Scullion and Scullion, this issue). At an individual level, we can find a host lacking clinical signs of disease,[30] cases showing important and negative modifications in behavior[31] (see Ramnath, this issue), a greater or lesser reduction in host fitness,[32-34] an increase in asymmetry of certain organs,[13,35] and even cases in which parasitation (by one or several species) leads to the death of the host. The immediate consequences of parasitic disease may also be important at the population level,[36] as a density-dependent factor preventing continuous exponential growth of host population.[37,38] Also, the effects of an infectious disease on one particular host species may have an impact on other species by means of direct or indirect interactions.[39]

The cost to both humans and domesticated animals of becoming parasitized is, in terms of human misery and economic loss, incalculable.[40] Between 400 and 900 million people become infected with *Plasmodium* spp. each year, and more than 2 million, mainly children from sub-Saharan Africa, die of malaria.[4,41] As another example, economic losses in livestock caused by *Fasciola* spp. worldwide are estimated at US $2 billion per annum.[42]

Recently, the role of pets as reservoirs of antimicrobial-resistant bacteria (microparasites) has been stressed.[43]

In this context, parasites are usually considered as pests, and the risk of associating and confounding a particular way of life with a status arises[44] (see Pizzi, this issue).

Parasites and the Exotic Pet Trade

Wildlife constitutes an important but poorly known reservoir for many emerging infectious diseases, most of them of zoonotic concerns. Factors involved in the current trend of such diseases are related to the use of improved diagnostic methods, human behavior, modifications of natural habitats, changes in agricultural practices, consumption of exotic foods, development of ecotourism, and globalization of trade.[45]

The trade in live wildlife involves capture from the wild and the sale of billions of animals of many species each year. This includes the exotic pet trade, which deals with an increasing range of wild animal species, from invertebrates to mammals. Many of these animals have zoonotic potential and may harbor some important diseases, such as severe acute respiratory syndrome (SARS), monkey pox, rabies, hantavirosis, tularaemia, avian chlamydiosis, yersiniosis, alveolar echinococcosis, arthropod-borne encephalitis, or tick-borne diseases. These, among others, can be spread through contact with exotic pets.[46,47] This risk may be increased if the animals are kept in captivity before arrival at their destination.[23]

Scratches and bites are important, if not the main, mechanisms of disease transmission, but other infections may be transmitted via cutaneous, mucous, digestive, or respiratory routes, and by direct contact with pet animals, their excreta, or the use of different vectors.[48] Moreover, certain people, such as small children, pregnant women, and immunodeficient patients are considered to be population sectors with a high risk of becoming infected by such diseases.[48,49]

A recent review[50] addressed the contamination of coastal marine environments with massive amounts of feces from people, their pets, and domesticated animals. This involves important zoonotic protists, such as *Giardia* spp., *Cryptosporidium* spp., and *Toxoplasma* spp. These encysted parasites may be filtered and concentrated by shellfish, which are eaten by humans and marine mammals.

Other recent studies performed in Japan provided evidence of the introduction of viruses, bacteria, and macroparasites (e.g., nematodes) with imported murid and other rodent pets (e.g., squirrels) that had been shipped from diverse parts of the world, such as North America and Europe,[51-53] despite the fact that uncontrolled importation of pet mammals from foreign countries ended in September 2005.[53]

The implications of movement of species from one country to another are diverse. Veterinary costs for the treatment of such exotic animals may be significantly higher than for more conventional pets because they often require the services of veterinarians with relevant specialist training.

The problems increase if owners release their imported pets into the wild because either they have become too large or aggressive, or because their maintenance is proving too expensive. Conservation issues then arise for native fauna and there are also health concerns as alien parasites are usually introduced with the translocated animals.[23] In this context, it is interesting to note that there is another debate: the North American Animal Welfare Committee has suggested a differentiation between wild indigenous and exotic imported animals and outlined some of the acceptable situations for such ownership, such as permitting the keeping of semi-domesticated animals for conservation purposes through research, exhibition, and education programs. However, the Council on Public Health and Regulatory Veterinary Medicine argued that the American Veterinary Medical Association needs an immediate and unambiguous policy proscribing the keeping of any wild animal as a pet.[54]

Perspectives for the Future

Because current knowledge of wild animal parasite biology and pathogenicity is so poor, it is usually not possible to accurately measure the risks involved when undertaking wildlife translocations (including those involving exotic pets), particularly over a long period of time.[23] Therefore, basic studies on the parasitofauna of most wild animal hosts are still needed and these include an improvement and refinement in diagnostic methods (see Cooper, this issue). Conventional diagnostic methods have limitations that reflect a limited knowledge of epidemiology, ecology, and biology of many parasitic diseases of exotic pets.[55] Polymerase chain reaction–based techniques have become simple, fast, and reliable and are available at most veterinary diagnostic laboratories. These techniques allow the detection of the DNA of different parasites from various tissue samples or biologic samples and, further, its characterization of the organism to a specific level.[55,56] Importantly, the versatility of these molecular methods is such that it permits a search for genetic diversity at infraspecific level and to infer phylogenetic relationships between different parasites, even at a supraspecific level. This work needs to be complemented with the development of specific treatments for such parasitic diseases. Long-term monitoring of these parasite infections may help us to understand better which factors affect their epidemiology. The development of specific vaccines, both for humans and for pets, may become the keystone for preventing the spread of such diseases.[57]

Despite these advances, the research may be inadequate if international wildlife trade continues to increase year by year, with a concomitant increase in the range of wild species that are sold as pets. Also, the breeding and rearing of exotic pet animals by some owners are gaining popularity in many countries of the world.[53] These trends emphasize the need to introduce educational programs directed toward discouraging people from buying exotic pets if the importation and spread of exotic parasitic diseases are to be prevented or reduced.[48] Such measures must be reinforced with legislative action aimed at controlling the international wildlife trade, regulate the keeping of wildlife as pets, preventing the release into the wild of these animals, and restricting the acquisition of an exotic pet to those with appropriate training and experience.[58] Legislative measures need international coordination and cooperation if the goals are to be achieved.

Whatever may or may not be achieved in terms of control, the welfare of nondomesticated animals that are kept as companion or pet animals is all important and can be summarized under the now widely followed "Five Freedoms." These are requirements that captive animals should have freedom from thirst, hunger, and malnutrition, freedom from physical and thermal discomfort, freedom from pain, injury, and disease, freedom from fear and distress, and freedom to express most normal patterns of behavior. These criteria, as well as the broader-based concepts described above, are issues that must concern all veterinarians—and those from other disciplines—who deal with exotic pets, their owners, and their parasites.

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